GAIT STUDY

OF DYSVASCULAR

LOWER LIMB AMPUTEES

IN EARLY STAGE OF REHABILITATION

APPENDICES — VOLUME 2

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2000

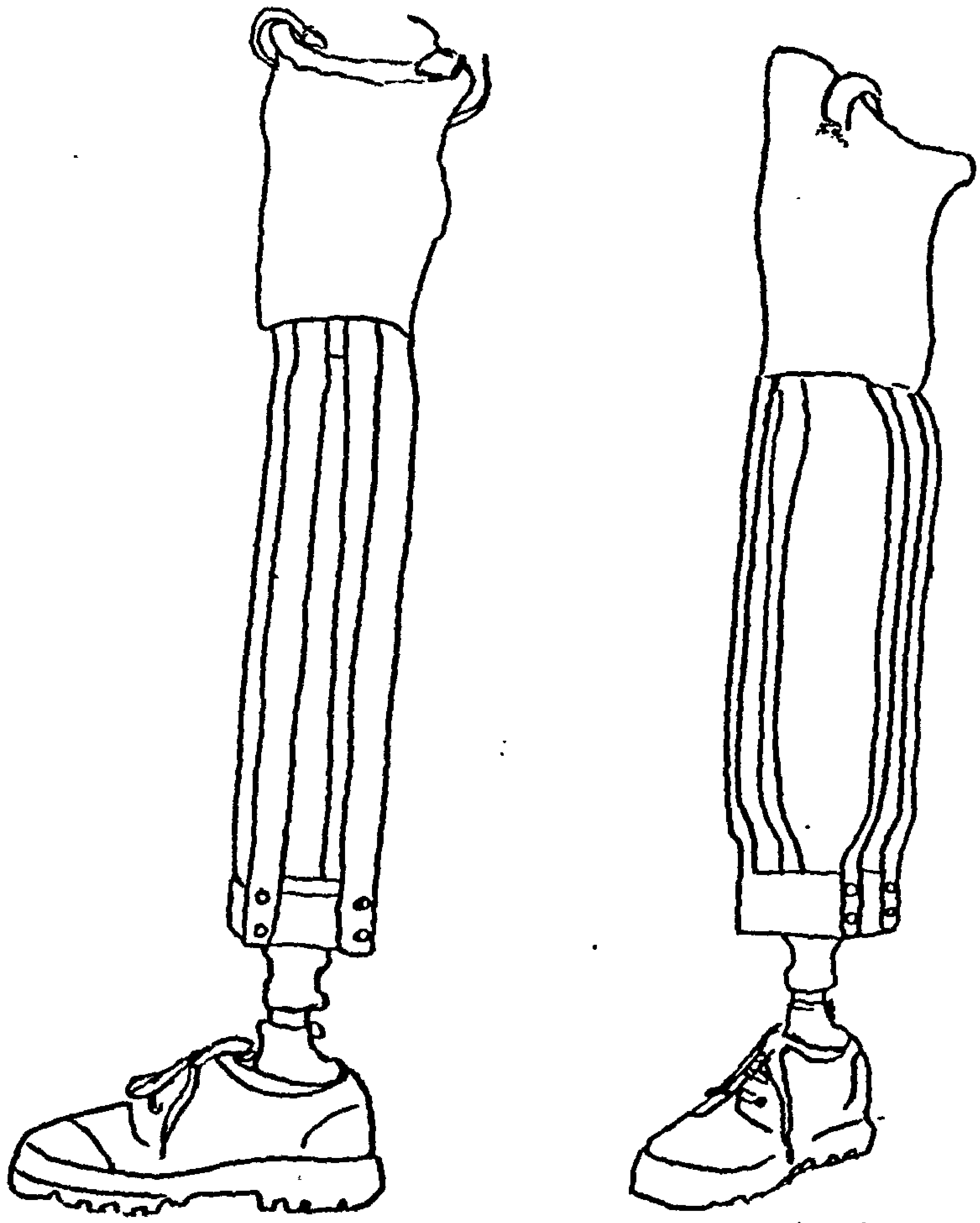


Fig II.1 and II.2 : The off loading prosthesis with an ischial bearing

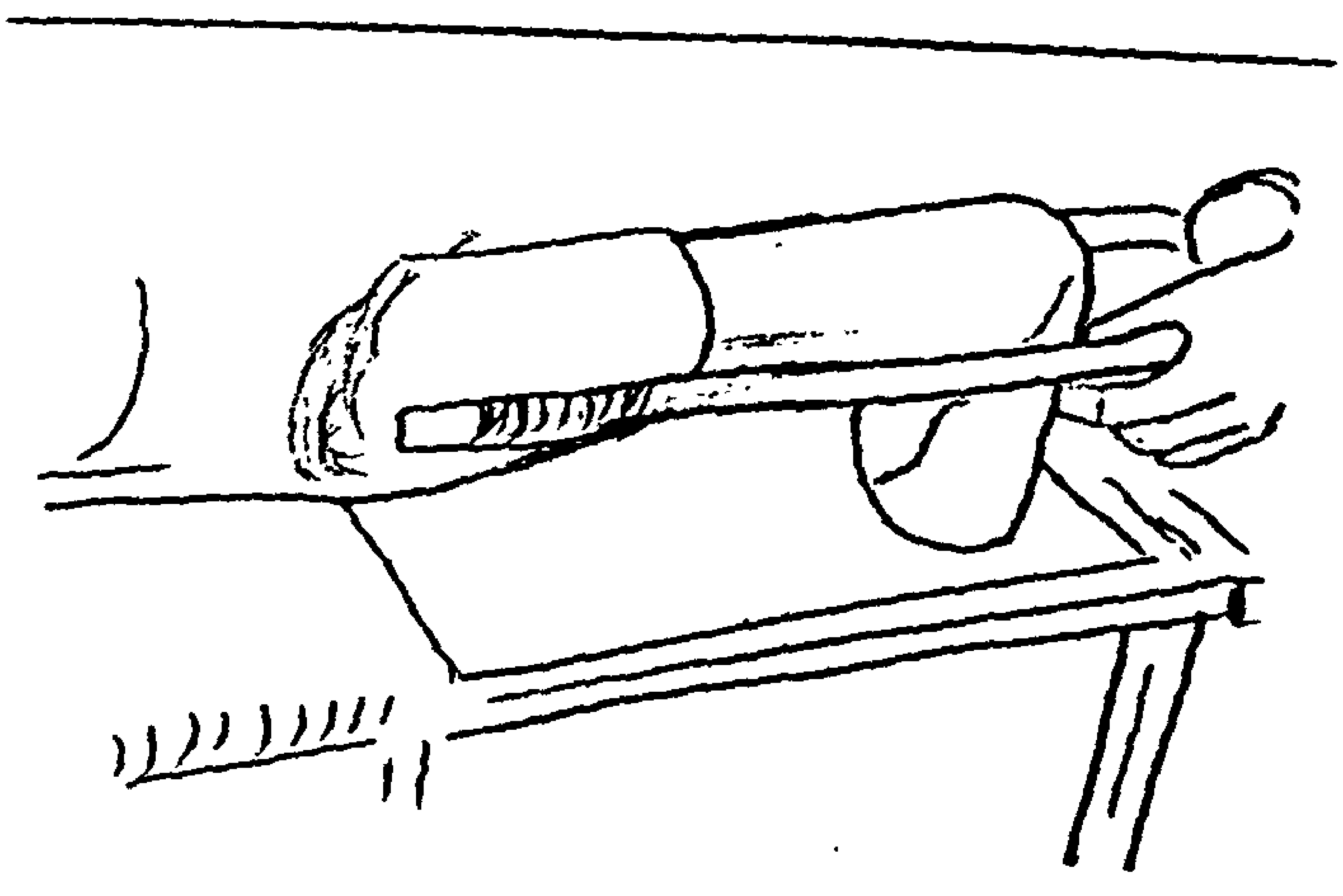


Fig II.3: Manufacturing of an ischial bearing prosthesis; the patient is lying on a special table

11.II DESCRIPTION OF THE REHABILITATION PROCESS IN THE VILLIERS - SAINT - DENIS CENTRE

11.II.1 Introduction

In the following sections, the description of the rehabilitation process is shown having the aim to show the particular context in which the tests made in this dissertation were conducted. It seemed also important to describe entirely the prostheses used by the patients.

Choosing prosthesis is by definition a collective decision associating the medical doctor, the prosthetist, the physiotherapist and the patient.

The decision is taken according to several factors, by decreasing order, the wound (its shape, its condition, its time since surgery), the trophic state of the stump, its foreseeable evolution, the age, the health and the motivation of the patient.

11.II.2 Criteria for the selection for transtibial amputees

11.II.2.1 IF THE WOUND IS LARGELY OPEN

It is possible to observe the following associate problems:

- salient bony shaft or extension beyond the distal section of the soft tissue of the stump;
- largely open wound ascending at the sides or a largely circumferential early scar with risks of disunion;
- severe pain to the smallest contact which it is possible to measure according to the recommendation of Huskinsson (1974), known in France as the "Canadian Scale";
- weak trophicity of the stump: ischaemic stump and/or inflammation;
- stump stitched up recently with sutures;
- adherent skin on the tibial crest and triggering some strong pain when there is some traction towards the proximal region.

In all these cases, a provisional off-loading prosthesis with an ischial bearing is supplied, to start the gait recovery and active re-education phase immediately.

11.II.2.2 IF THE WOUND REMAINS OPEN A LITTLE

The following problems could be found in association.

- bony shaft covered to the distal end of the stump
- wound not ascending more than a little on lateral faces of the residual limb
- pain in net regression
- trophicity of the stump improved

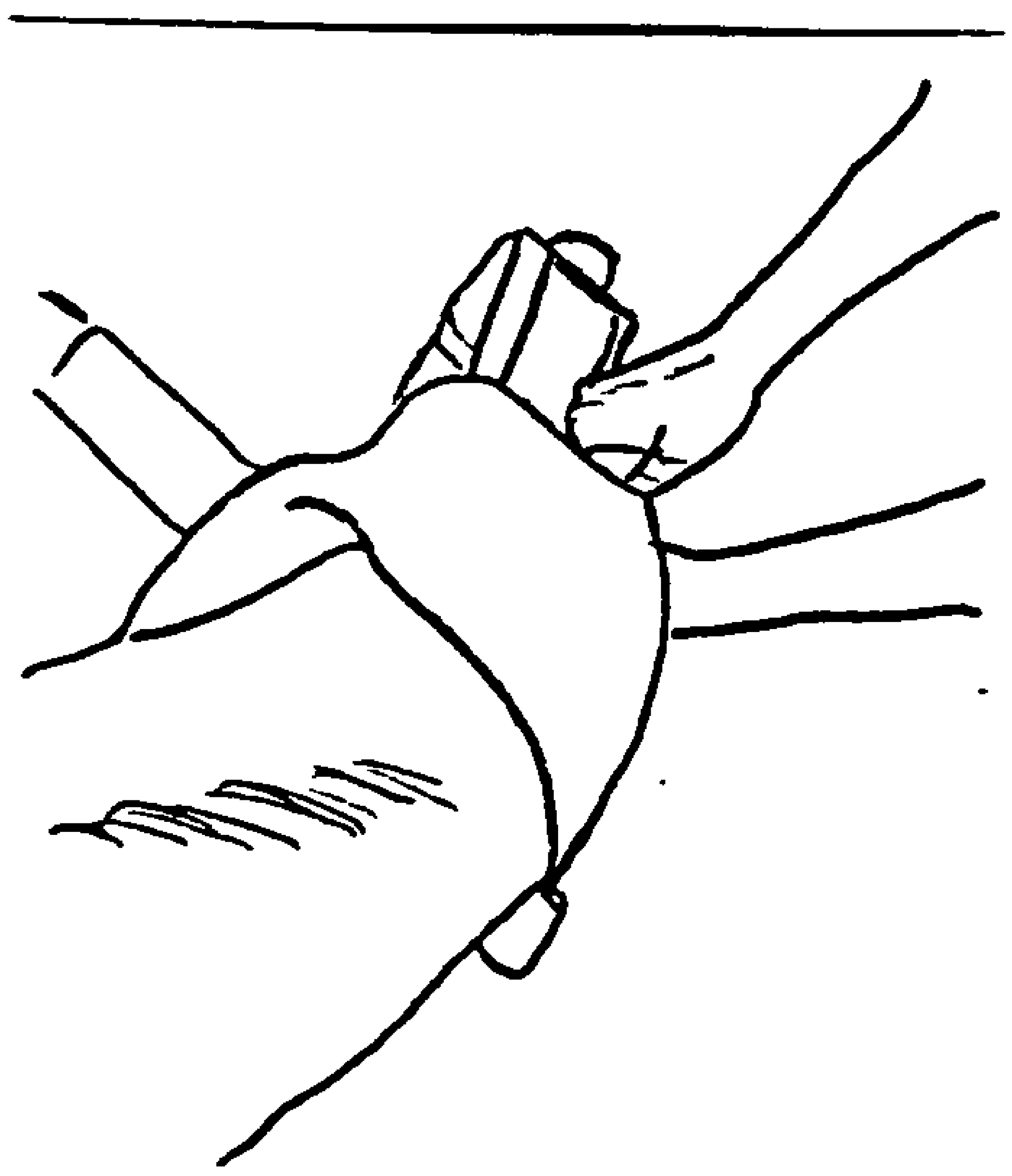


Fig II.5 : The socket is turned a quarter of turn medialward

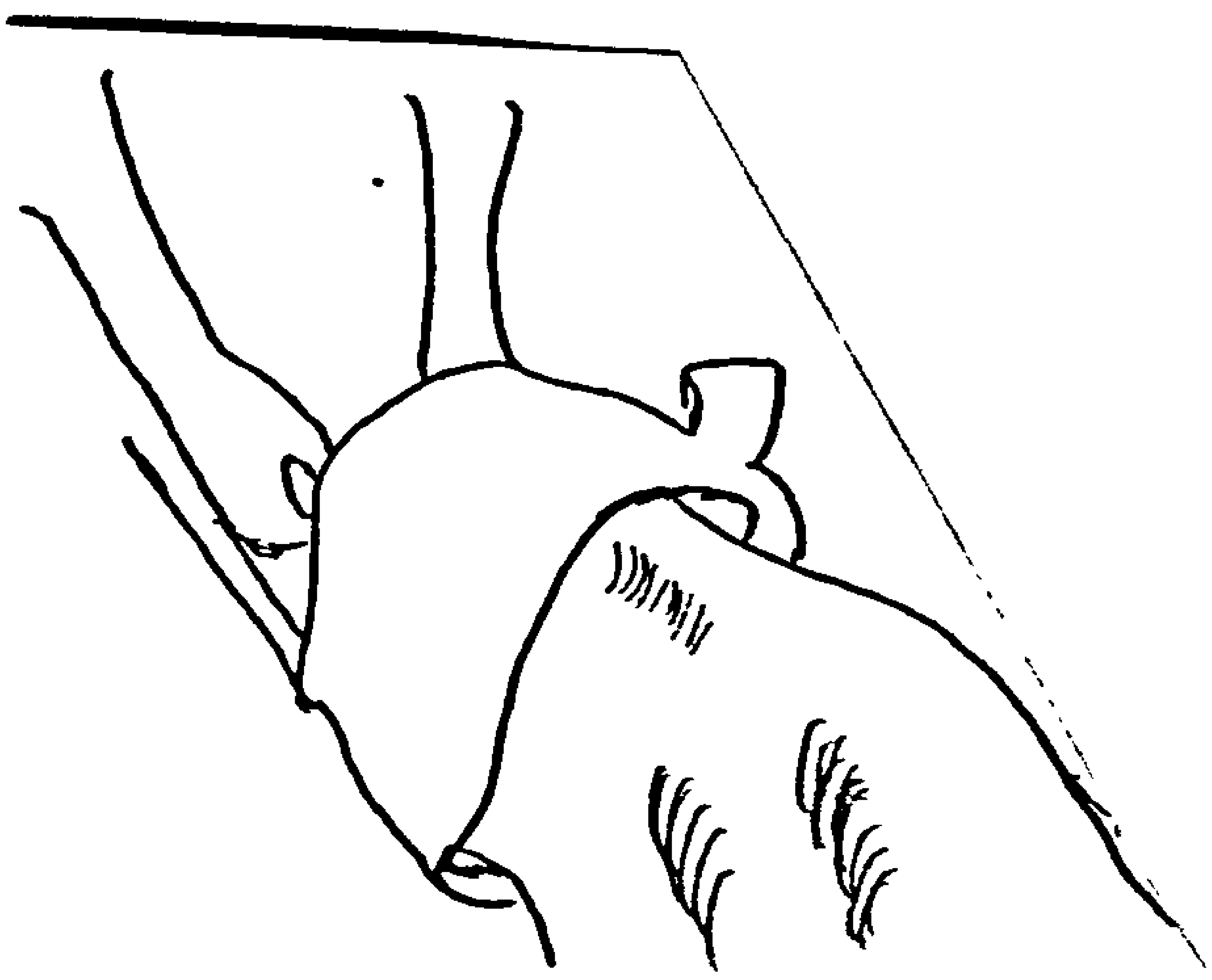


Fig II.4 : The fitting of an ischial bearing prosthesis

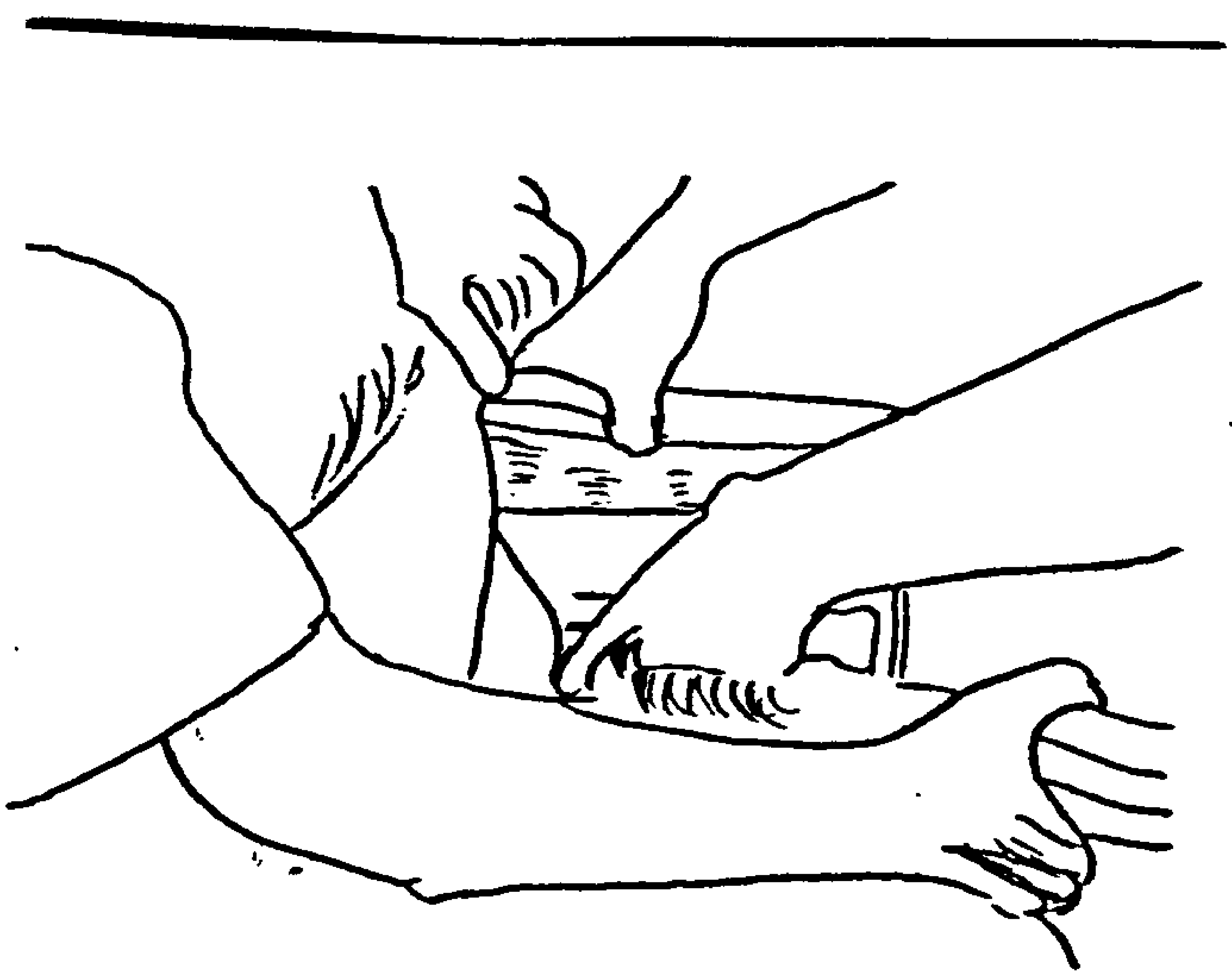


Fig II.6 : The socket has been split and spaced

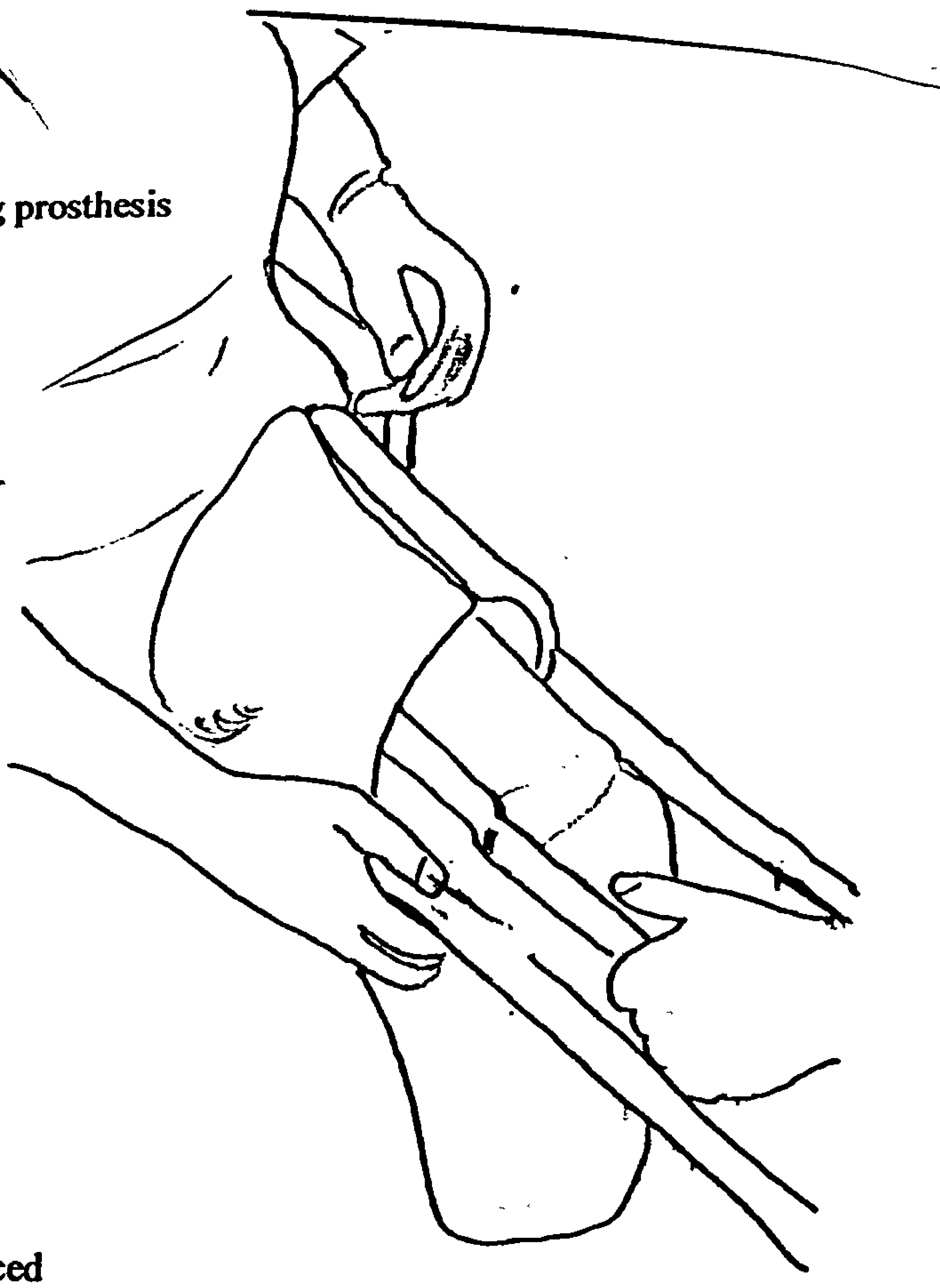


Fig II.7 : The two parts of the socket are shut edge to edge

• stump sutured more than 21 days previously without any disunion

• skin beginning to loosen its adherence, following the description about adherent cicatrix made by Lija & Johansson (1993)

• general state of the patient clearly improved

• muscular strength progressing

• stump already healed but still unstable in volume

In all these cases, a provisional distal prosthesis is made of Plaster of Paris.

This prosthesis is made directly on the stump. The use of the gypsum allows it to be easily and rapidly remade when necessary. These advantages were noticed by Ozialcin & Sesli (1989).

To compensate for the stump volume variation, we use a hydraulic compressive device (see description in the following section).

11.II.2.3 IF THE STUMP HAS HEALED OR ALMOST HEALED

• stabilisation in volume of the stump

• shape of the stump (not too pear-shaped) compatible with a rigid socket without any volume compensation device

• tibial crest covered as much as possible and trophicity of the skin as good as possible

• largely blurred pain and gait quality already achieved

• best possible independence

In all these cases, a definitive endoskeletal prosthesis with acrylic resin socket is constructed.

The stabilisation in volume of the stump is practically the main criterion to envisage progression to a definitive prosthesis. This stabilisation is assessed by a fortnight to three weeks of wearing the same plastered socket, provided that the daily duration of use is significant enough and without any discontinuation at the end of the week. In this case, one can envisage progress to the definitive prosthesis. In the beginning, this prosthesis is left without any cosmetic foam, so that it can be modified if necessary. The cosmetic dressing is provided only a few days before the discharge of the Rehabilitation Centre. The foot used for both the definitive and provisional prostheses is usually a monoaxial foot (see below: the different feet).

Although the advantage of using the partial transcutaneous oxygen pressure ($TcPO_2$) described by Casillas *et al.* (1990) in France and Yablon *et al.* (1995) in America, this parameter is not used. The daily experience gathered in the Villiers-Saint-Denis Vascular Rehabilitation Unit shows a lack of accuracy due to pain and local conditions.

11.II.3 Criteria for the selection for transfemoral amputees

The criteria of selection are simpler. It is necessary to ensure the integrity of the skin at the perineal edge, in front of the ischium and above the inguinal fold.

It is important to pay attention to possible scars, coming from by-pass surgery, that appear fragile. If the stump was stitched and some threads are still on, it seems wiser to wait the removal of them to make the socket. The selection of the prosthesis is more restrained: ***CONVENTIONAL PROVISIONAL FEMORAL PROSTHESIS MADE OF PLASTER OF PARIS*** with a locked knee and a monoaxial foot plus an opposite shoulder-belt for suspension.

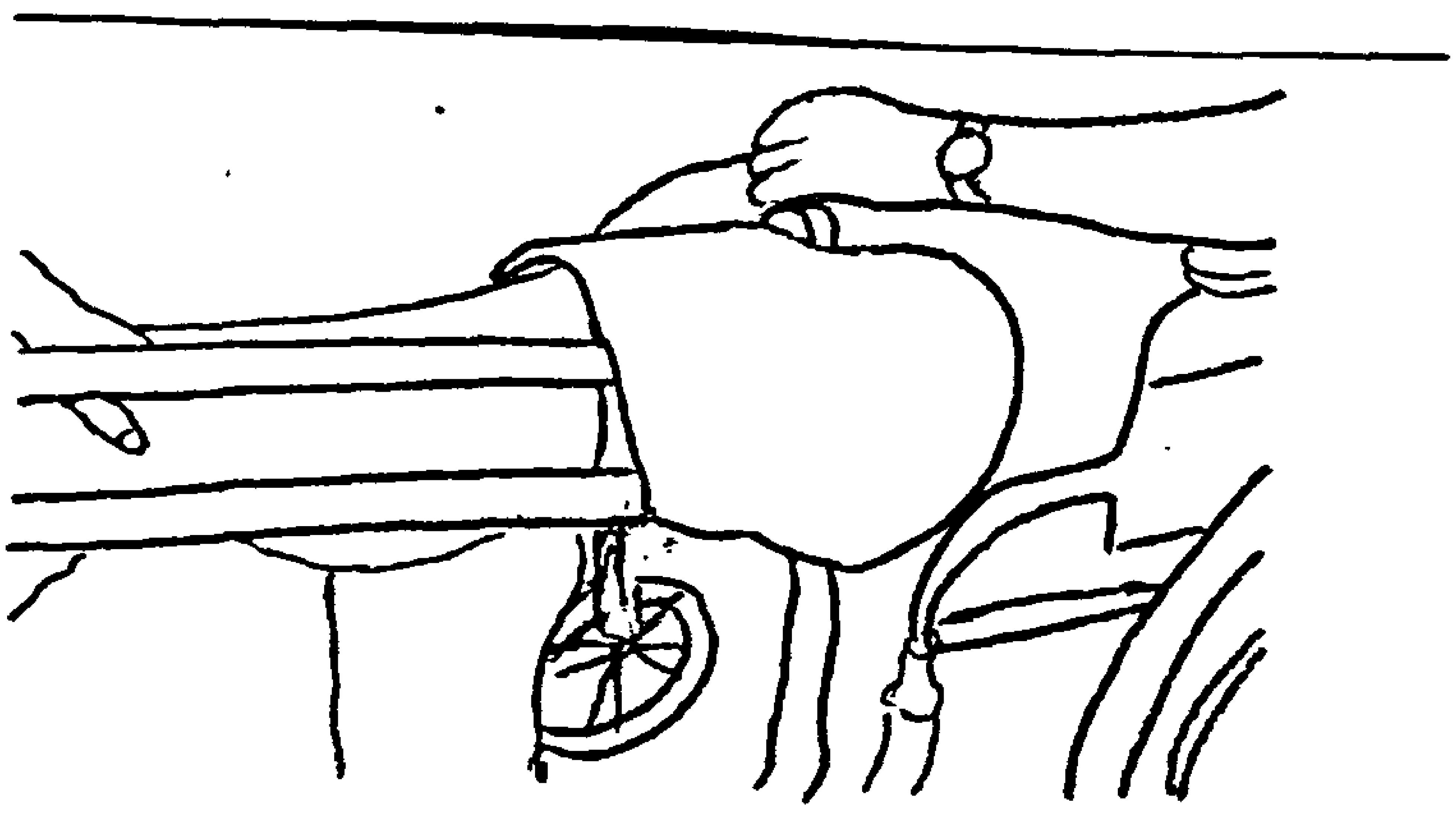


Fig II.8 : The fitting of an ischial bearing prosthesis : the patient's trouser is used as a stockinette

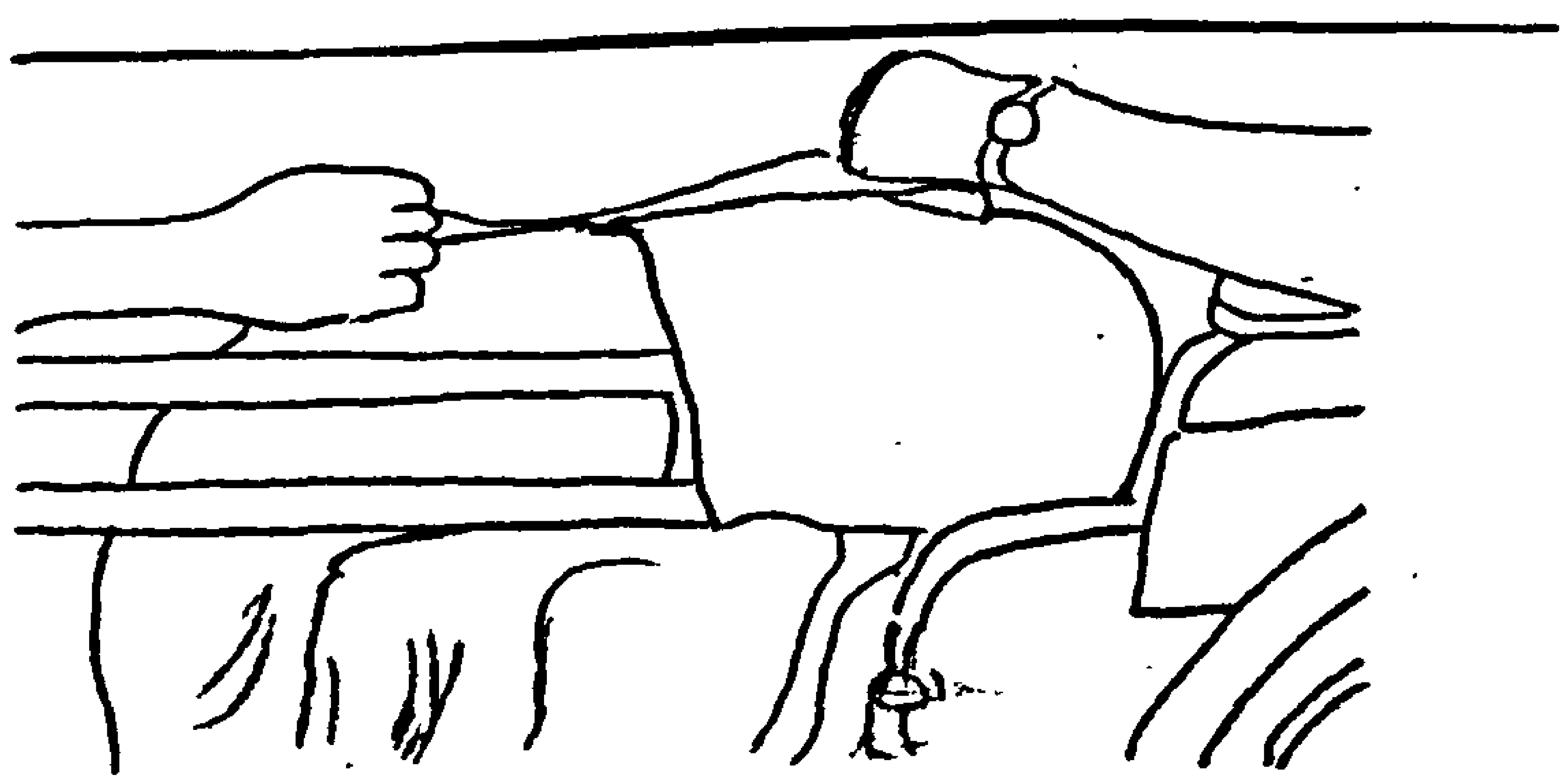


Fig II.9 : The fitting of an ischial bearing prosthesis : most of the donning must be done sitting

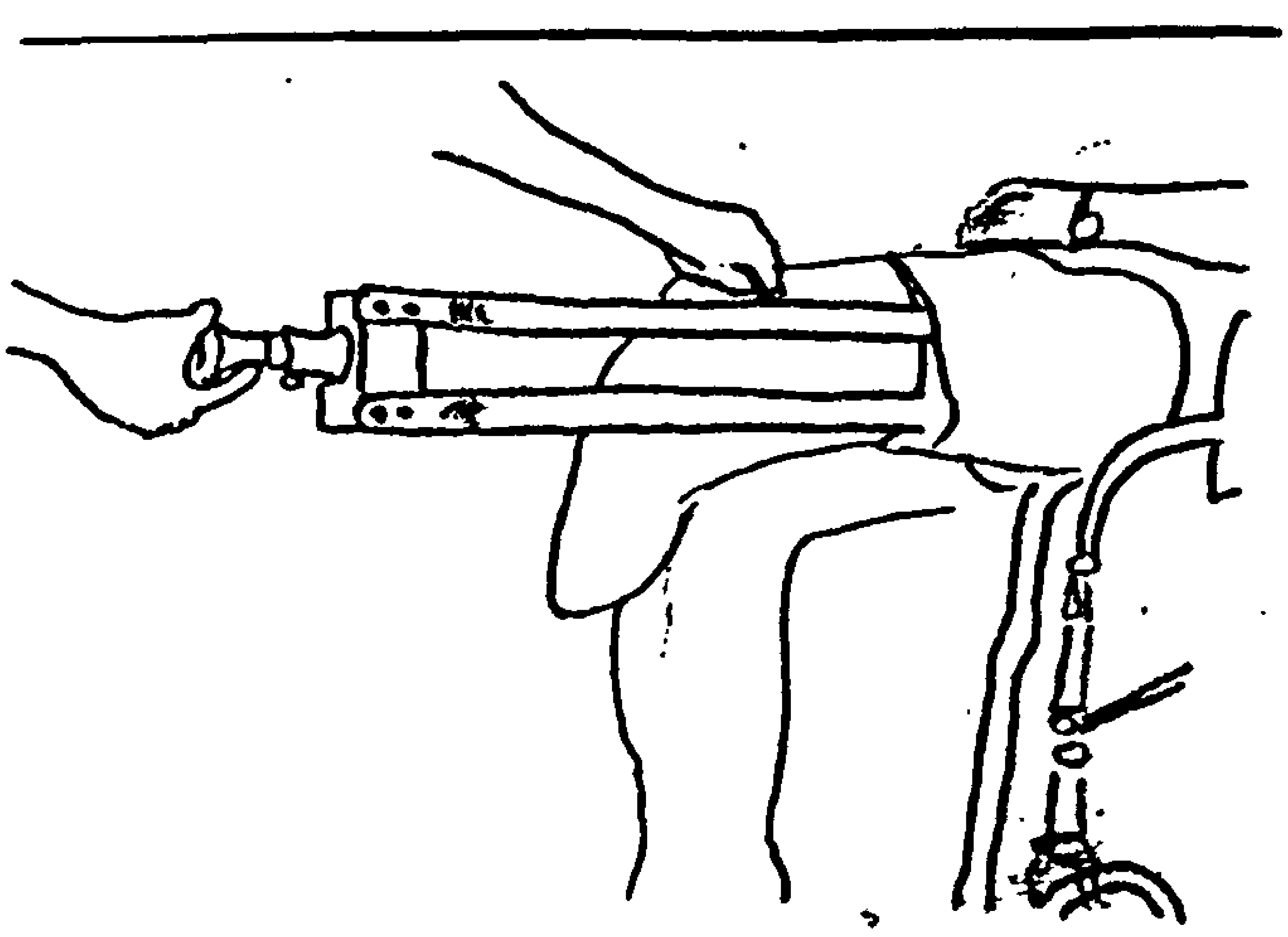


Fig II.10 : The fitting of an ischial bearing prosthesis : the therapist must pull on the four sides of the « trouser - stockinette »

When the volume is stabilised (with the same criteria as above for transtibial amputee) and if the general shape of the stump is close to that of the opposite limb, it is possible to envisage a ***DEFINITIVE FEMORAL PROSTHESIS***. Both the provisional prosthesis and the definitive one are in the majority of cases provided with a locked knee, a monoaxial foot and a harness as described below.

11.II.4 Description of the different prostheses: below – knee level

11.II.4.1 THE OFF-LOADING PROSTHESIS WITH AN ISCHIAL BEARING

In the literature, one speaks also of the polyvalent prosthesis or multifunctional orthosis [1]. It is shown in figures II.1 and II.2[2].

11.II.4.1.1 Description and manufacture

The basic principle is to consider temporarily the transtibial patient as a transfemoral amputee with only one loading area situated under the ischial zone. The residual limb is free of strains and stresses. A flange made of gypsum, similar to a brim of quadrilateral thigh socket, is made directly on the patient, lying down on a special table. That allows the device to be done slowly without any risk of tiring a weak patient as shown in figure II.3.

Lateral metallic stems connect this flange to a piece of wood to which a peg leg is most often fitted or in some cases a monoaxial foot is used.

11.II.4.1.2 The alignment

Before speaking about alignment, some terminology must be defined. As presented by British Standards (BS 7313, 1990), three stages of alignment must be distinguished for practical reasons: the bench alignment, the static alignment and the dynamic alignment. They are defined as follows:

- **bench alignment** refers to the initial assembly and alignment of the components of a prosthesis according to their characteristics given by the company that provides these components.

- **static alignment** refers to the process whereby the bench alignment is refined with previously acquired data regarding the patient and while the prosthesis is being worn by the lie - down or standing up patient.

- **dynamic alignment** refers to the process whereby the static alignment of the prosthesis is optimised by using observations of the movement pattern of the patient. It is a team process: prosthetist, physiotherapist and patient. This dynamic alignment must be re - checked many times as the patient improves his rehabilitation.

It is most important to check the length of the prosthesis which is made about one to three centimetres shorter than the opposite side in order to facilitate the swing phase of the gait. There is not any possibility of flexion at the knee level. The possibility of a flexion contracture at the hip must be considered. If the patient regains sufficiently his strength and if the flexion contracture regresses, it is necessary to revise the dynamic alignment.

11.II.4.1.3 Indications

[1] In Scotland and other countries in Northern Europe, the pneumatic PAM Aid system is widely used for the same purpose.

[2] All of the figures showed in this chapter were drawn by the author of this thesis from photographs taken in his Rehabilitation Unit by himself.

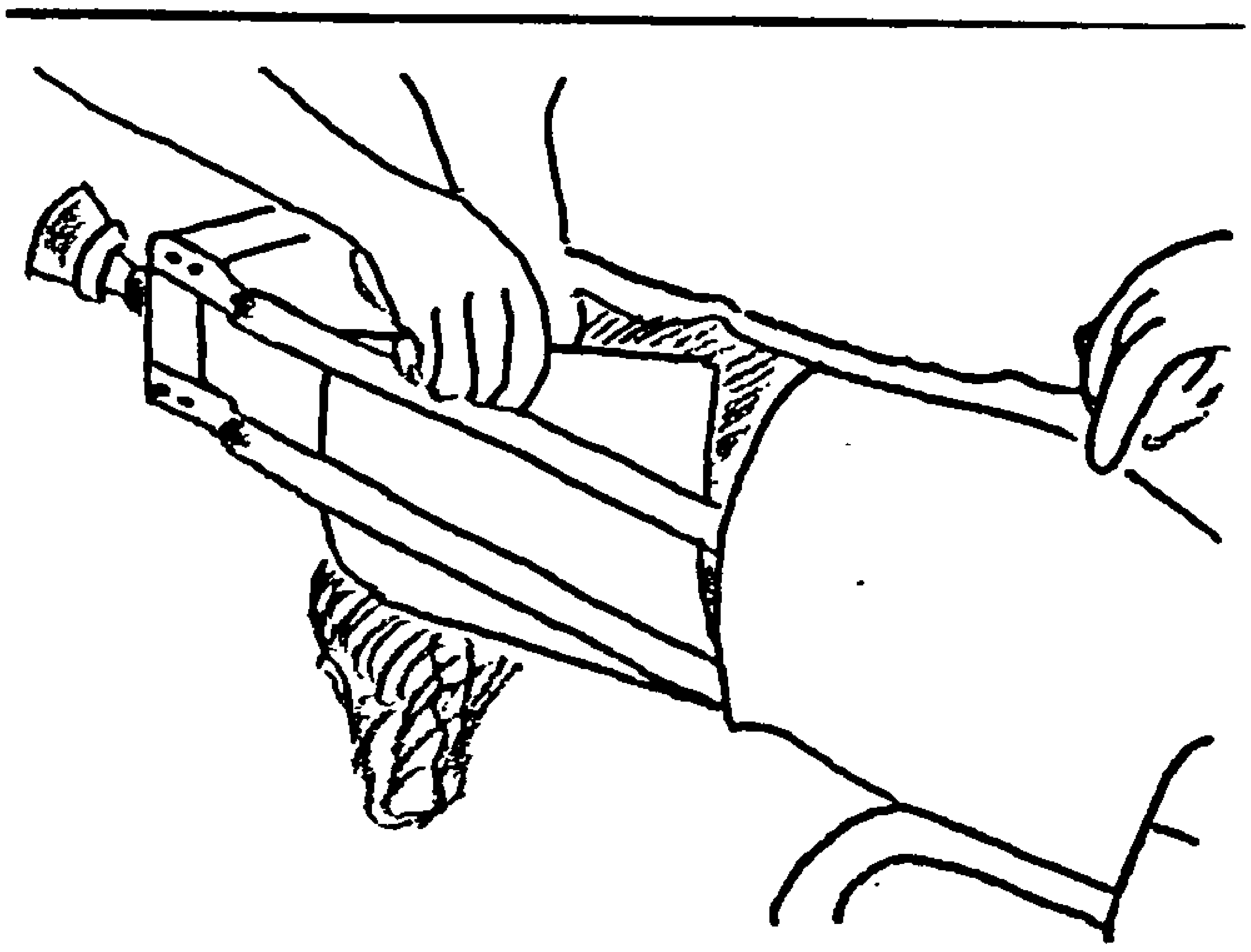


Fig II.11 : A piece of foam is placed laterally to protect the stump

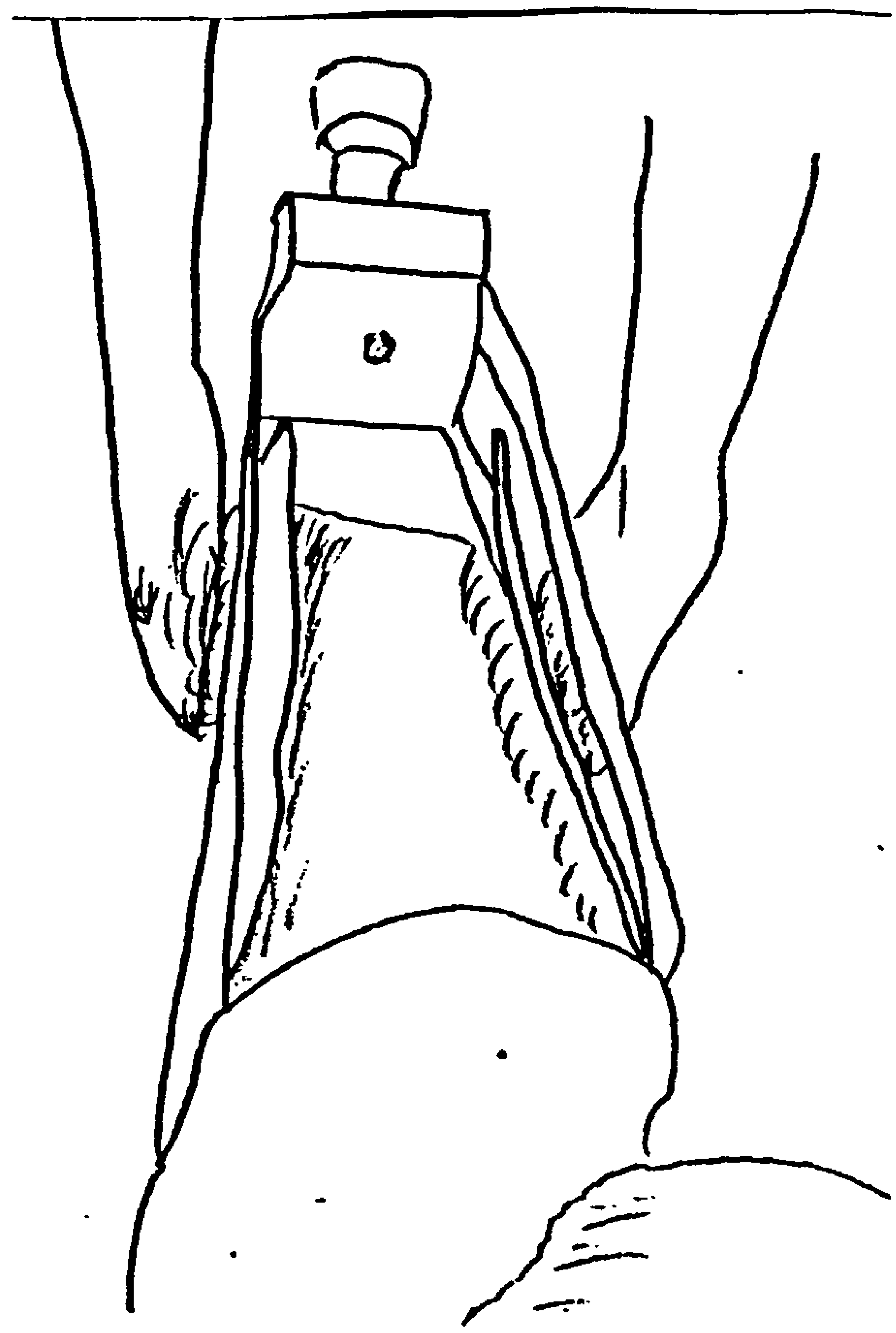


Fig II.12 : Other view of the protecting foam

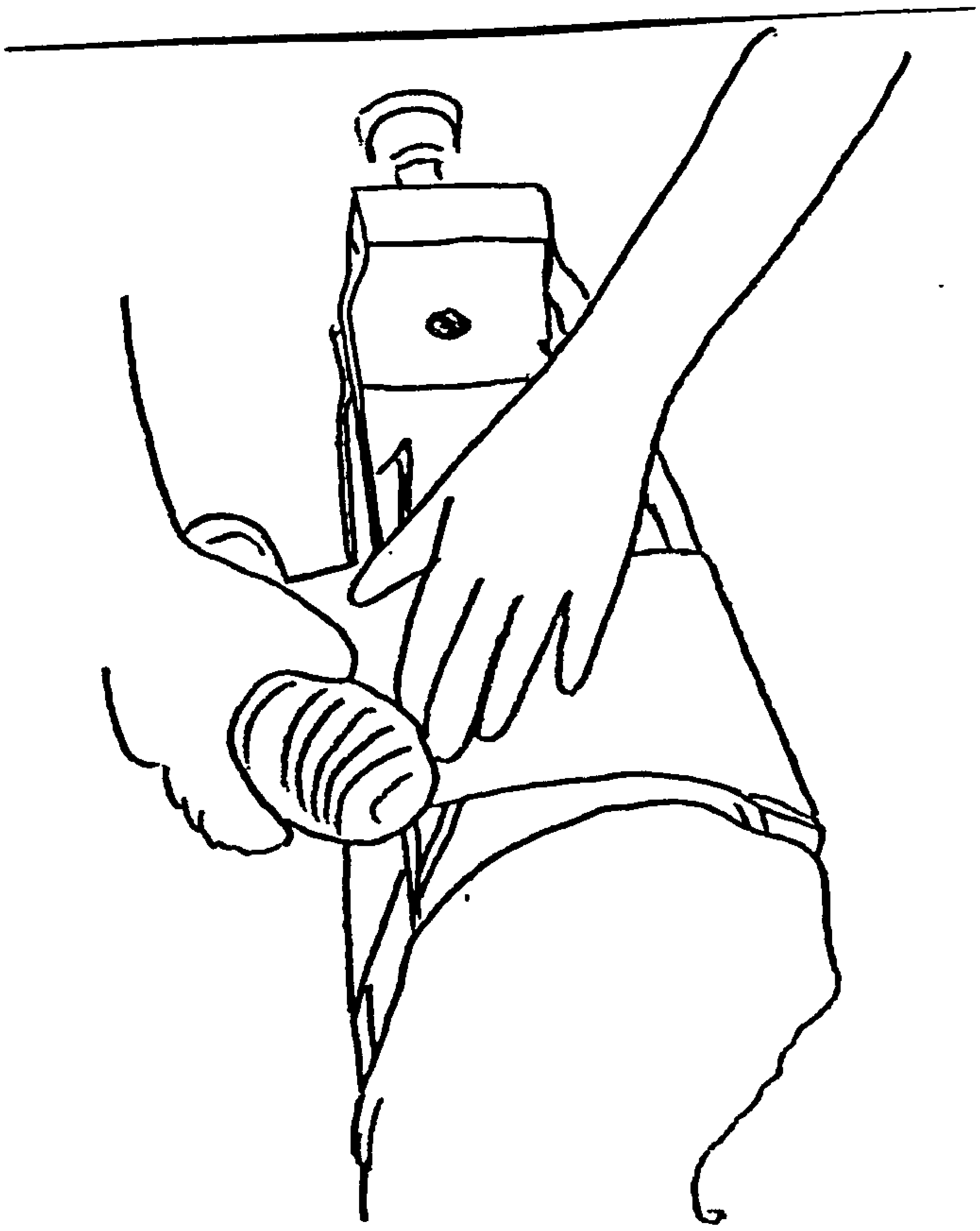


Fig II.13 : A unstretchable crêpe bandage around the prosthesis

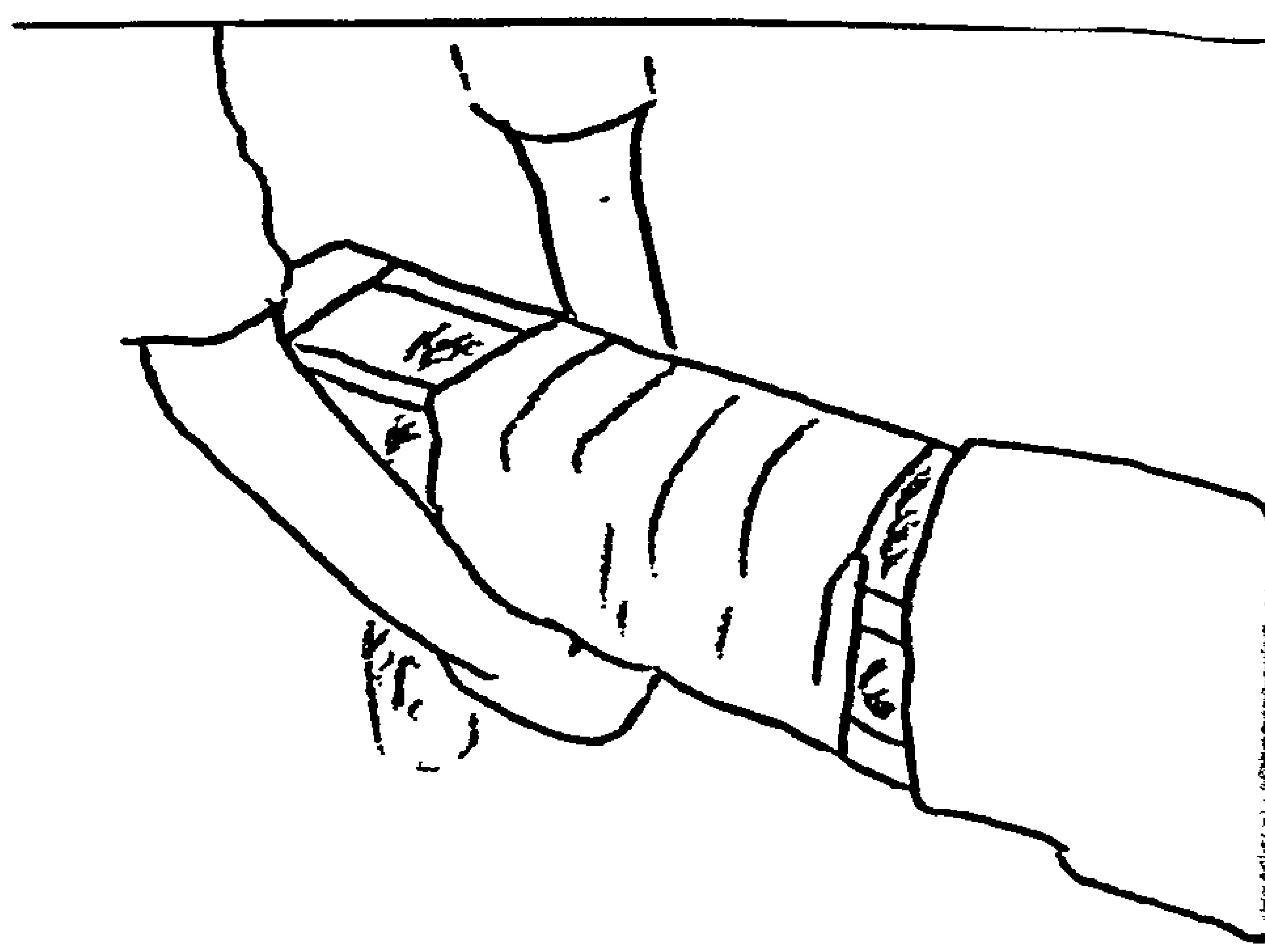


Fig II.14 : Finishing to bind the unit

We have already seen indications for this prosthesis (see section II.1.1), we will add some later when it will be a question of combined hip - knee contracture of ischaemic origin.

11.II.4.1.4 Donning

To put on an ischial bearing prosthesis, it is necessary to turn it a quarter of turn medialward so that the socket can pass over the knee at its greater diameter. The pathway of the patella is easier (figures II.4, II.5). If difficulties of donning persist, we split the flange along its length. The two sides of the socket during the pathway through the stump and the knee are shown in figures II.6 and II.7. When the socket is on the level of the thigh, the physiotherapist shuts the two parts of the socket edge to edge with an unstretchable strip. The socket resumes its usual shape.

Attention is drawn to the fact that in rare cases, if the donning is easy, after use the doffing is not, since the stump and even the knee have been able to increase their volume when the patient stands up. The solution is to use a stump shrinker as those described by Lambert & Johnson (1995).

Often, we use the trousers of pyjamas as a tubular stockinet (figures II.8, II.9, II.10, page 63A). When the patient is in good contact at the ischial area (manual verification), we ask him to stand up to adjust the shoulder-belt. In case of an axillo-femoral by-pass (AFBP), the strap is placed on the ipsilateral shoulder. The patient now can sit down again: we ask him to spread his knees to the maximum. We surround the stump by a piece of Pelite® foam to protect it and we bind the unit in a unstretchable crêpe bandage to ensure a control of the prosthesis (figures II.11 and II.12, II.13, II.14).

11.II.4.1.5 Advantages and disadvantages

The first advantage of this prosthesis is its simplicity, to make as well as to put on, to wear and to use. It allows upright standing, with pelvic loading for all below-knee amputated patients whatever their stump or pain condition are. The stump is free of all stresses. Pain must not increase in the standing up position and during gait. The donning and the doffing have to be made easily, without any mechanical scraping pain. The off- load prosthesis is the first prosthetic device which the amputees meet, therefore the quality of this first contact is paramount.

The **Intermittent Dynamic Heavy Work** (IDHW) as a gait recovery programme can begin as soon as possible. It allows an early ambulation programme starting the development of the collateral circulation and acceleration of the healing. If the patient is concerned about the cosmetic appearance, we must make it understood that this prosthesis is more than provisional (average duration of use about one month).

The prosthesis allows the maintenance of the extension of the hip (figures II.15, II.16 and II.17) and the re-education of hip flexion (see. infra section II.5).

Physical re-training on a tread-mill is possible (figure II.18).

Contrary to appearances, the range of motion of the knee is always sufficient with no blocking in extension or flexion position or avoiding the increase of a pre-existing permanent flexion at the knee joint. Nevertheless, it is necessary to couple the use of this prosthesis with some manual training for joints and muscles in flexion - extension.

11.II.4.2 THE DISTAL PROVISIONAL PROSTHESIS IN GYPSUM

A prosthesis is distal when it is fits directly on the stump.

11.II.4.2.1 Description and manufacture

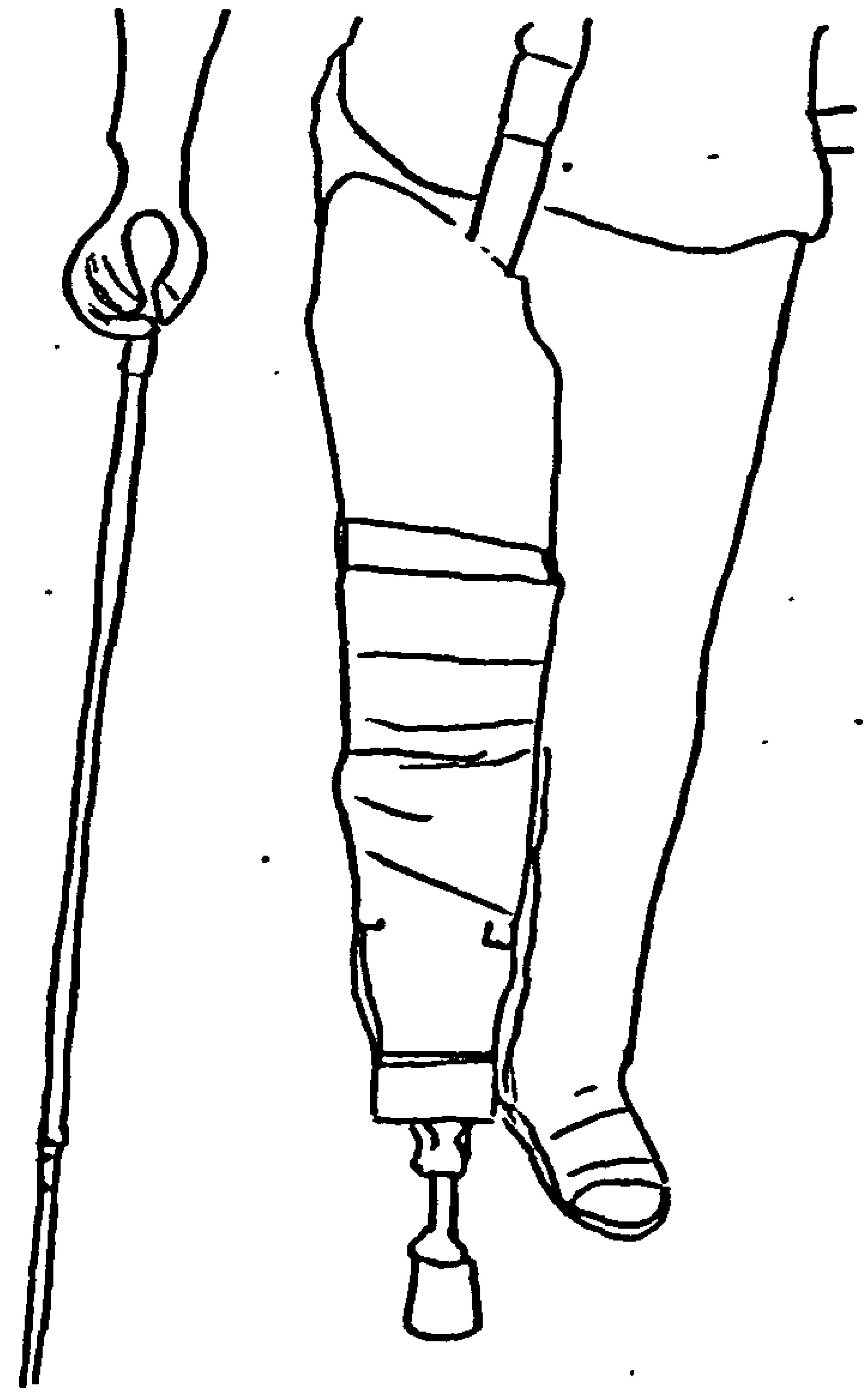


Fig II.15: Ischial bearing prosthesis : front

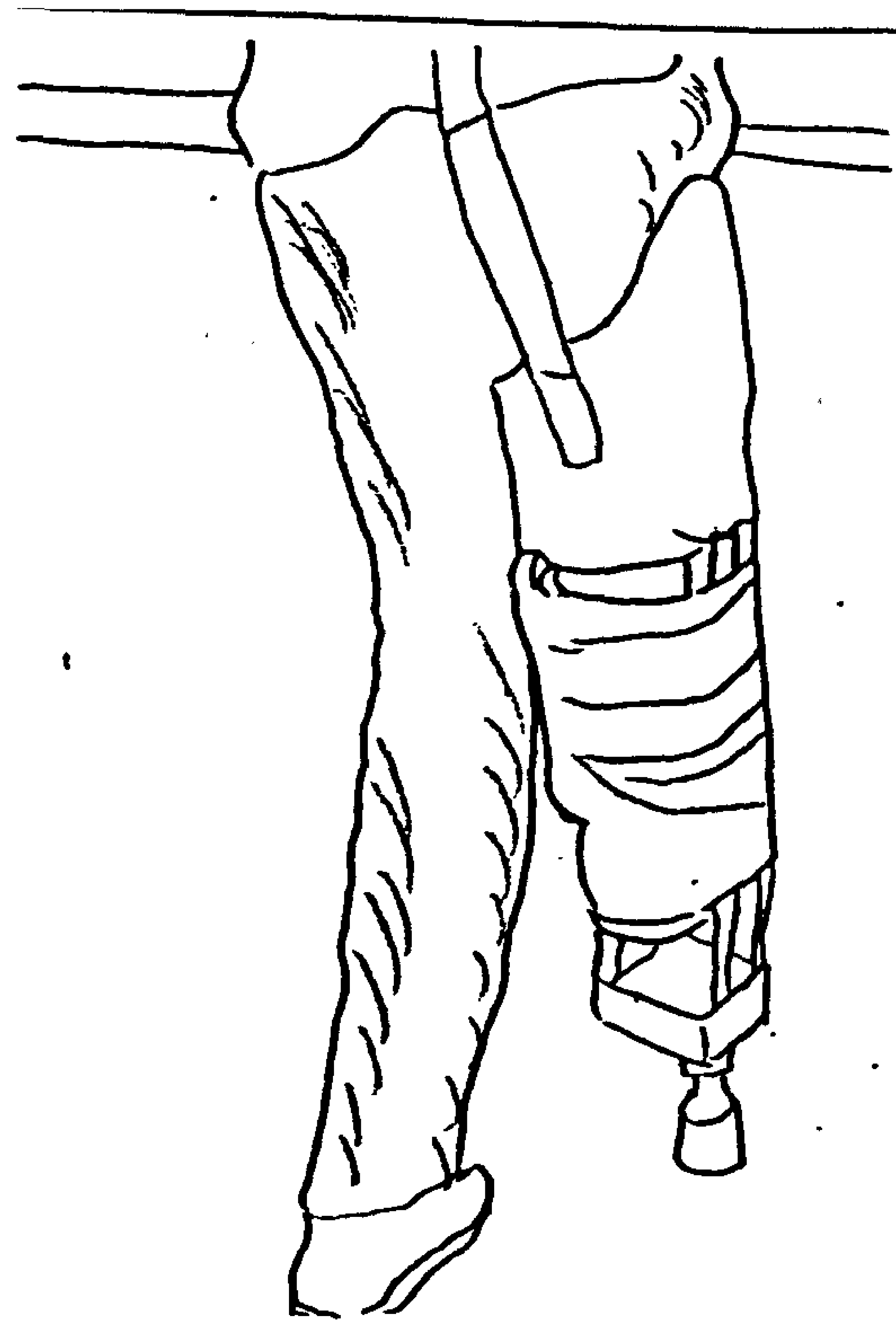


Fig II 16: Rear

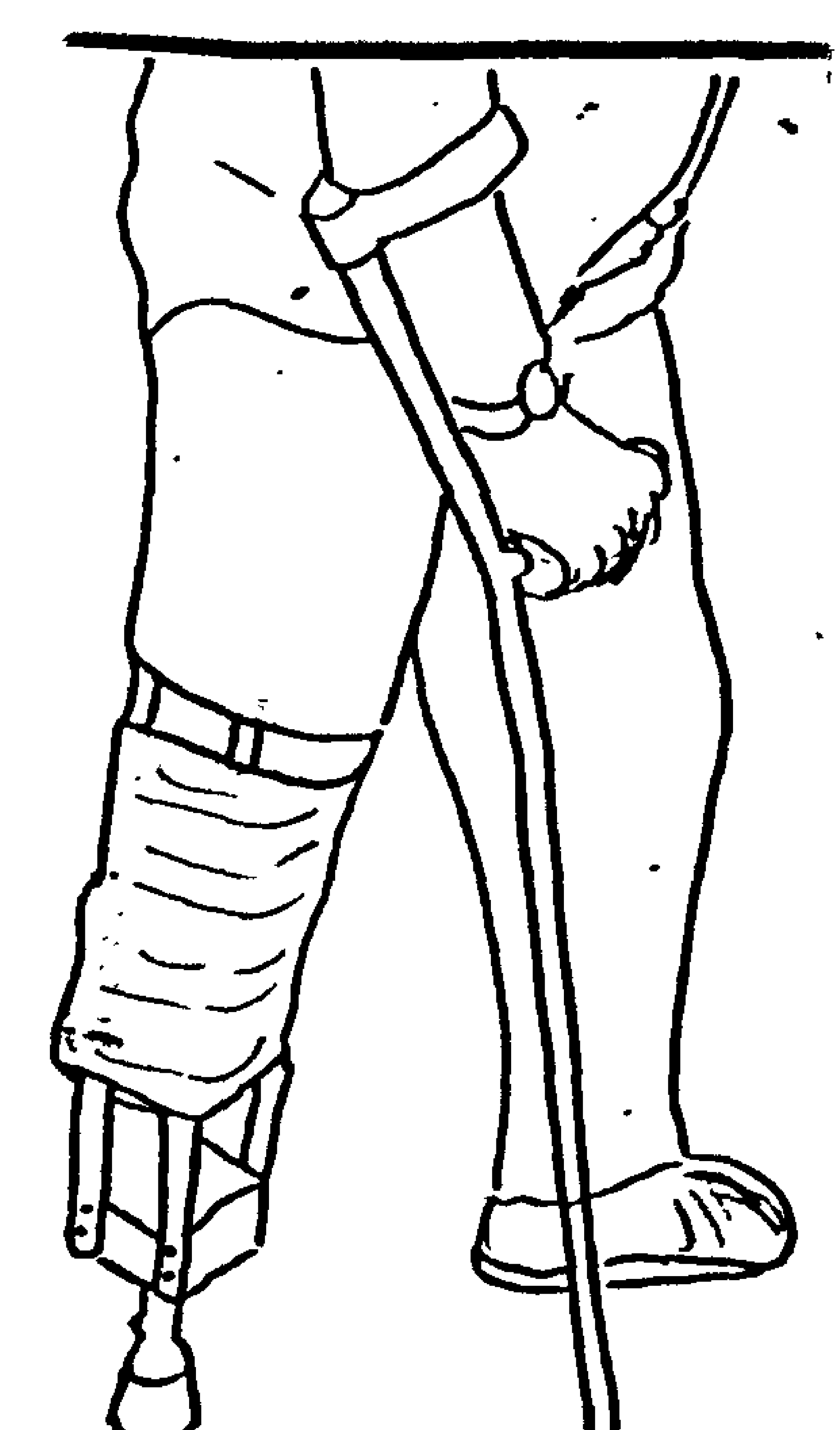


Fig II.17: Lateral view

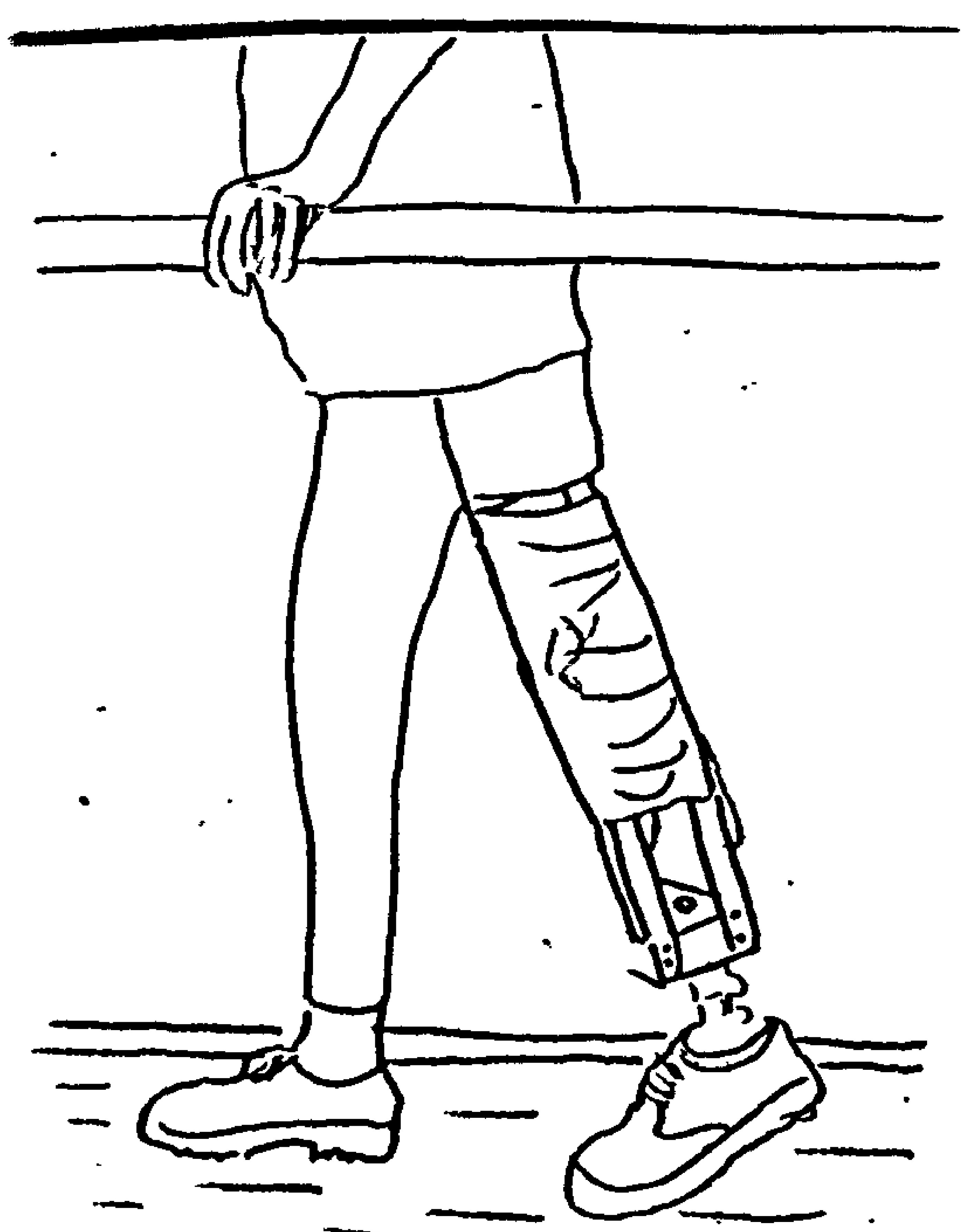


Fig II 18: The patient uses a treadmill

It foreshadows the definitive prosthesis but the material of manufacture is different. The load is mainly transmitted to the patella tendon. The counter-load is on the inferior part of the popliteal space, under the bending fold of the knee. The socket retention is extended over the femoral condyles. The kneecap is always included into the socket.

The gypsum in inexpensive and easy to use. The prosthesis can therefore be remade when necessary, which is important for stumps whose volume is unstable over a long time. The patient lies down, his stump free of contact on a specially fitted table as shown in figure II.19. The prosthesis is made directly on the stump covered by a special stump-cover bonnet. The tibial crest is protected by a latex foam tongue (figure II.20) and the bottom of the socket is always left empty because of the wound (figure II.21). The full time for manufacture is about half an hour (figure II.22). The dynamic fitting is made on the day after the socket has dried.

This apparatus includes a hydraulic device that allows the volume of the socket to be varied. With fragile stumps, this allows the socket volume to be a little bit bigger than its contents. It allows some fitting adjustments and some possibility to compensate a part of the daily volume fluctuations of the stump while limiting piston movements of the former in the socket. The adaptation is accurate since the water used is incompressible (figure II.23). This device used at the Centre Médico-Chirurgical of Villiers-Saint-Denis is not necessary in all cases. Other teams use air or even nothing, in this case it is the fluctuation of thickness of the stockinet that allows adaptation to the stump volume.

Problems of volume fluctuation of vascular stumps are one of the biggest problems of their limb fitting.

The foot used is the most often monoaxial. In early stance, a posterior shock bumper replaces the eccentric braking contraction of the Tibialis Anterior starting from heel strike (0 to 15 % of the gait cycle). An anterior stop looking like a plastic washer locks the ankle axis at 90° (figure II.24) . The dorsiflexion is provided by the flexibility of the forefoot. It is shown in figure II.25.

Other feet can be considered mainly the SACH foot but the monoaxial foot seems to us the best for patients at this stage. The difference between these two artificial feet was completely studied by Goh *et al.* (1984).

It is necessary to ask the patient to wear perfectly comfortable shoes on the opposite foot and as new as possible, with for women a reasonable heel height (about 3 cm) and large enough.

11.II.4.2.2 Alignment

The alignment is conventional and is shown later in section II.4.3.2. The only particularity is that the device is often deliberately made short during the first weeks of the training programme. This is done to increase the loading on the prosthesis at early stance phase. The swing phase is equally facilitated, indeed, in the beginning of the use of this prosthesis because of fear of pain and loosening of the prosthesis, patients have a tendency to walk with the amputation side knee straight. One of the aims of the re-education is teaching them to bend their knee at the best time to minimise their limp. This height, as well as alignments require to be re-adjusted periodically, by dialogue between the physiotherapist and the prosthetist, as the re-education of the walking pattern progresses.

11.II.4.2.3 Indications

Indications were highlighted in section II.1.2. On the average, between two and four plastered provisional prostheses are made for each patient.

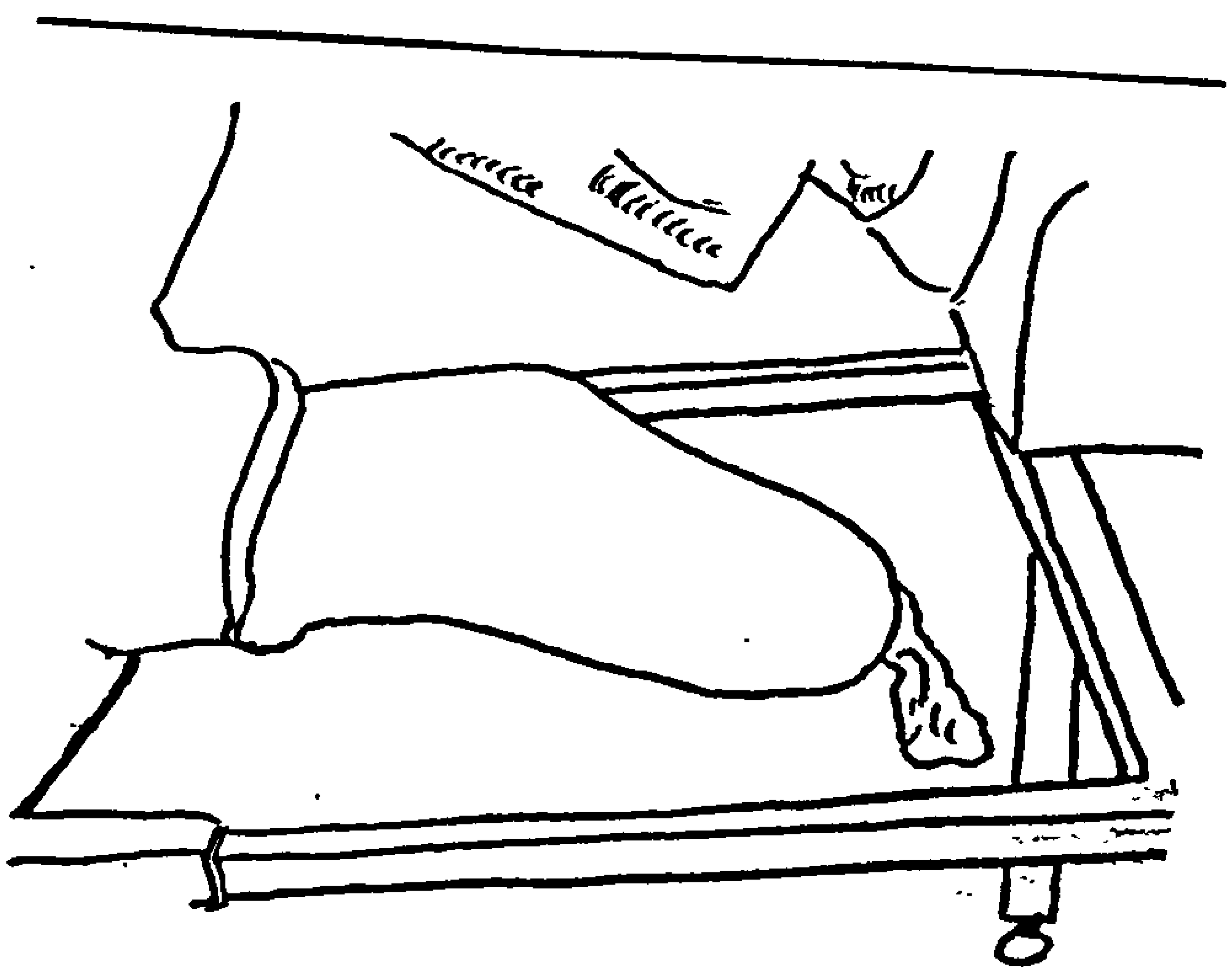


Fig II.19: Distal provisional prosthesis: the building of a gypsum socket on a special table

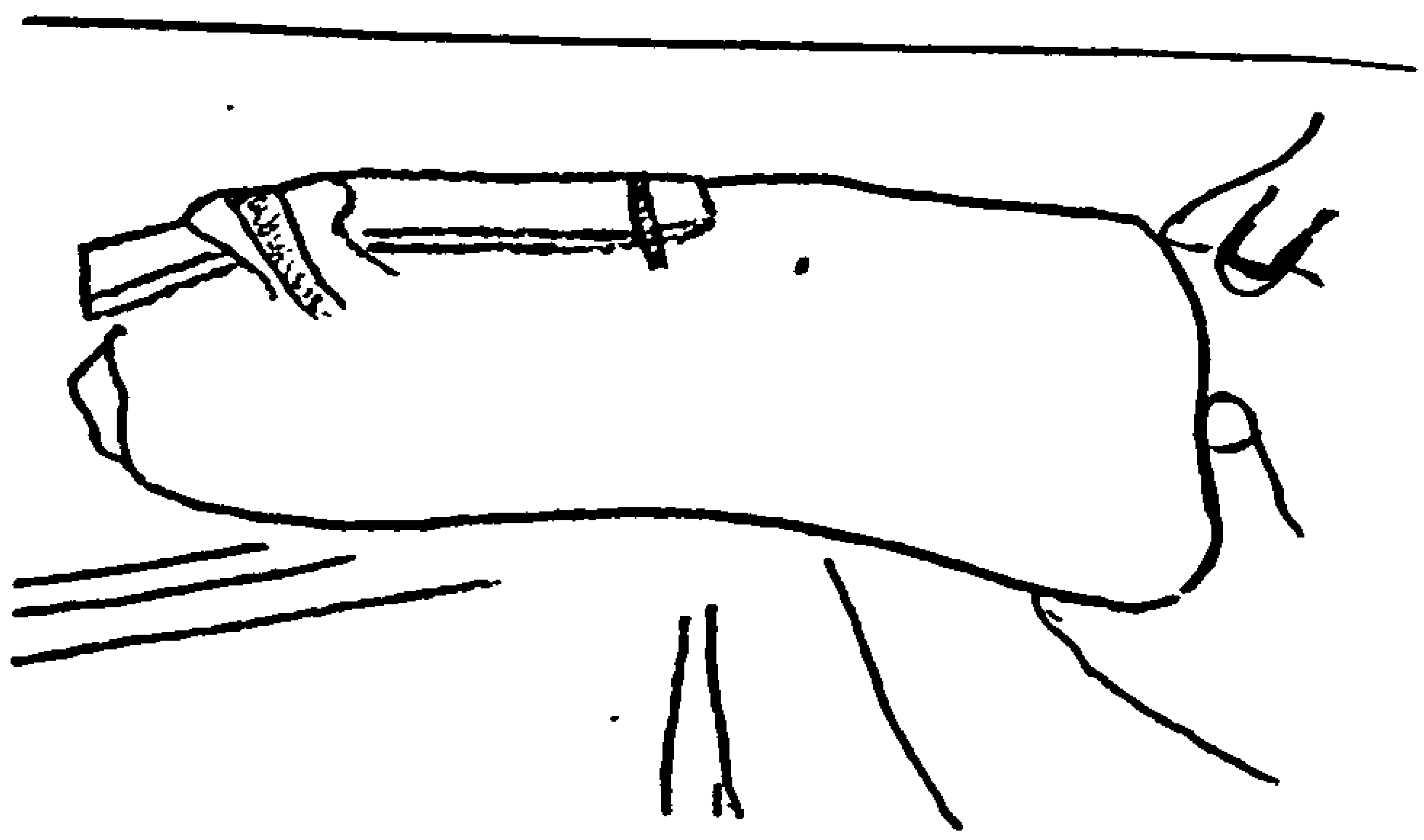


Fig II.20: Some latex foam is put to protect the tibial crest

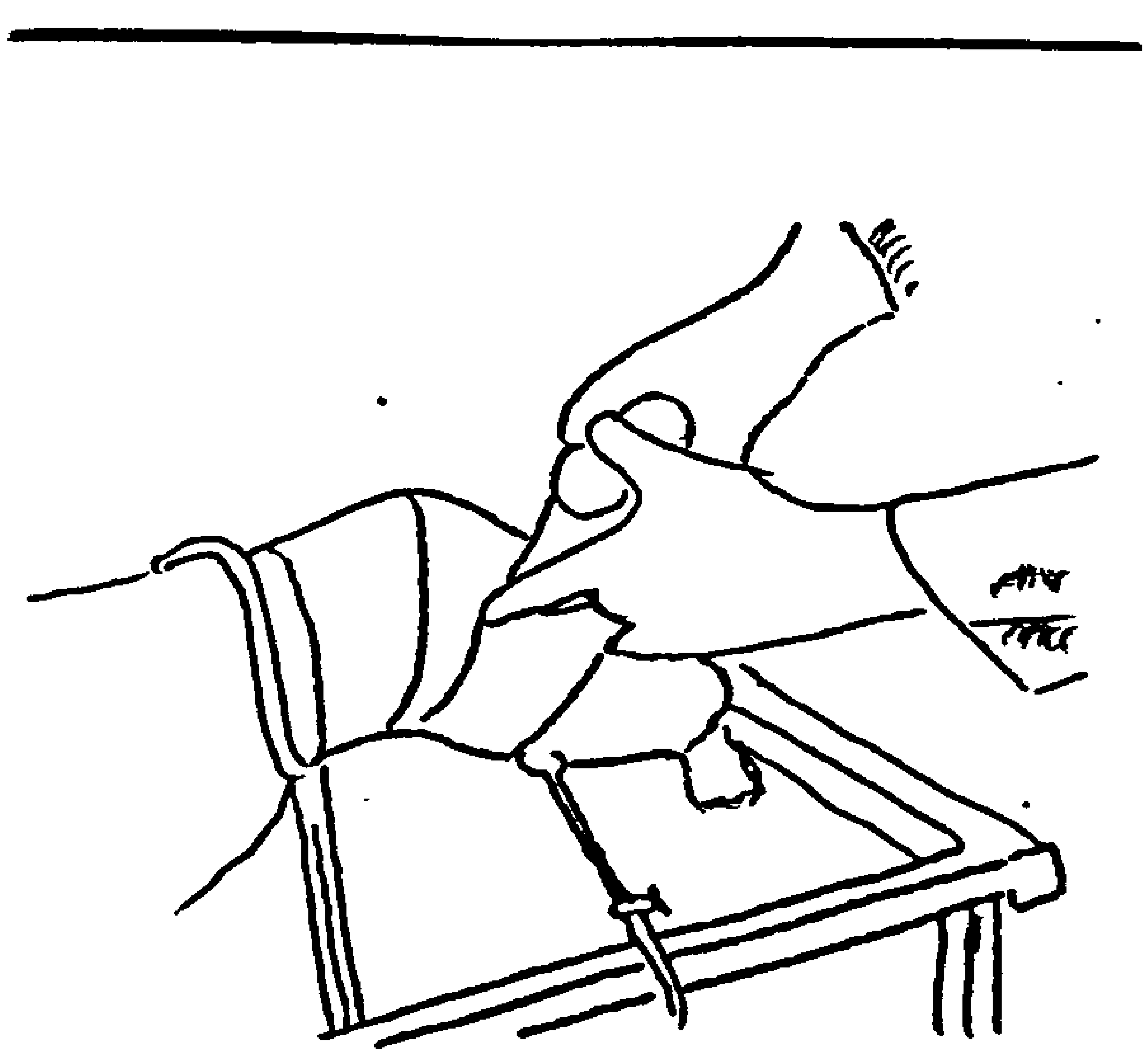


Fig II.21: The gypsum bandage is turned round the stump

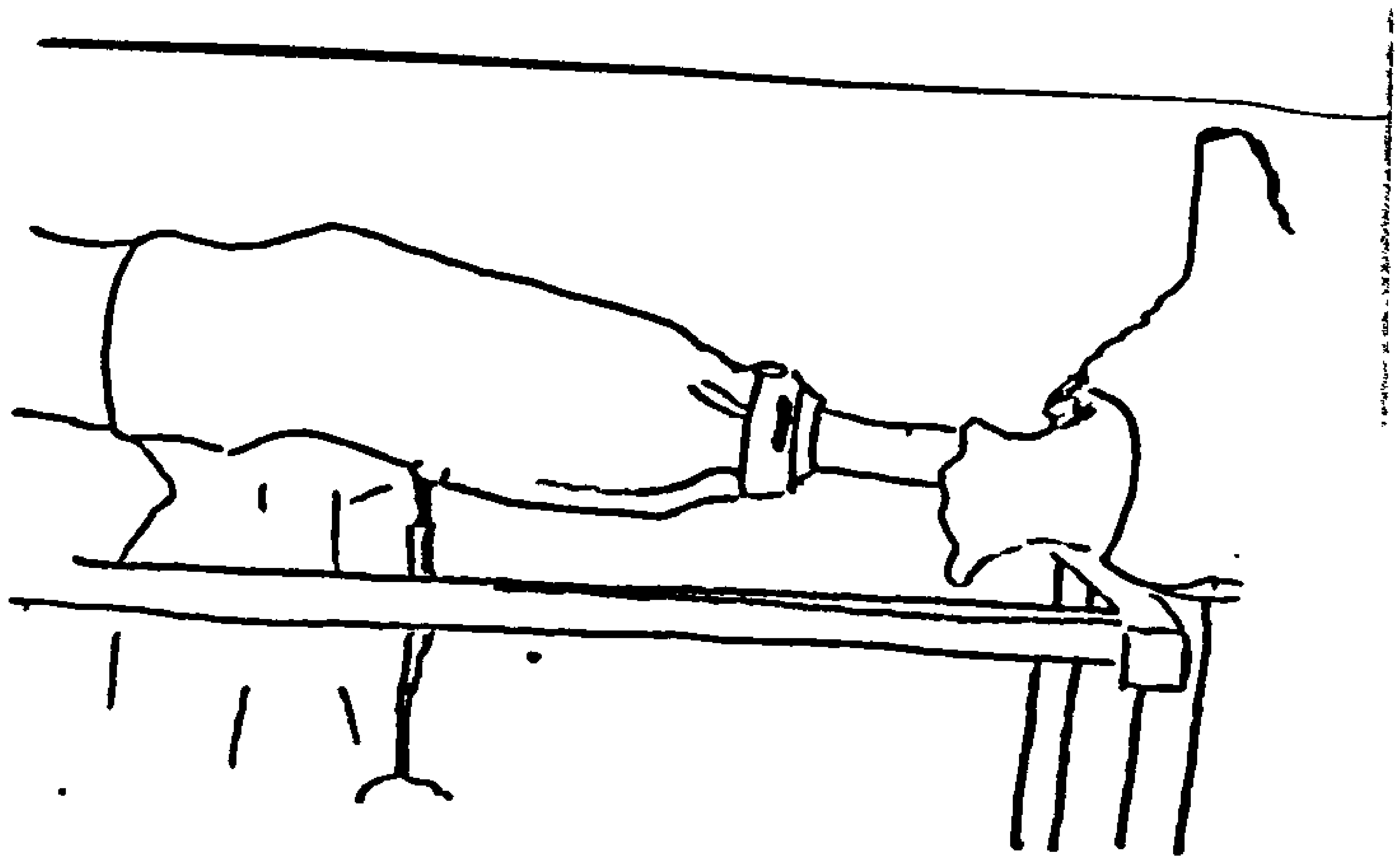


Fig II.22: Fore-aft static alignment on the table

11.II.4.2.4 Donning and doffing the prosthesis

The prosthesis is donned with the patient sitting and his stump should be as relaxed as possible. A tubular stockinet passing through the bottom hole of the prosthesis allows the stump to slip into the socket (figure II.26 and II.27). This is easier if the internal bag of water is empty. It is not necessary to pull the stockinet directly but only to touch on the left and right then straight front to back (figure II.28). When the patient feels loading areas to be in good position as shown in figure II.29, the water is pushed from the external bag to the internal one as shown in figure II.30. The aim is to adapt the contents to the container. The grip has to be felt by the patient but it is not necessary that it should resemble a tourniquet. Figure II.31 shows a provisional prosthesis completely fitted. The physiotherapist must not hesitate to adjust the stump - socket relationship by means of the stockinet thickness or a thicker bonnet. The absolute imperative is that, during the change between swing and stance gait phases, there is the minimum of friction and pistoning motion of the stump inside the socket. However, it is illusory to want to suppress them totally although the skin of the vascular patient is very fragile by definition, as shown by Mak *et al.* (1994) about the biomechanical assessment of below - knee residual limb tissue. It takes a long time to heal and it is necessary to reduce the risk of hurting it. Figures II.32 and II.33 show a patient wearing his provisional prosthesis and using only one cane.

For doffing, the order of manoeuvres is opposite. First, empty the water in the external bag then, when the stump is slackened, pull the tubular stockinet upwards by alternated traction. The prosthesis is maintained on the ground by the other hand or by placing the therapist's foot on the front of the ankle piece of the prosthesis.

11.II.4.2.5 Advantages and disadvantages

Besides the low cost and high-speed manufacture, gypsum is a good choice material because of its porosity. Not only is the socket largely open but also the gypsum allows the healing wound on the stump to breathe. The skin is not at risk of maceration or excessive sweating. We have never met true allergy to the gypsum, although some additives are introduced during manufacture.

The major disadvantage of this prosthesis is that it requires close supervision at all times. Maladjustment can occur at any time. The role of the physiotherapist permanently supervising his patient is vital:

- when the subject is able to don and doff the prosthesis independently, the quality of the donning has to be regularly controlled by the physiotherapist;
- to ensure that the tip of the stump does not touch the prosthesis;
- to pay attention to the absence of folds in the stockinet, especially if there are several thicknesses;
- if pain or any small problems appear, do not hesitate to withdraw the prosthesis to put on it again;
- believe what the patient says;
- verify the colour of the skin after each doffing: particularly in respect of redness, cyanosis, ... and that the patella tendon loading area is present on the correct place;
- to ensure that the prosthesis is inspected at the end of each day and training to find any mechanical problems or if the socket is starting to be fragile;

Suspicion of stump - prosthesis conflict discovered by the nurse during dressing time must be reported to the physiotherapist and the prosthetist. The problem must be immediately corrected. The efficiency of the provisional plastered

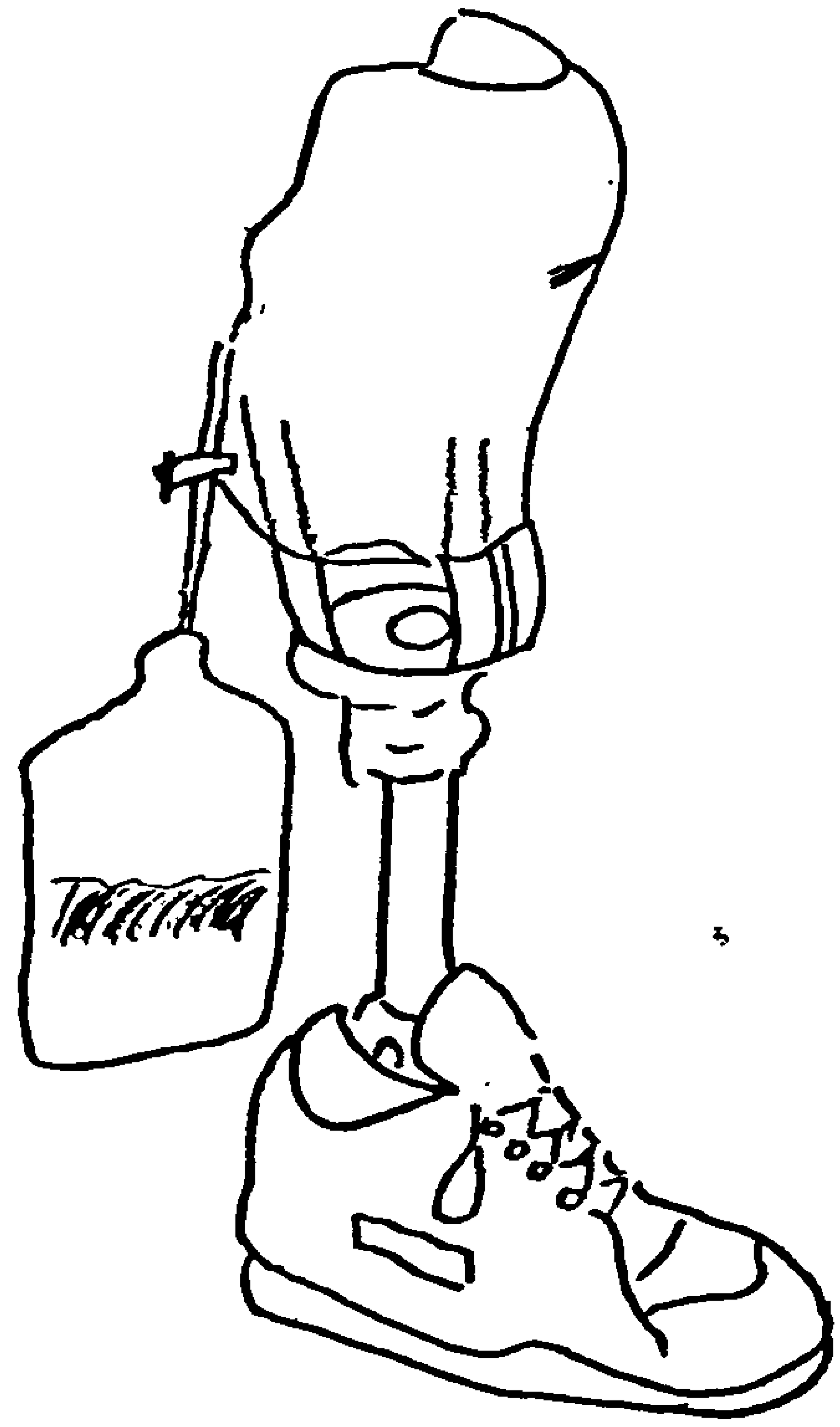


Fig II.23: Provisional prosthesis with the external water-bag of the hydraulic system. The patient had a small permanent bending knee contracture

Fig II.24: Schematic view of the artificial ankle with the front ring and the rear bumper

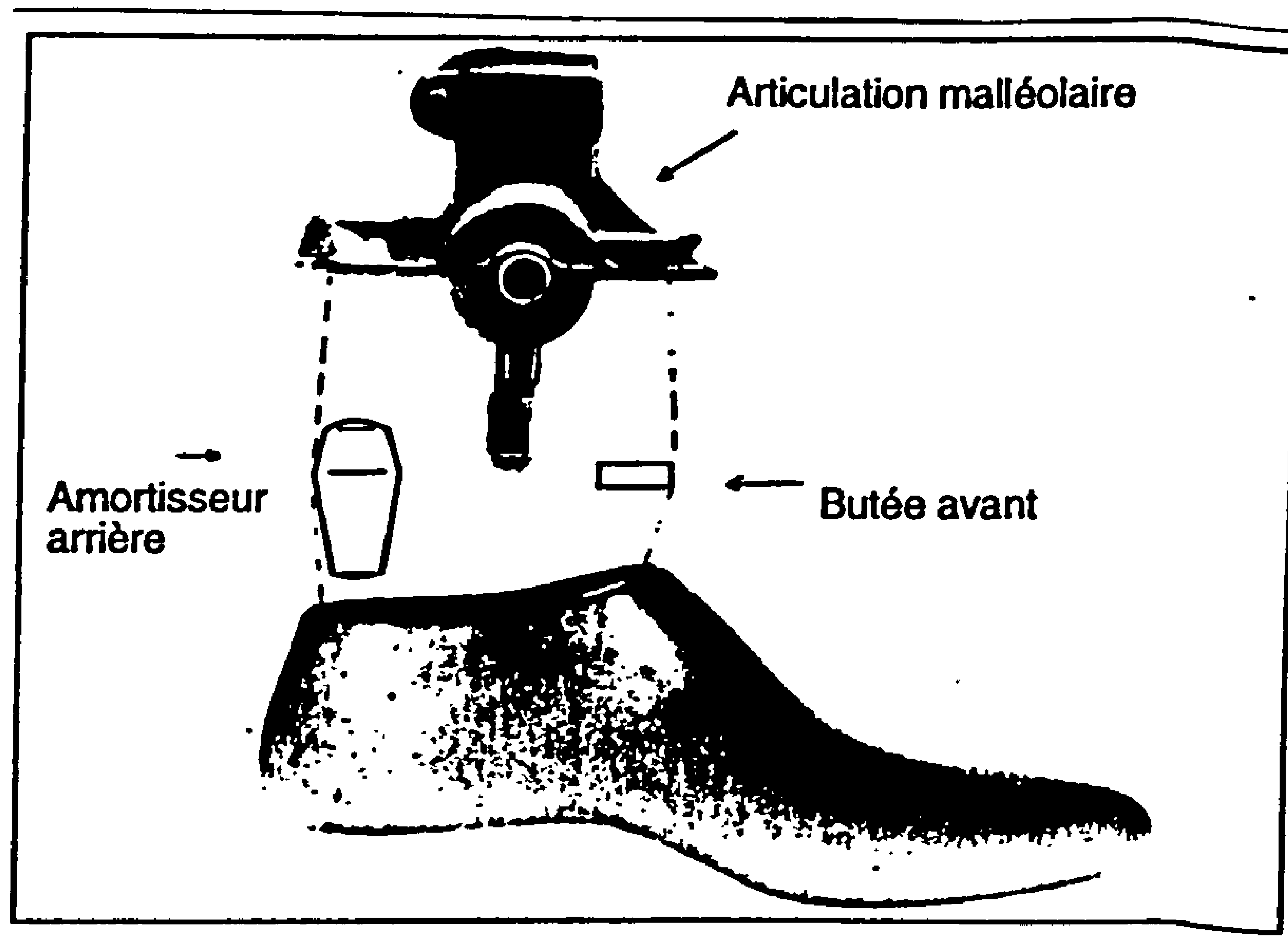
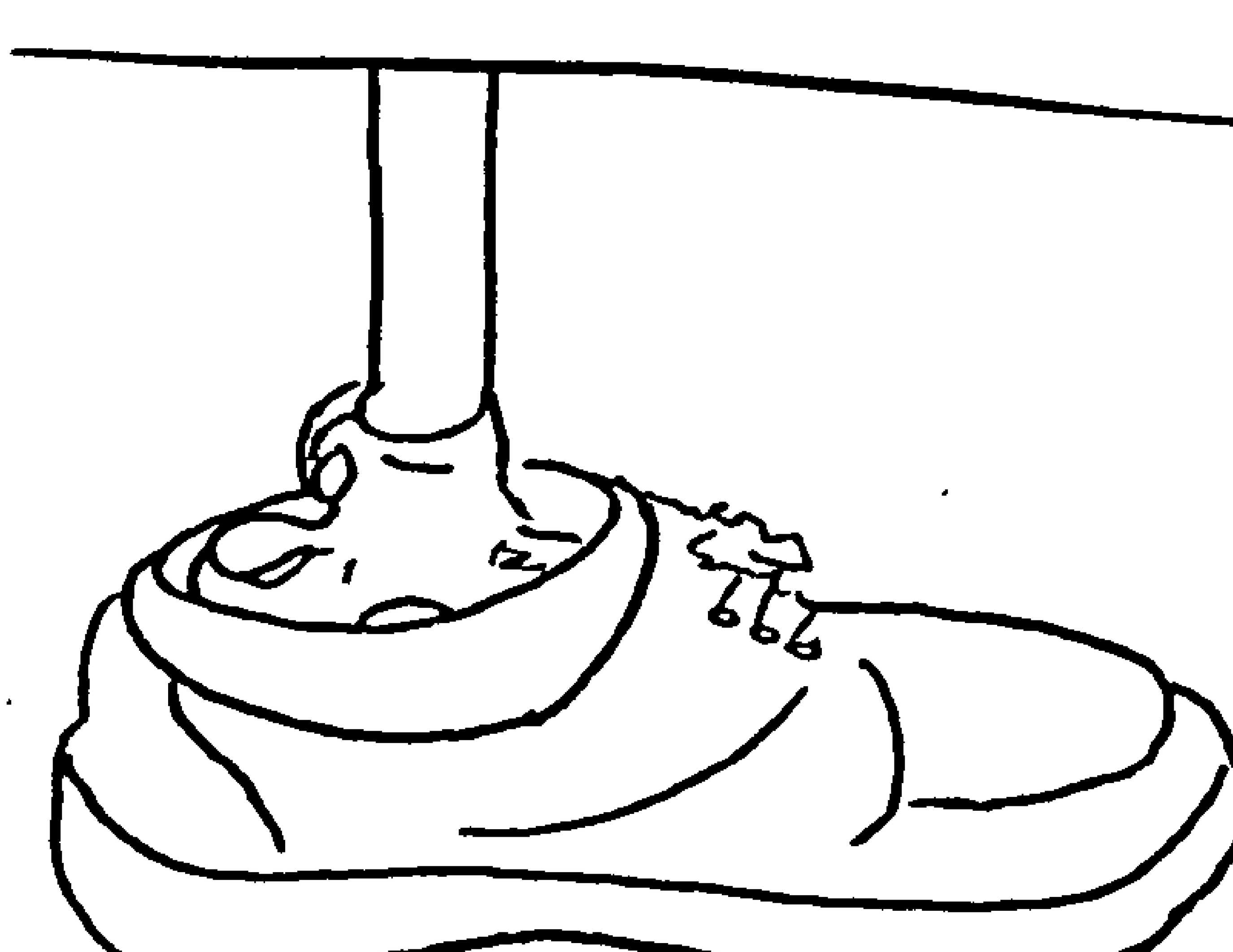


Figure II.25: The artificial monoaxial foot with the shoe, the ankle and the shank tube



prosthesis depends on close communications between the members of the rehabilitation team.

All of these provisional prostheses were fully described by Dechamps (1982) and Bertholus *et al.* (1990).

11.II.4.3 THE DEFINITIVE PROSTHESIS

11.II.4.3.1 Description, manufacture and fitting

The term **fitting** of a prosthesis is used for the shaping and contouring of the inner surfaces of the socket to the outer surfaces of the stump (New York University, Post - Graduate Medical School, 1968). This term is reserved for the definitive prosthesis.

From a cast of the stump, the socket is formed under vacuum on a retouched positive. This allows relief of pressure at places such as the Tibialis crest, head and tip of the fibula and transmission of load at suitable axes. It is manufactured in layers of acrylic resin with a thermal making up comfort soft socket in polyethylene foam (Pelite®). Improving the contact between bony landmarks and the overlying skin and the rigid socket is necessary (figure II.34 and II.35). The material used was described by Charpentier & Tourneux (1994).

In our Limb Fitting Unit, it begins to be useful to use a CAD - CAM system for transtibial amputees: BodyScan® and ShapeMaker®.

Loading areas include:

- main load: on and on either side of the patellar tendon and perpendicular to it
- secondary loads: under the tibial plateau particularly the medial one
- counter - load: popliteal recess, just under the flexural fold of the knee (figure II.36)
- femoral condylar support areas. The wings of the socket look like a clamping clip over the condyles. The kneecap is most often relieved of any stress allowing complete extension. We do not cover the patella except in cases of a very short stump to favour the guides of the prosthesis (figure II.37). For the same purpose, suspension systems are usually not used except for undersized residual limbs. These suspension systems and their effects on gait were analysed by Wirta *et al.* (1990).

The socket is triangular in horizontal cross - section: the angles are occupied by: forwards the tibialis crest; in post lateral, the fibula; in the post medial, the embossing of what remains of the muscle bulk of the Triceps Surae.

This socket looks like a Kondylen Beitung Münster prosthesis (KBM) without any corner up the medial condyle as shown in figures II.36 and II.37. This device is often named the Flexible KBM (FKBM).

The material of this socket is thermo plastic. It is possible to heat it, to deform it and on cooling, the material keeps its shape. That allows local adaptations especially at the tip of the tibialis crest, head or tip of the fibula or other usual locations. If required, the prosthetist can very easily make holes in the socket to reduce excessive pressures.

The socket is extended by a shank tube. Between the two, one can attach a system allowing modifications of the alignment. However, most often, the shank tube is strongly stuck up on the socket and it is connected to a foot. It is not possible to easily remove the shank tube.

This is why **a new easily removable transducer** was essential as was said in chapter 2. The use of the University of Strathclyde pylon transducer (Berme *et al.* 1975) was impossible.

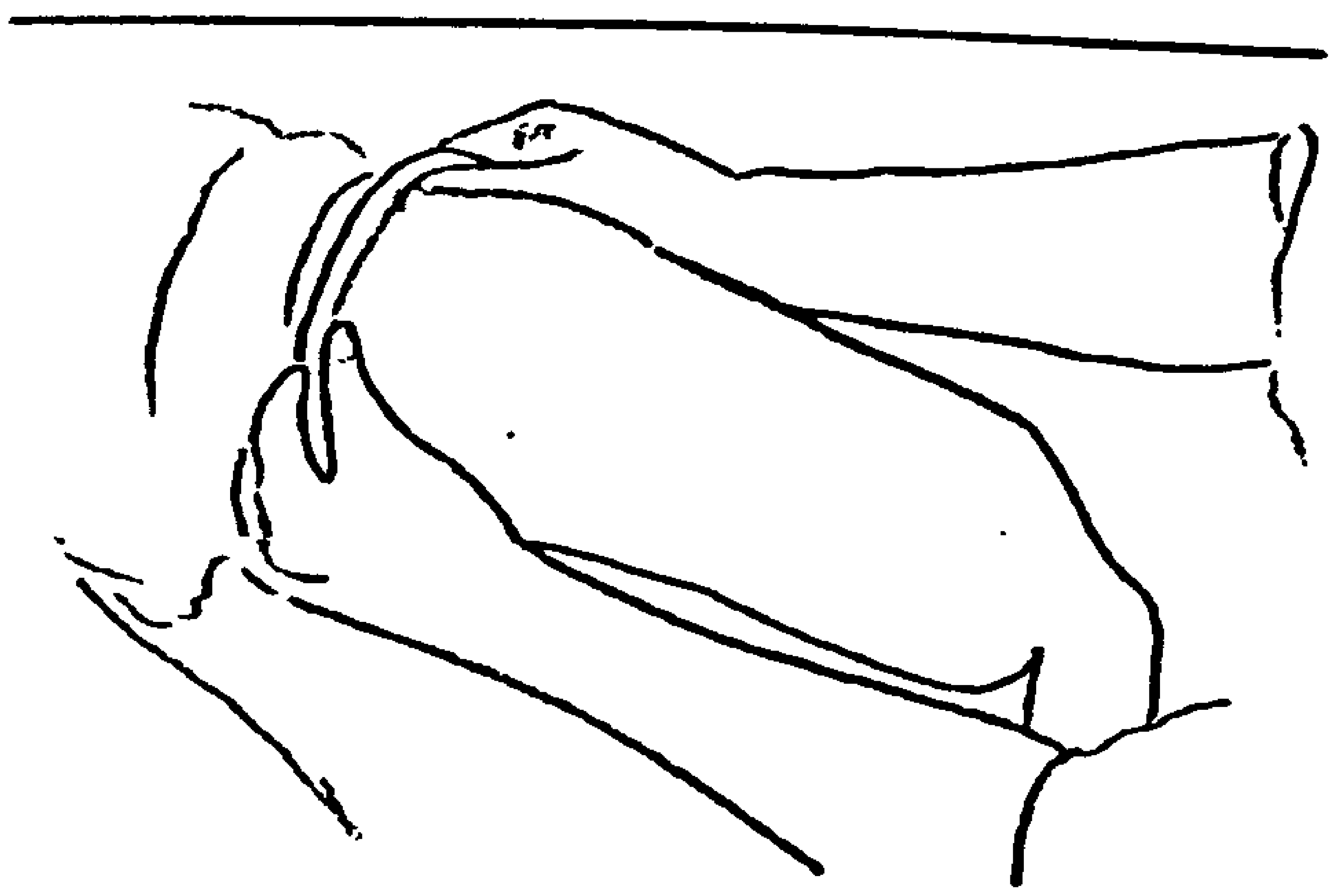


Figure II.26: The fitting of the provisional prosthesis: the stockinette is putting over the stump

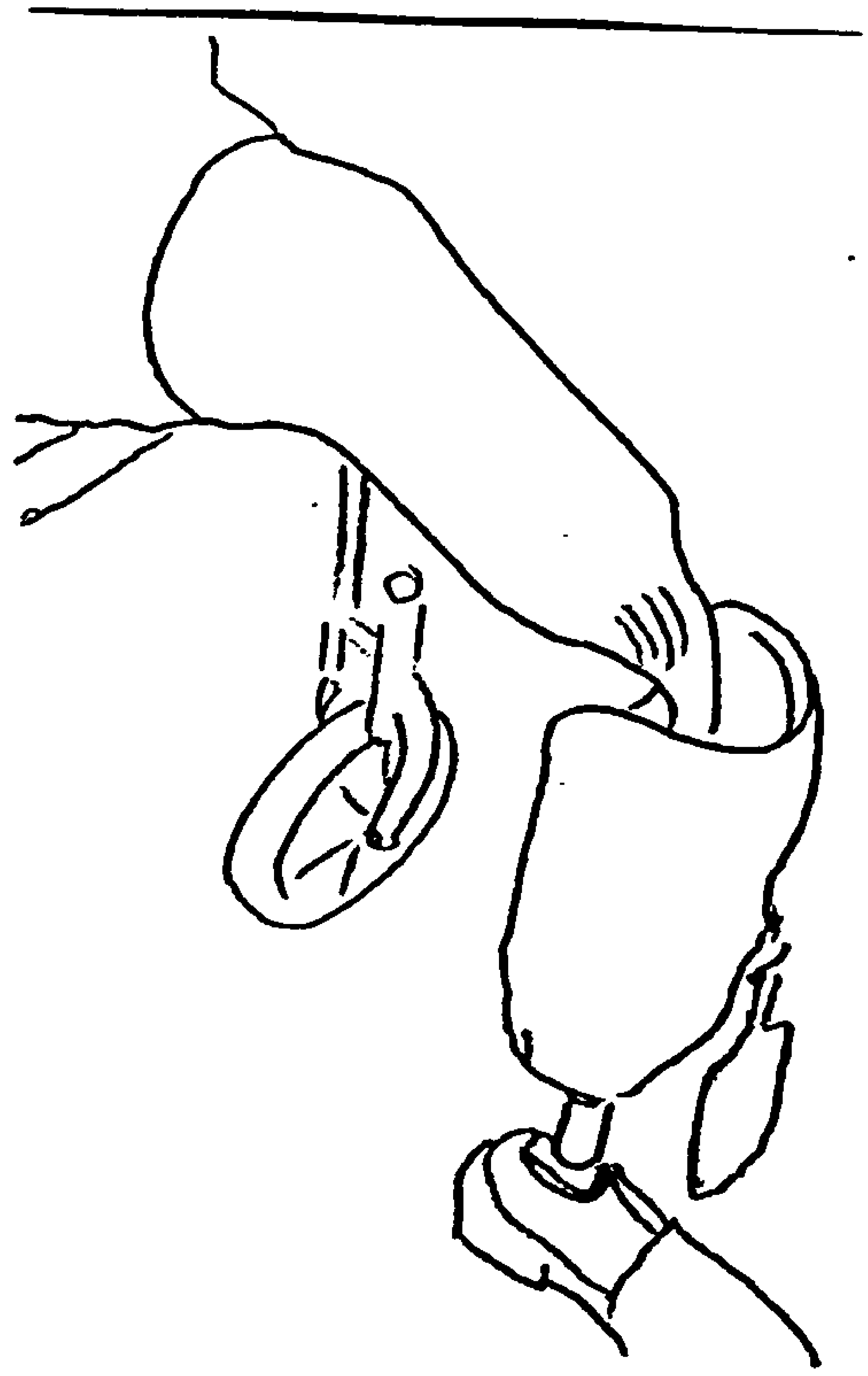


Figure II.27: The bottom part of the stockinette goes through the socket

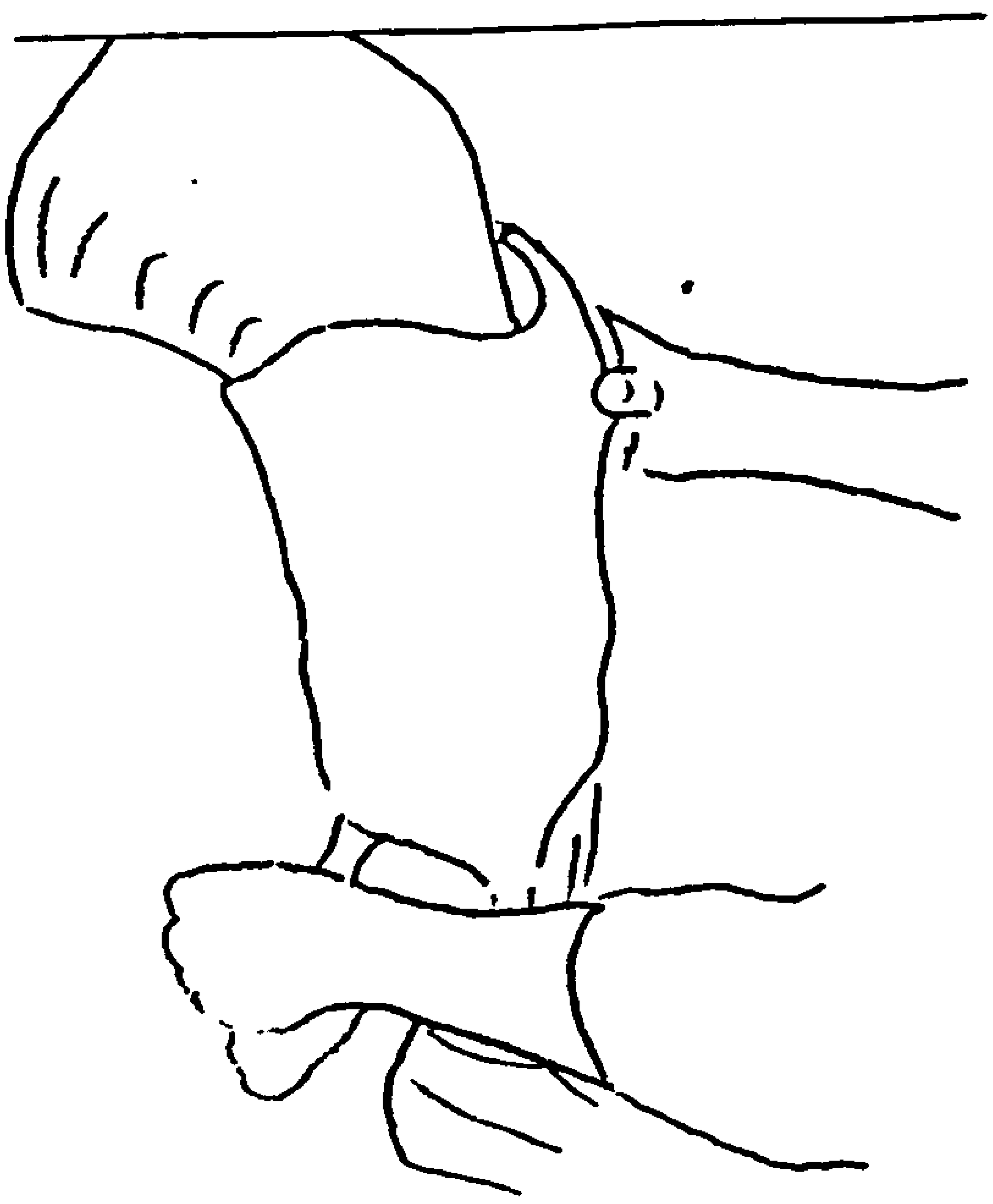


Figure II.28: The therapist pulls on the stockinette

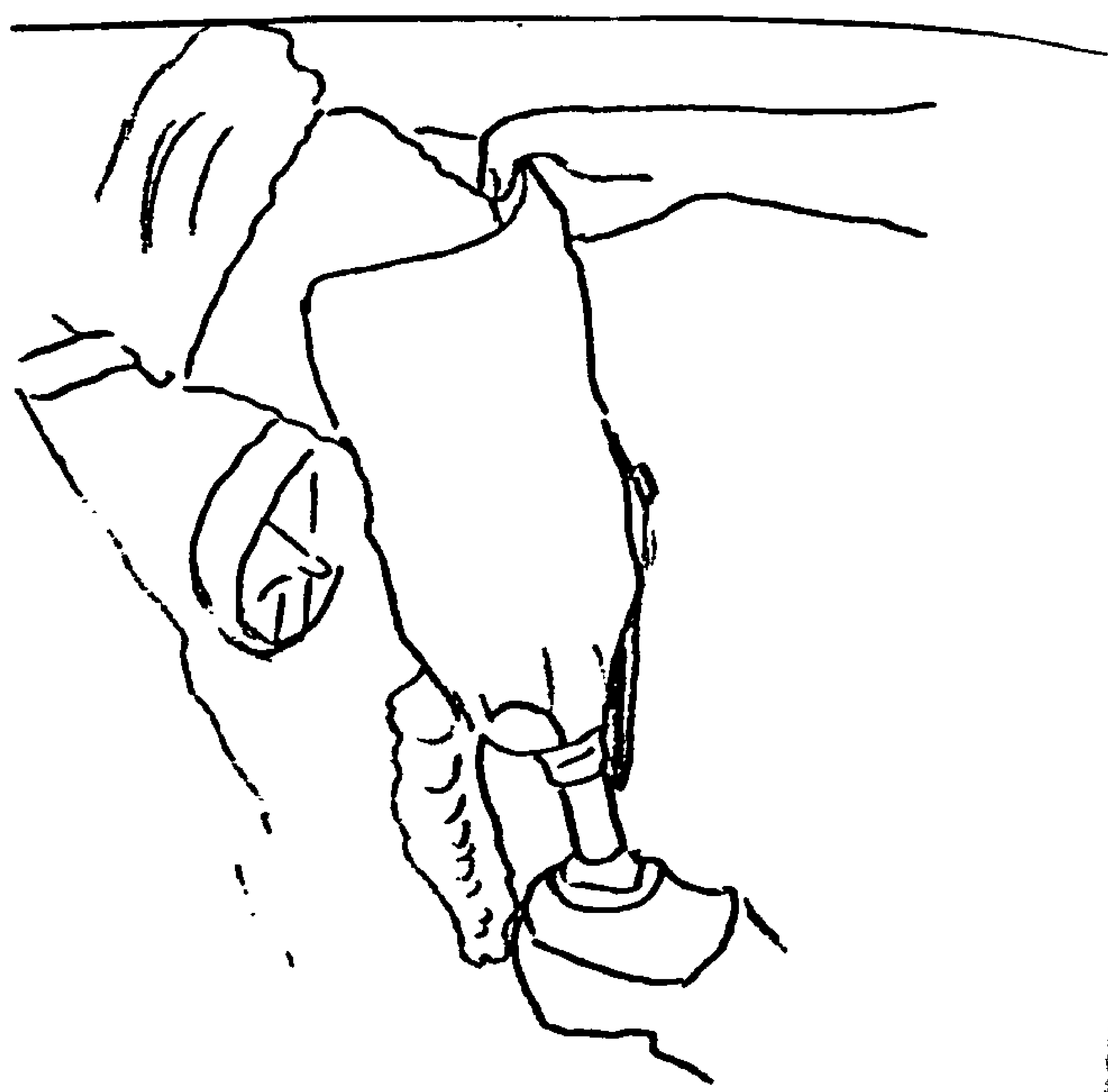


Figure II.29: The fitting is almost finished

At present, the foot is most often the same monoaxial articulated foot as was used in the provisional prosthesis[3]. This foot gives satisfaction in most cases. The SACH foot seems to us too rigid for the axial load of the majority of patients as well as for their level of activity. Other feet are available (see II.3.3.4), but in the Villiers-Saint-Denis Unit, they are reserved for the youngest vascular subjects.

When the date of discharge from the Rehabilitation Centre is decided, the cosmetic cover of the prosthesis is constructed. It is a honeycombed sponge sculpted by the prosthetist to be similar to the opposite side. This sponge is covered by two layers of stocking. This cosmetic way of doing makes the cosmesis beautiful enough in appearance and to touch, but it is fragile.

The process of finally verifying that all aspects of the prosthesis (including fit, function and cosmetic appearance) are satisfactory at delivery is referred to as the **check - out** (New York University, Post-Graduate Medical School, 1968).

Since the rigid tube is central, the prosthesis is designated endoskeleton. It is the current most frequently used type of prosthesis but it is always possible to make an exoskeleton prosthesis. In this case, the stiffness is external, the appearance is less pleasant but more solid. The weight is also more. The choice depends on the patient, the length of his stump, his environment, the care that he can bring to the maintenance of his prosthesis and his level of activity.

11.II.4.3.2 Alignment

The alignment is conventional. In the static point of view, we have:

frontal plane: the vertical line passing in front of the middle of the inguinal ligament, just above the femoral artery, passes by the middle of the knee, the middle of the shank tube and the centre of the ankle piece. The length is sometimes one to two centimetres shorter than the opposite side. This is done to facilitate the swing phase and to increase the axial load during the stance phase of the gait.

sagittal plane: a vertical line from the anterior part of the great trochanter crosses the knee in its anterior third, passes a centimetre forward of the shank tube and ends forward of the bi-malleolar axis, to the junction of the rear third and the front two-thirds of the artificial foot.

horizontal plane: there is a lateral rotation of the foot, identical to that of the opposite foot (toe-out angle).

These alignments are theoretical. They are named static alignments. It is necessary to adapt them to each patient according to many factors: length of the stump, pain, former gait patterns, level of re-education and the activity level, intrinsic possibilities of the patient and his desires. This list is not exhaustive. Finally, they comprise the dynamic alignments.

All patterns, alignments and the height can change and it is necessary to revise them often. This is notably evident, after discharge from the Rehabilitation Centre, when the patient has resumed his normal functional activities.

11.II.4.3.3 Variants

The main variants depend most often on the stump shape and the residual range of motion of the knee. If a new prosthesis is supplied to an established vascular amputee accustomed to a typical individual prosthesis, also consider:

- covered patella;

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[3]Manufacture by PROTEOR, 11 rue des Buttes, 21000 DIJON, France.

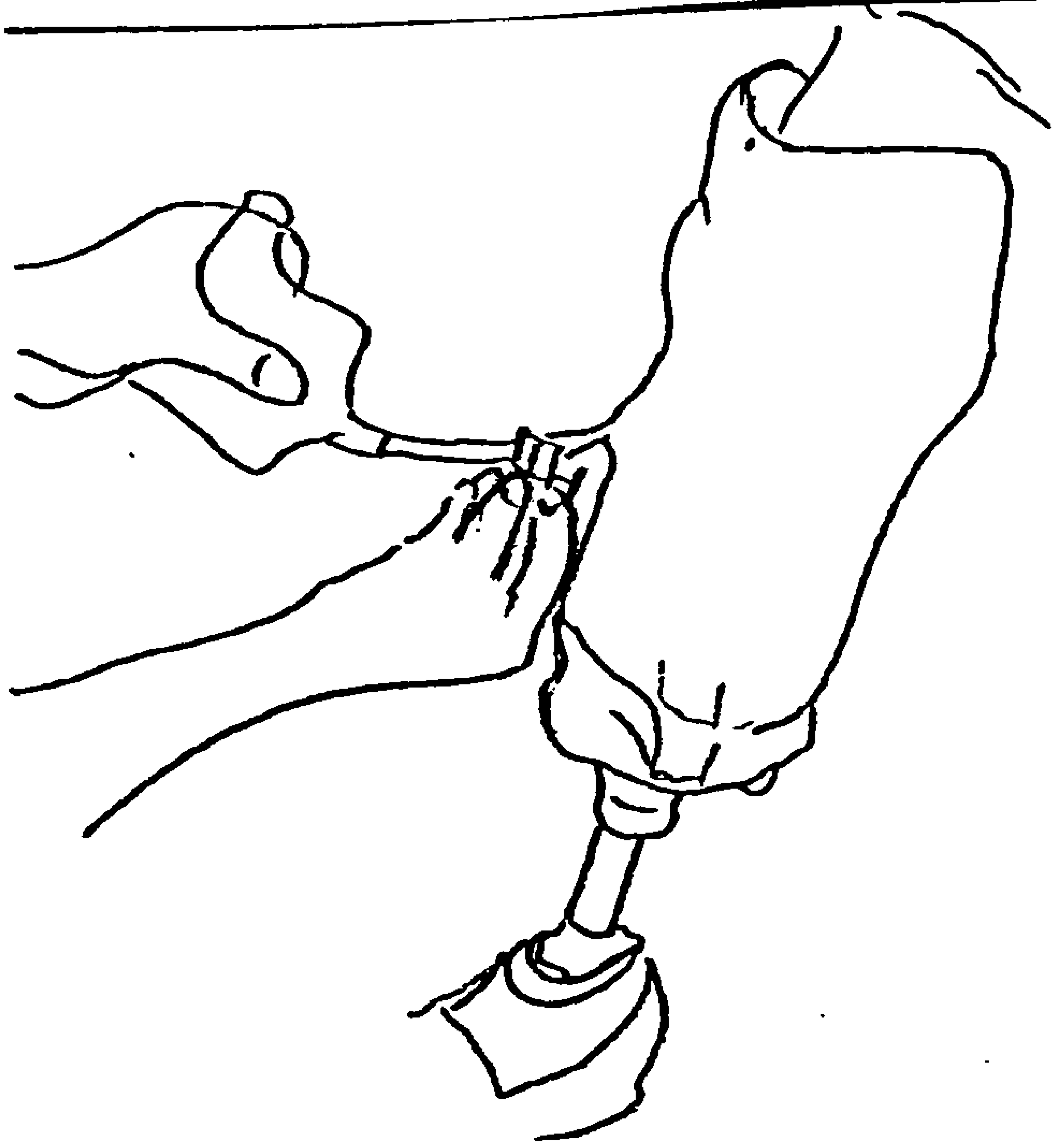


Figure II.30: The water is pushed from the external bag to the internal to adjust the different volumes

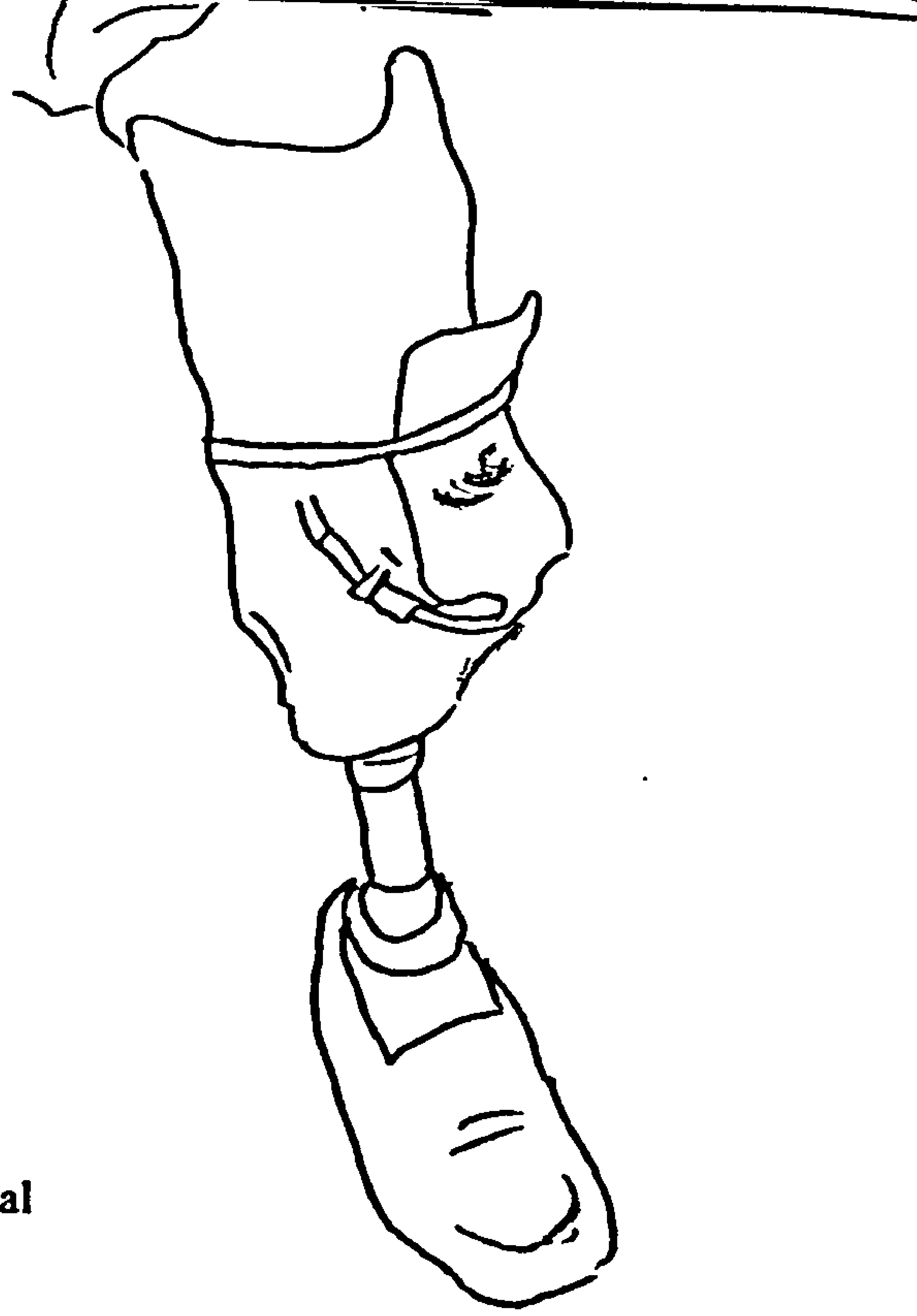


Figure II.31: The donning is finished

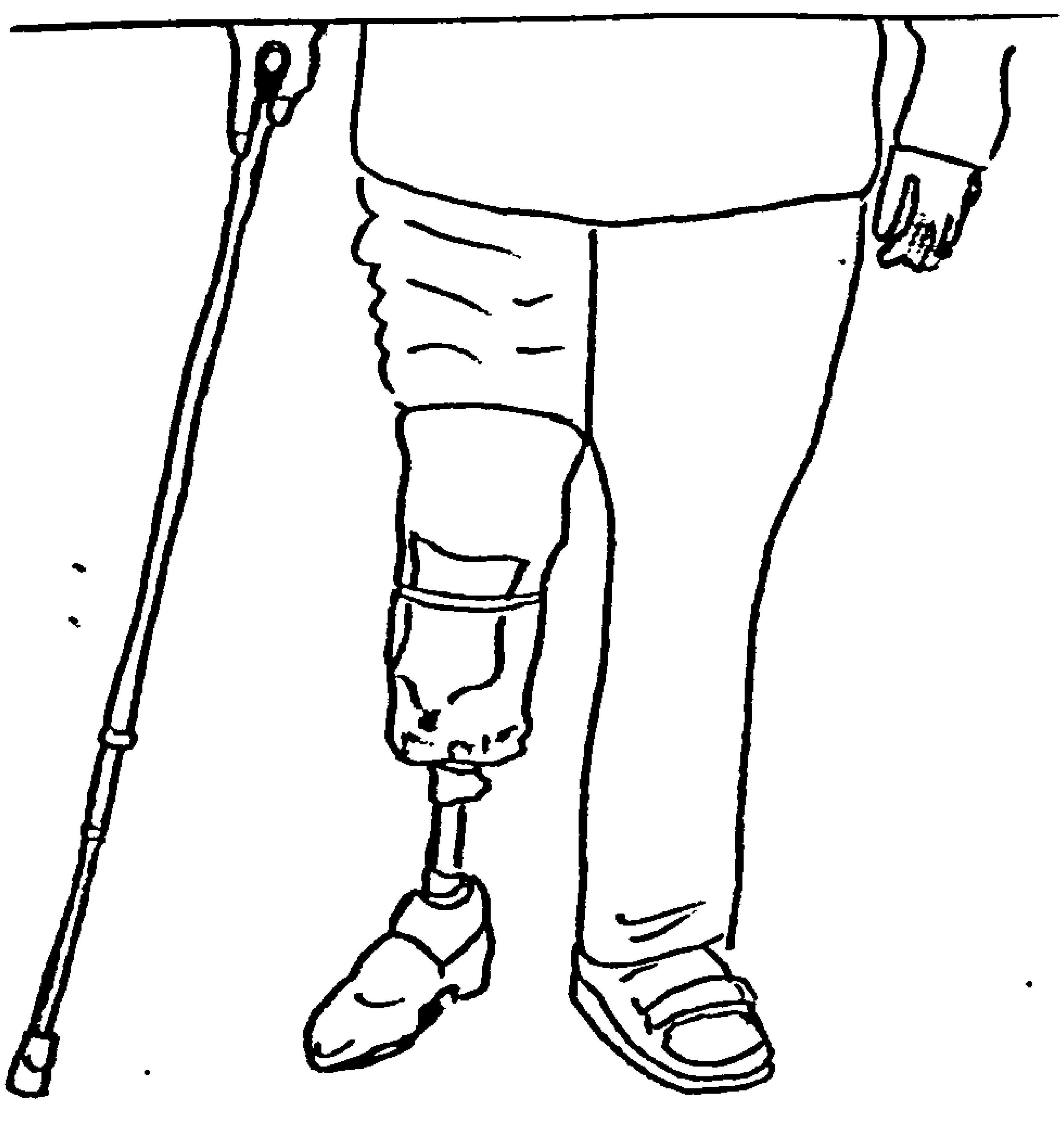


Figure II.32: The patient is standing up with his provisional prosthesis.
He uses a cane (front view)

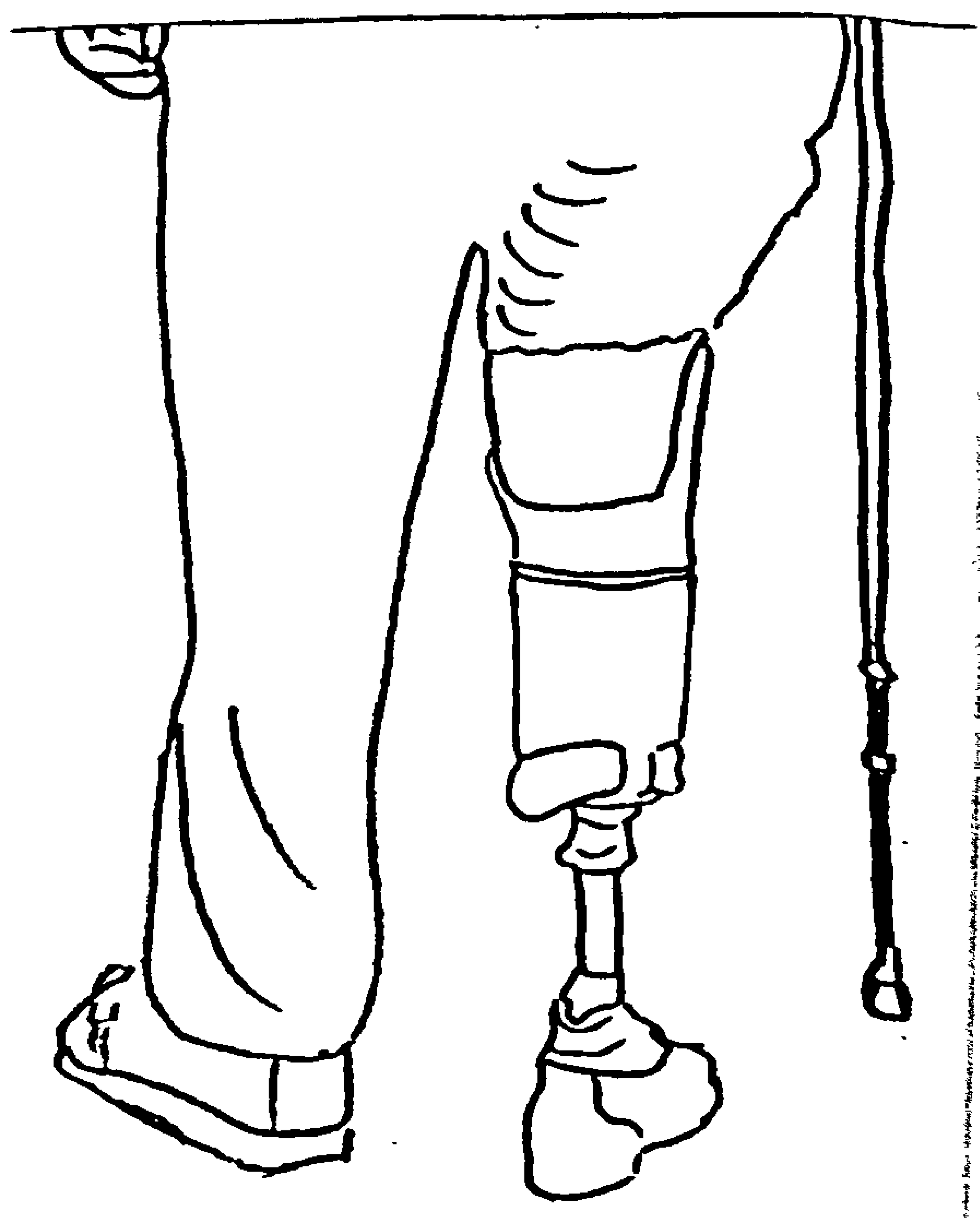


Figure II.33: A rear view of the same patient

- different materials in the manufacture of the soft socket or the socket itself;

- supply of an arch of cloth forming a grip that facilitates the donning of the soft socket for subjects whose lateral thumb - forefinger grip is insufficient as shown in figure II.38;

- conventional prosthesis with thigh brace. In our practice, it has nearly disappeared. It is used only for renewal for a patient accustomed to this type of prosthesis and who does not want to change his habits.

11.II.4.3.4 Different feet

Besides the two feet (monoaxial articulated and SACH) that cover about 95 % requirements, feet, more effective but costlier can be considered:

* Safe Foot II®, aesthetic and comfortable. It seems to have the best quality - price ratio.

* Multiflex®, polyvalent and comfortable as demonstrated by Dupont *et al.* (1996) compared with the SACH foot

* Flex-Foot® and Flex-Walk®: their indication is rare in vascular pathology; they are reserved for the most active patients.

Several new artificial feet are each year launched on the market as shown by Pitkin (1995) with a critical assessment given by Prince *et al.* (1994).

11.II.4.4 INDICATIONS FOR THE DEFINITIVE PROSTHESIS

Manufacture is commenced when the residual limb approaches its definitive shape with the most stable volume possible. This could occur when the same plastered provisional prosthesis has been assiduously worn during at least fifteen days or three weeks. It is necessary also to consider the size of the residual wound and to compare the circumference of the stump with the opposite side. The general state of the patient is equally taken into account as well as his gait recovery patterns with a minimum of pain.

It is a team - staff decision without any neglecting of the patient and his family because the discharge of the Rehabilitation Centre is impending.

11.II.4.4.1 Use

The point that seems us the most important is the very regular wearing of the prosthesis.

The soft - socket is put on first thing in the morning and worn all the day. The prosthesis is put on when the subject can do it, later in the morning. If required, according to the age and the fatigue of the patient, the prosthesis is removed for an after lunch sleep. In this case, the patient lies down and he continues to wear his soft - socket.

11.II.4.4.2 The fitting

The patient remains seated throughout the donning as shown in figure II.39.

A tubular stockinet, clean and not misshapen, is threaded on the stump and passed through the hole fitted in the bottom of the soft - socket (figure II.40). The stump's muscles of the patient are totally flabby. He introduces his stump into the soft - socket by pulling on the stockinet and not by pushing on his stump. That would entail a shrinkage of muscles of the stump and the knee with a modification of the shape of the stump (figure II.41). Consequently, the donning of the soft - socket could be more difficult with an important effort for the subject and possible pain. The patient can help himself by pulling downward the stockinet that projects (figure II.42). That makes the stump look like a spindle.

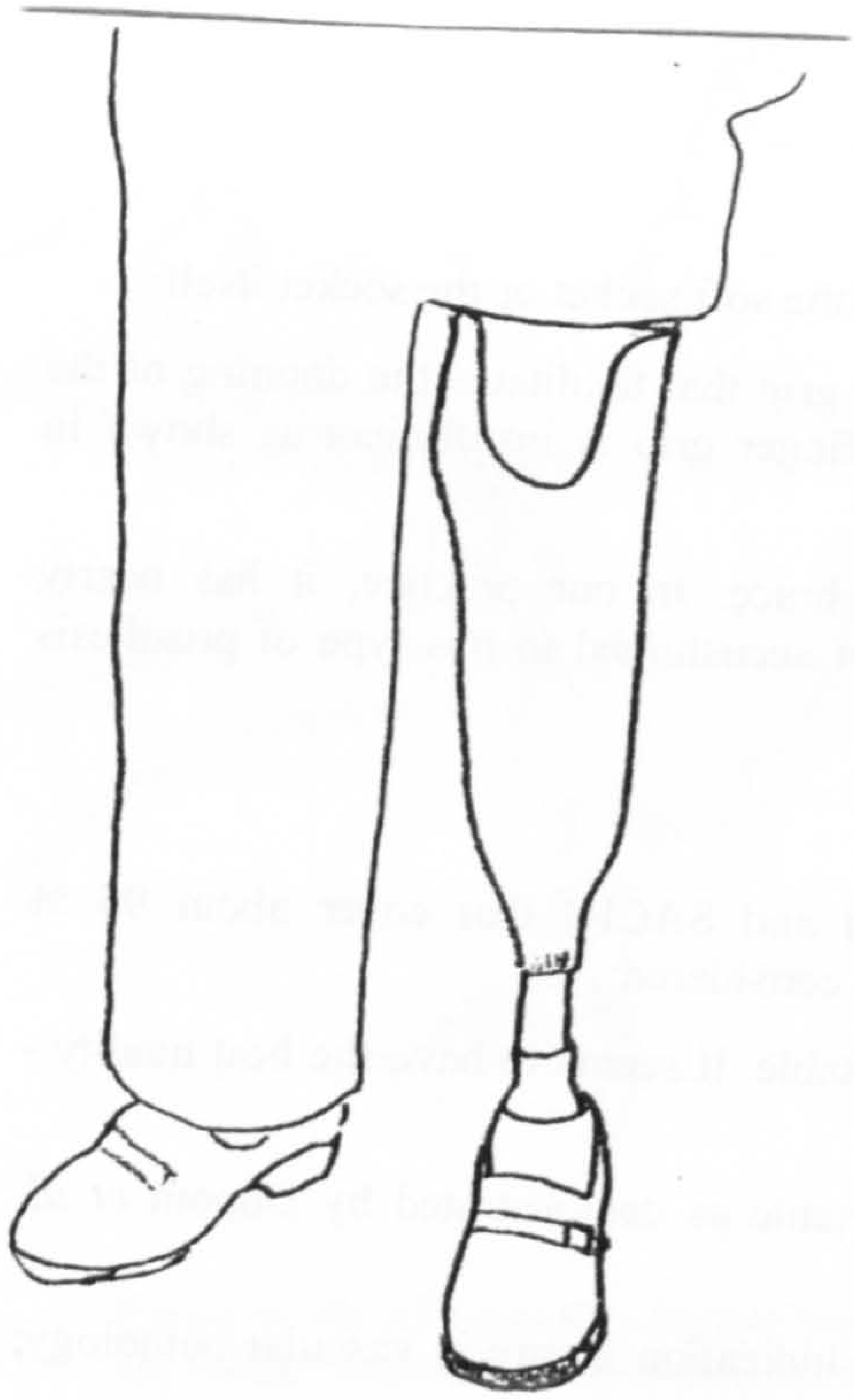


Figure II.34: A definitive transtibial prosthesis (front view)

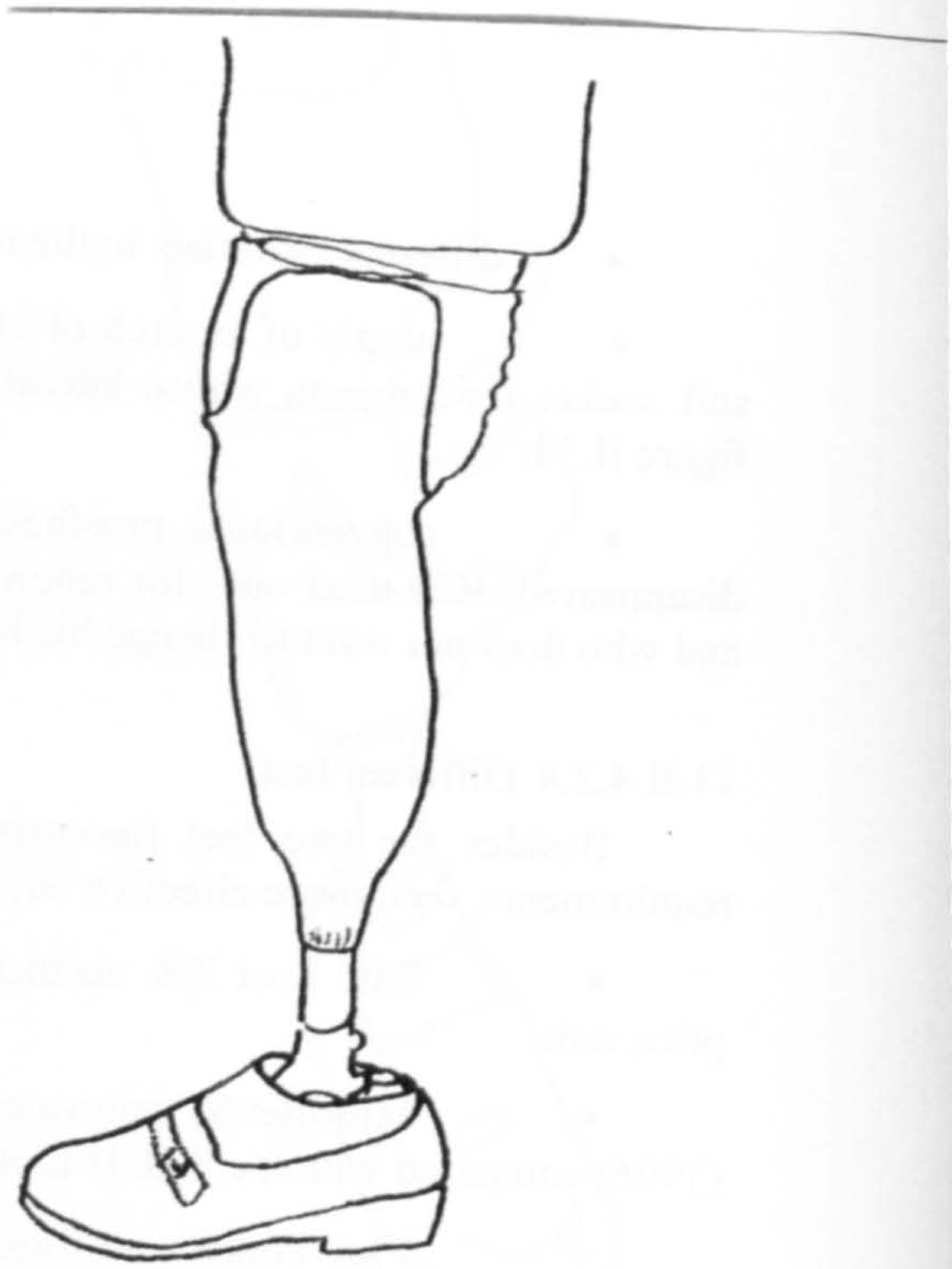


Figure II.35: The same prosthesis in a lateral view

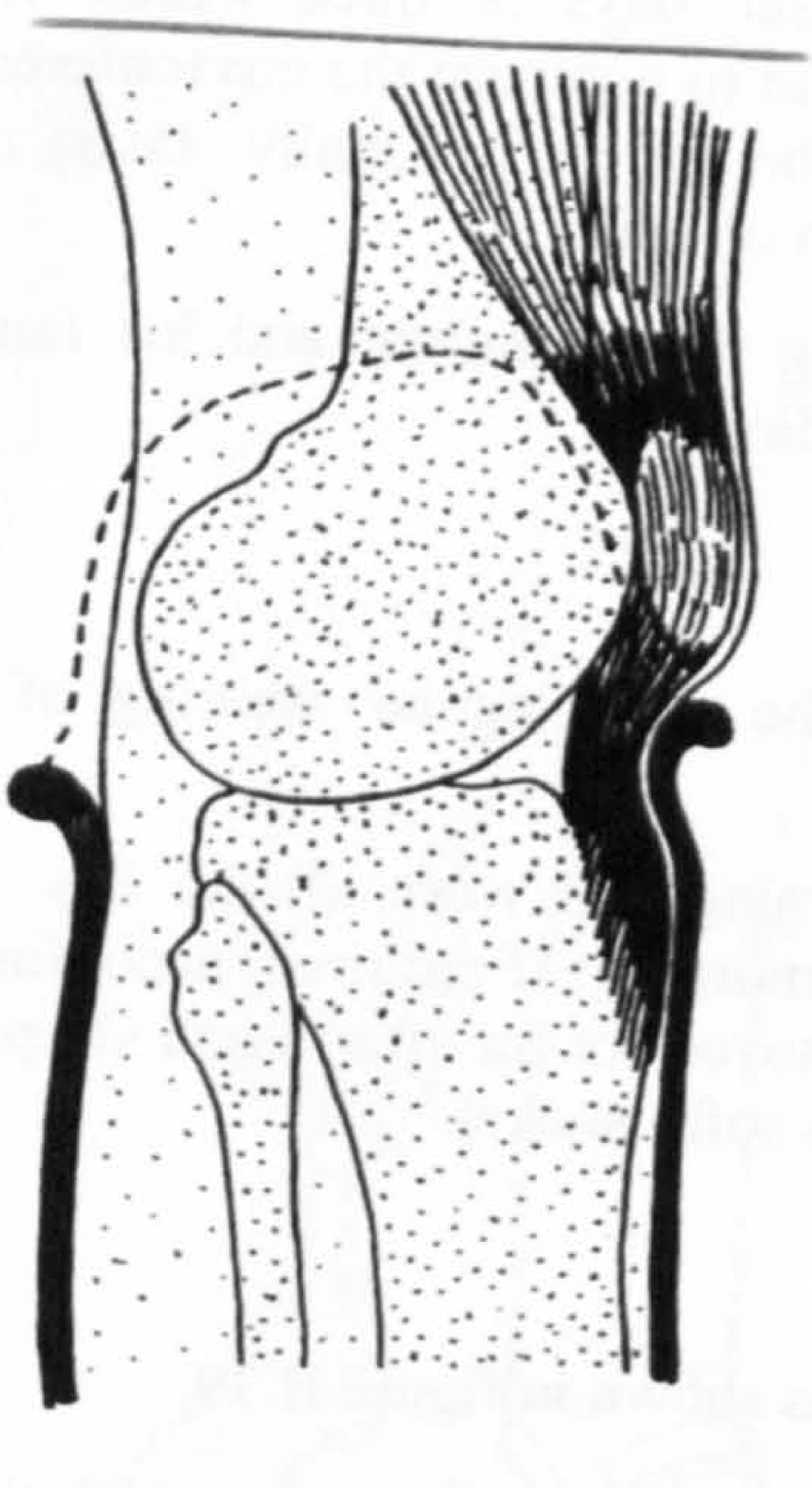


Figure II.36: The brim of a soft KBM transtibial prosthesis: main load on the patellar tendon, counter load on the popliteal recess (lateral view)

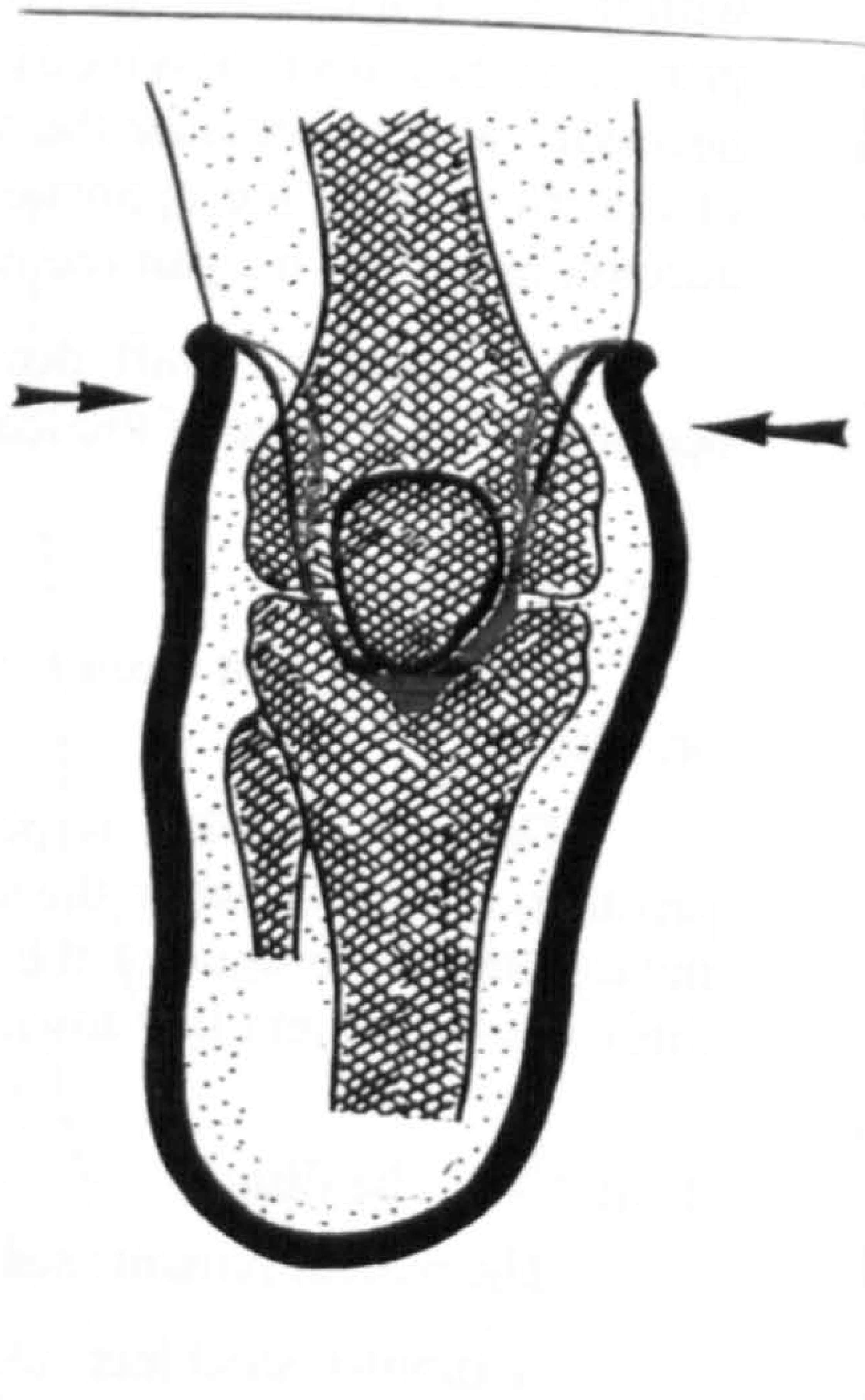


Figure II.37: Frontal view: femoral condylar support area

Consequently, it is easier to guide it into the soft - socket. This is particularly important for stumps that have some excess distal fleshy bulks. On the other hand, this action requires a good forward flexion of the trunk, which is not possible for all patients (for obesity or hip arthrodesis, for example).

The excess stockinet is folded over the soft - socket and serves as a slipping interface between the soft - socket and the socket as shown in figure II.43. This one is donned by pushing with the heel of the two hands over the two femoral condyles on a well curved and slackened knee as shown in figures II.44 to II.46. The socket must be brought into good alignment with the stump axis. The patient, seated, uses the bulk of his trunk as weight and does not need any strength in his fingers. He can take all the time he wants, by breathing calmly. Long stumps are more difficult to don because friction is more difficult to overcome.

This fitting on is relatively easy and can be easily accomplished and learned in the majority of cases.

11.II.4.4.3 The maintenance

The maintenance and the hygiene of the prosthesis are important. The socket represents a completely air proof environment in which the stump is enclosed all the day. To avoid many dermatological problems, it is necessary to wash the soft - socket daily by means of warm water and a neutral soap without any chemical addition, typically Castile soap. Hot water must not be used since the material is thermo sensitive and at risk of deforming; similarly it must never be dried on too hot a surface such as a central heating radiator. Washing should be done in the evening, and the soft - socket left to drain all night. The definitive prosthesis is delivered with two soft - sockets that are usually identical. The patient has to alternate the use.

The hard socket also must be washed regularly especially if the patient uses talcum powder.

11.II.4.4.4 Points to supervise

The skin of the stump has to be inspected each evening, including posterior areas using a small mirror. The most important points to verify are in the bony areas. The patient must look at the colouring of his skin and the possible appearance of dermatological problems. It has been well known for a long time that the skin of elderly people is particularly fragile. The effects of age and peripheral vascular disease on the circulatory and mechanical response of skin to loading were completely studied by Czerniecki *et al.* (1990).

If new pain occurs, the prosthesis must be removed for a full check of the stump, the soft - socket and the socket and then a careful redonning. If the pain persists, the patient must not hesitate to alert the prosthetist and the medical doctor.

If a point of friction or a stain appears on the dressing, the patient thinks often that if the dressing was thicker, it would be more protected. This solution is bad, any overthickness leads to an increase in strain on the area and worsens the conflict. It is necessary to explain that thoroughly to the amputee so that he is not tempted to change his dressing himself. On the other hand, some times, we try to decrease the load on a particular area (tip of the tibialis crest the most often) by putting some lateral overthicknesses above the dressing decreasing stresses on the bottom of the hollow thus created as shown in figure II.47. When a prosthesis becomes too large, the patient describes it as too tight. This is only an apparent paradox: because the prosthesis is too big, loads are transferred away from their normal position, the stump slips and jams in the bottom of the prosthesis. Resulting pain can have three origins

1. the end of the stump is overloaded on the bottom of the socket

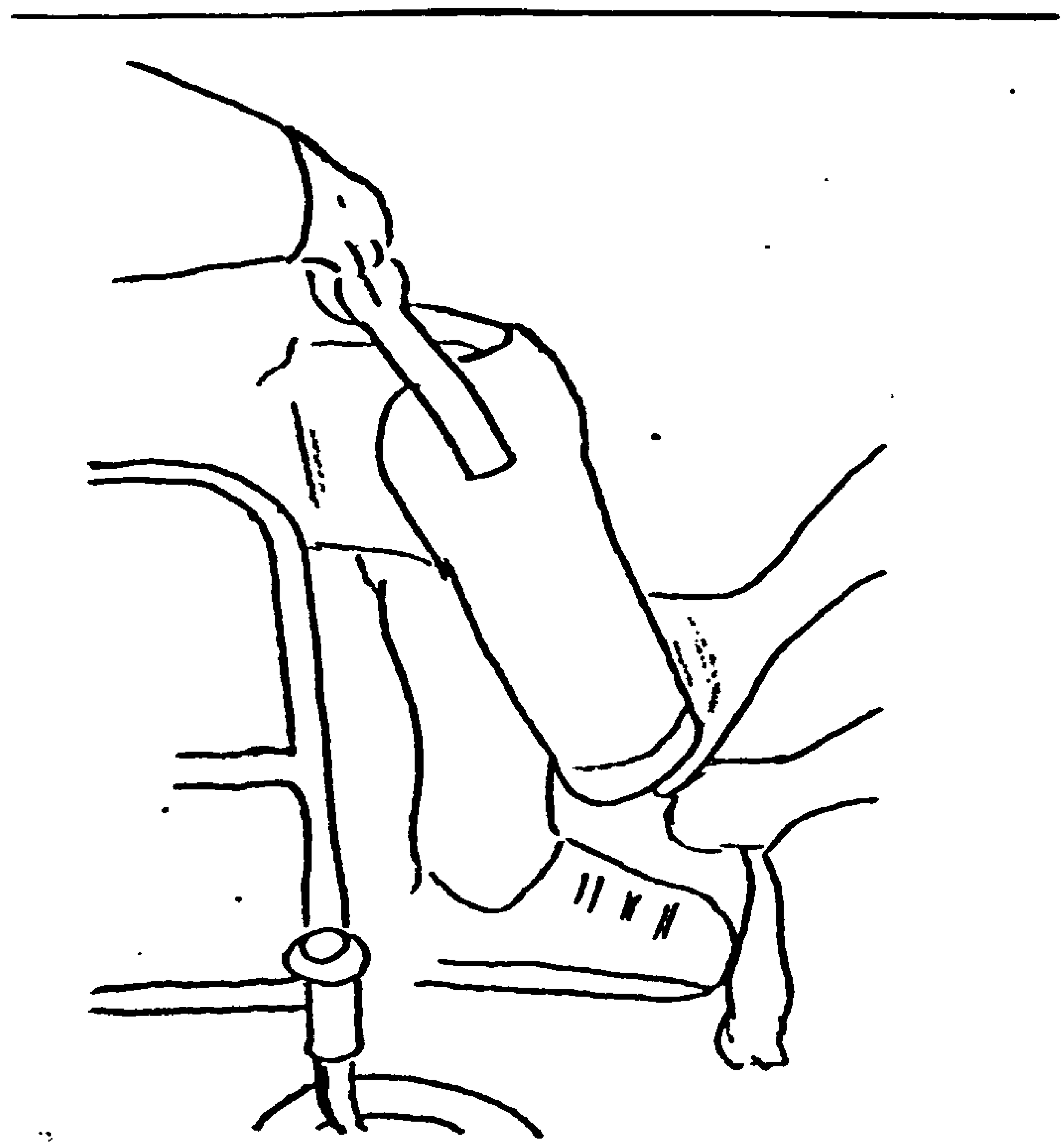
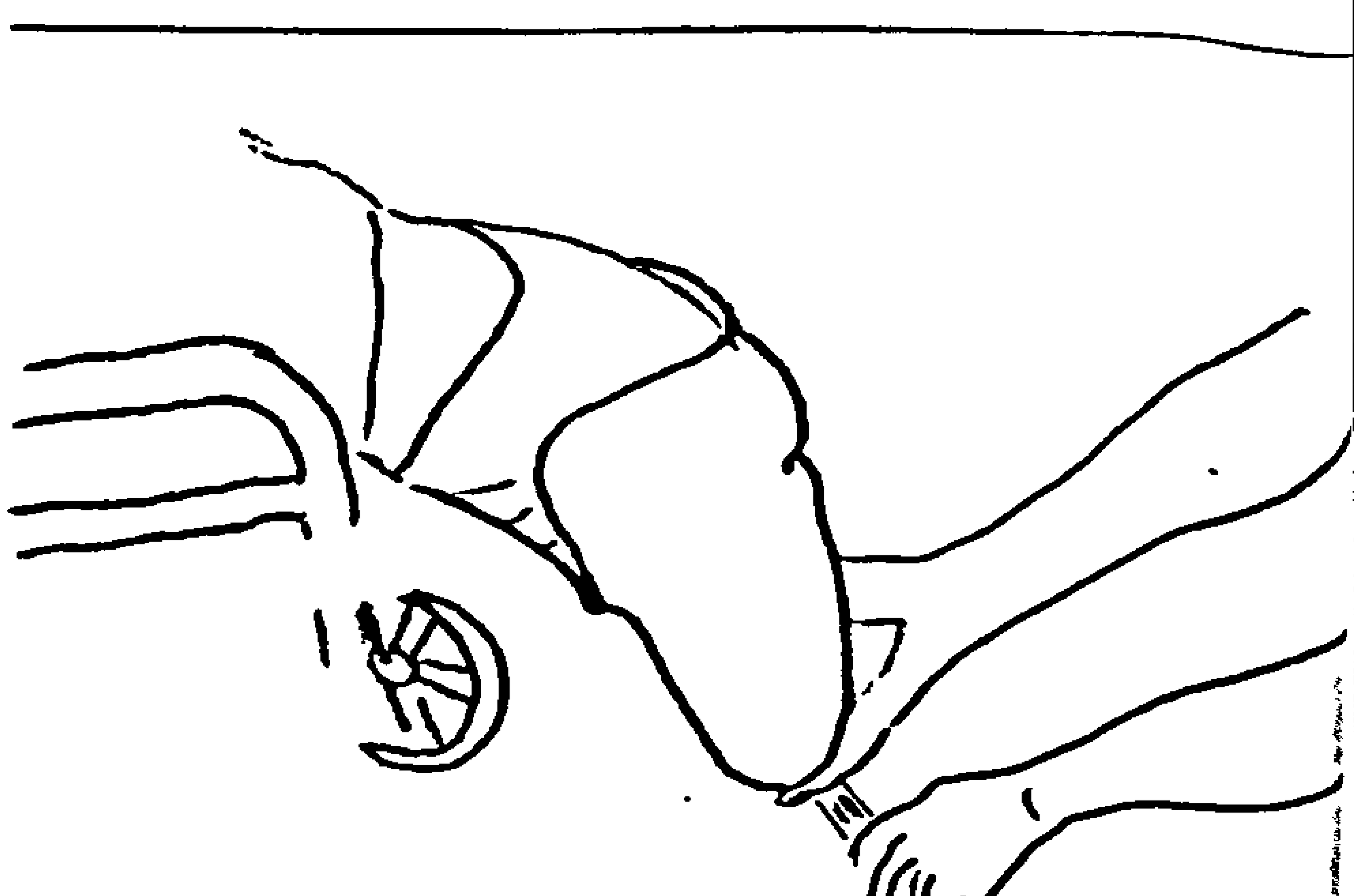


Figure II.38: A soft – socket with a "basket-handle" to facilitate the fitting for a patient who has not enough strength in his fingers



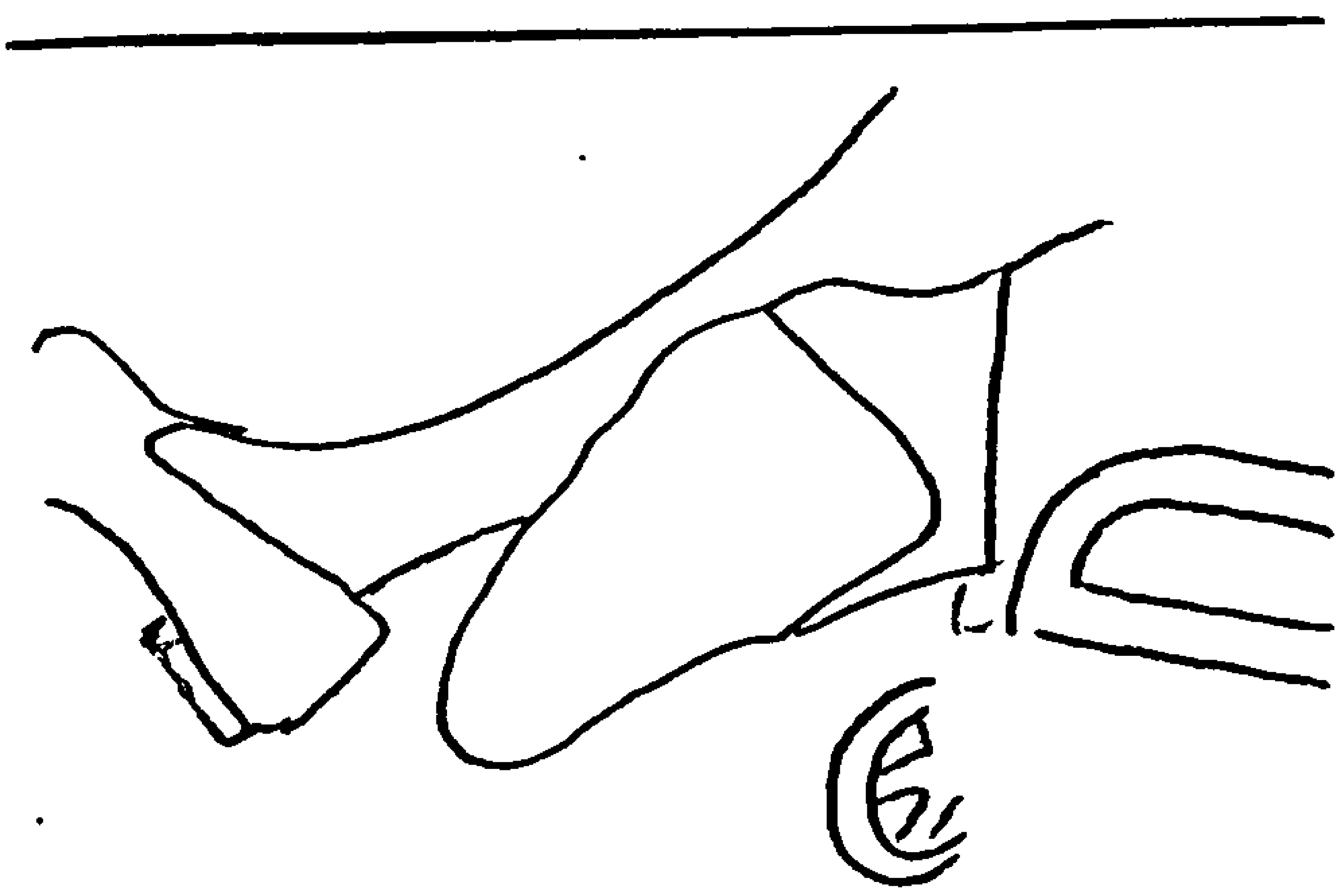


Figure II.39: The stockinette goes through the bottom hole of the soft - socket

Figure II.40: The donning of a definitive prosthesis begins with the soft socket

2. the tip of the tibialis crest is contacted because it is no longer across the hollowed bed expected for it

3. in the frontal plan, the fibula is found tightened against the shin, this entails a proximal loose put on of the upper fibula - tibial joint with the appearance of stresses in an area which has a rich sensory nervous net capsule. This phenomenon was described by ancient prosthetic workers as the nutcracker syndrome.

Each morning, it is necessary to verify the prostheses and if there is any uncertainty, a visit to the prosthetist is compulsory. As an after - sales service, a check-up visit will have to be regular after discharge from the Re-education Centre, at least two to three times a year.

11.II.4.4.5 Advantages and disadvantages

The usual designations of modern distal prostheses found in the literature are of no relevance for the physiotherapist. Namely for the most common: PTB = Patellar Tendon Bearing (USA 1958); PTS = Prothèse Tibiale Supracondylienne (France 1964); KBM = Kondylen Beitung Munster (Germany 1962). There are several variants in this nomenclature. Each of them possesses some advantages and disadvantages. The device we use is light (1,5 kg to 2 kg on the average) despite the weight of the foot and the shoe that are adversely distributed distally in relation to the stump and to the knee. This factor is therefore important and it was fully studied by Farber & Moreinis (1995). The prosthesis is easy to don and to use. It is not fragile and can be used over a long time even with the minimum of maintenance. Only cosmetic foams and overlapping stockings need a specific care, as shown in figure II.48.

Its major disadvantage is the absence of adaptation to the possible changes of volume of the stump. If it decreases, it is possible to increase the thickness of stockinet, by at most four to six layers, although control of the prosthesis becomes uncertain and the quality of the gait deteriorates. If the stump volume increases, it is possible to heat both soft - socket and socket in some few places but this is limited.

This constraint requires a good co-ordination between the different paramedical staff. Dressings have to be as uniform as possible having constant thickness and avoiding any areas of overload. This supposes that the nurse teams are perfectly trained.

In the same way, if the prosthesis has not been used during the weekend, it could become creased and difficult to put on Monday morning. Nevertheless, it is necessary to forbid any modification at this time, otherwise the socket is at risk of becoming too large when the stump resumes its Friday shape. Similarly, more generally, it is necessary to prevent a prosthesis being changed too rapidly after a period when the gait has ceased for whatever reason and the patient must be convinced of this. The consequence is that although the prosthesis is designated « definitive », (having an administrative number with a separate invoice), allows the patient to leave the Re-education Centre, it is not really very definitive. It becomes badly fitted reasonably quickly after discharge from the Centre. The patient changes his way of life, his eating habits and his stump changes in shape. Usually, his residual limb starts a weight-reduction but not always. A new prosthesis is often rapidly necessary in the weeks that follow discharge from the Centre.

A last disadvantage is that the socket is a perfectly closed environment where there may be severe sweating problems to be controlled (see section II.4.4.3).

11.II.5 Description of the different prsotheses: above – knee level

11.II.5.1 THE PLASTER OF PARIS PROVISIONAL TRANSFEMORAL PROSTHESIS

It is entirely similar to the well-known quadrilateral prostheses described in the literature many years ago.

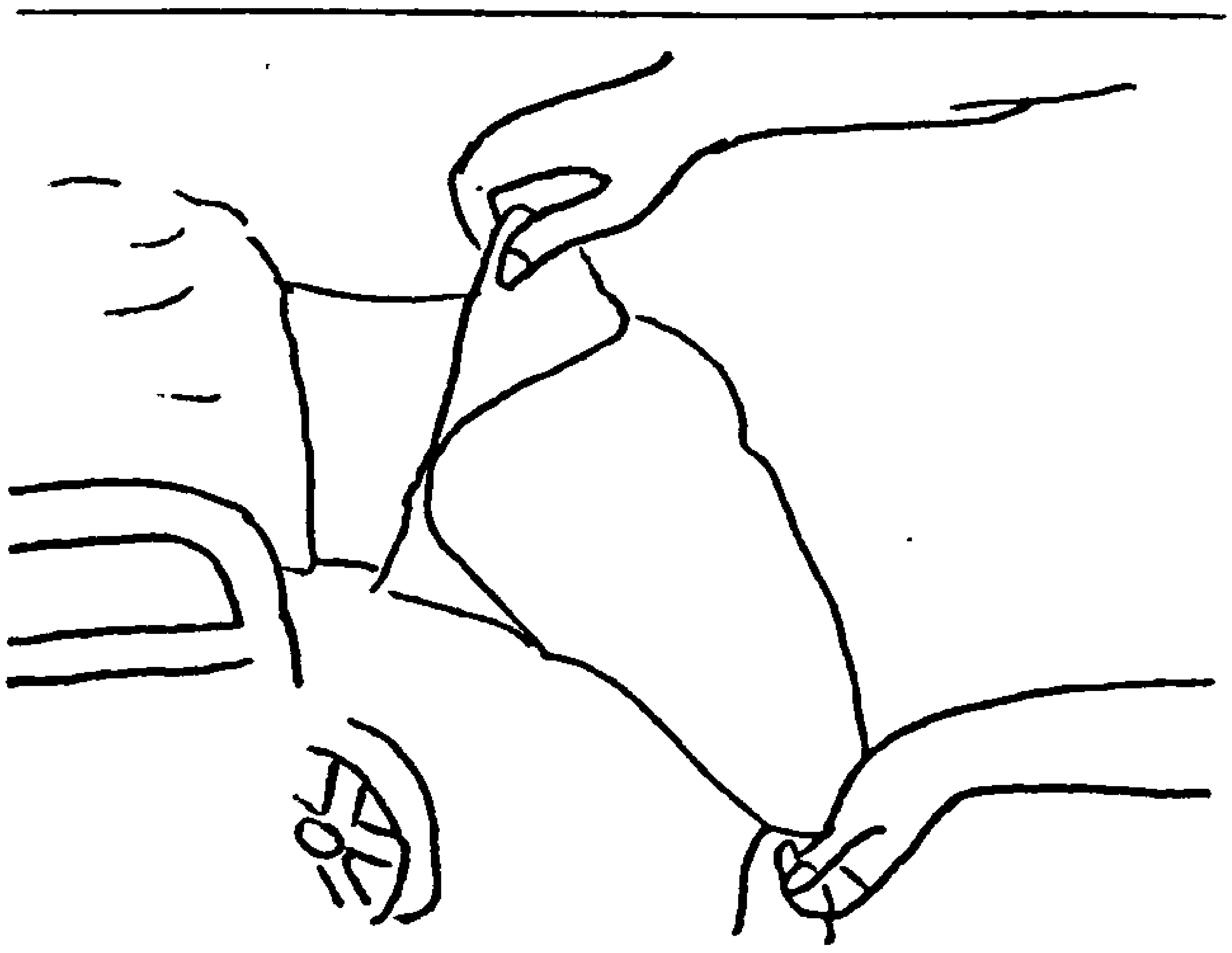


Figure II.41: For an easy fitting, the knee must be bent and the stump slacked

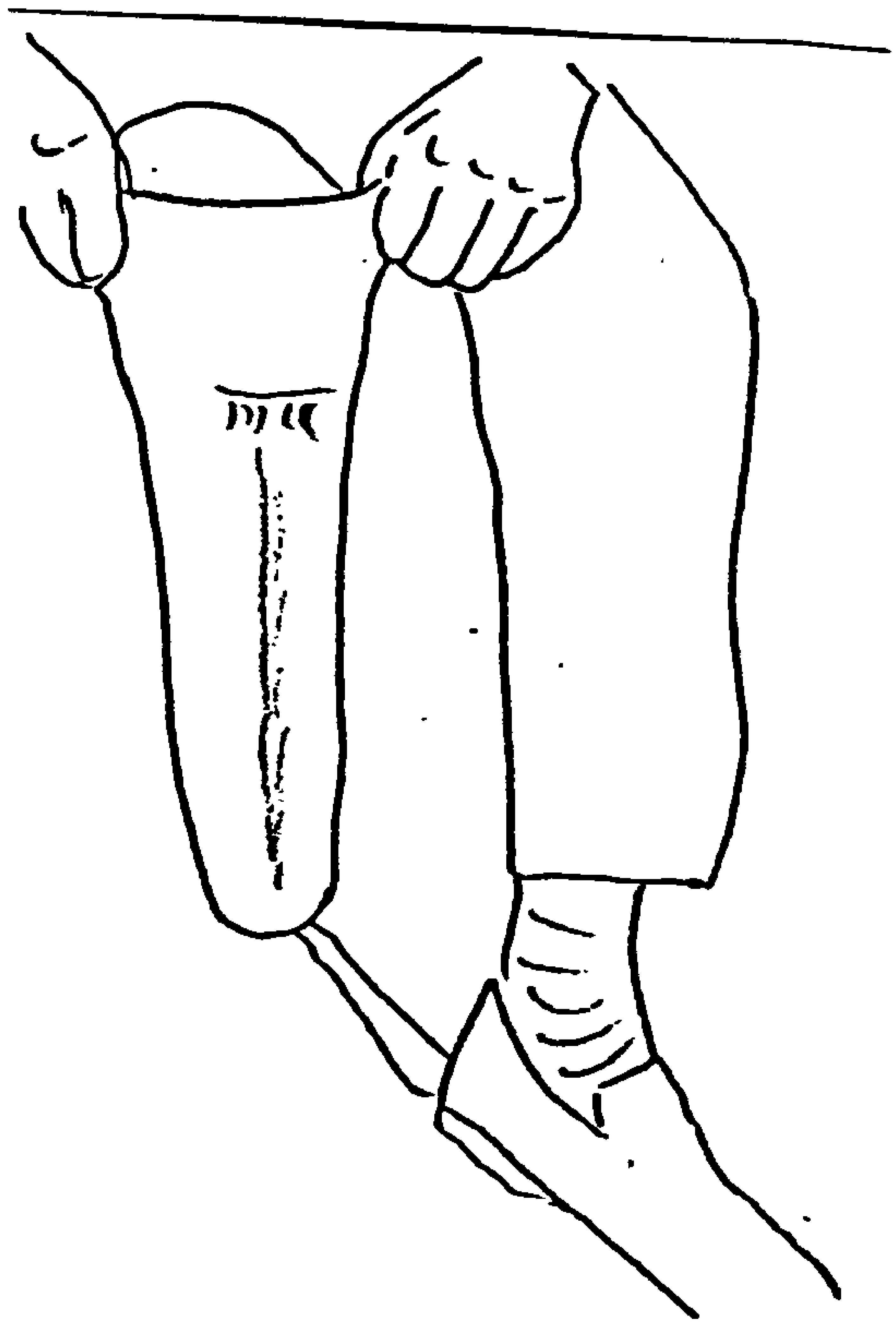


Figure II.42: The patient needs help to learn the donning

Figure II.43: The stump covered with the soft-socket is put into the socket easily because the slipping interface of the stockinette

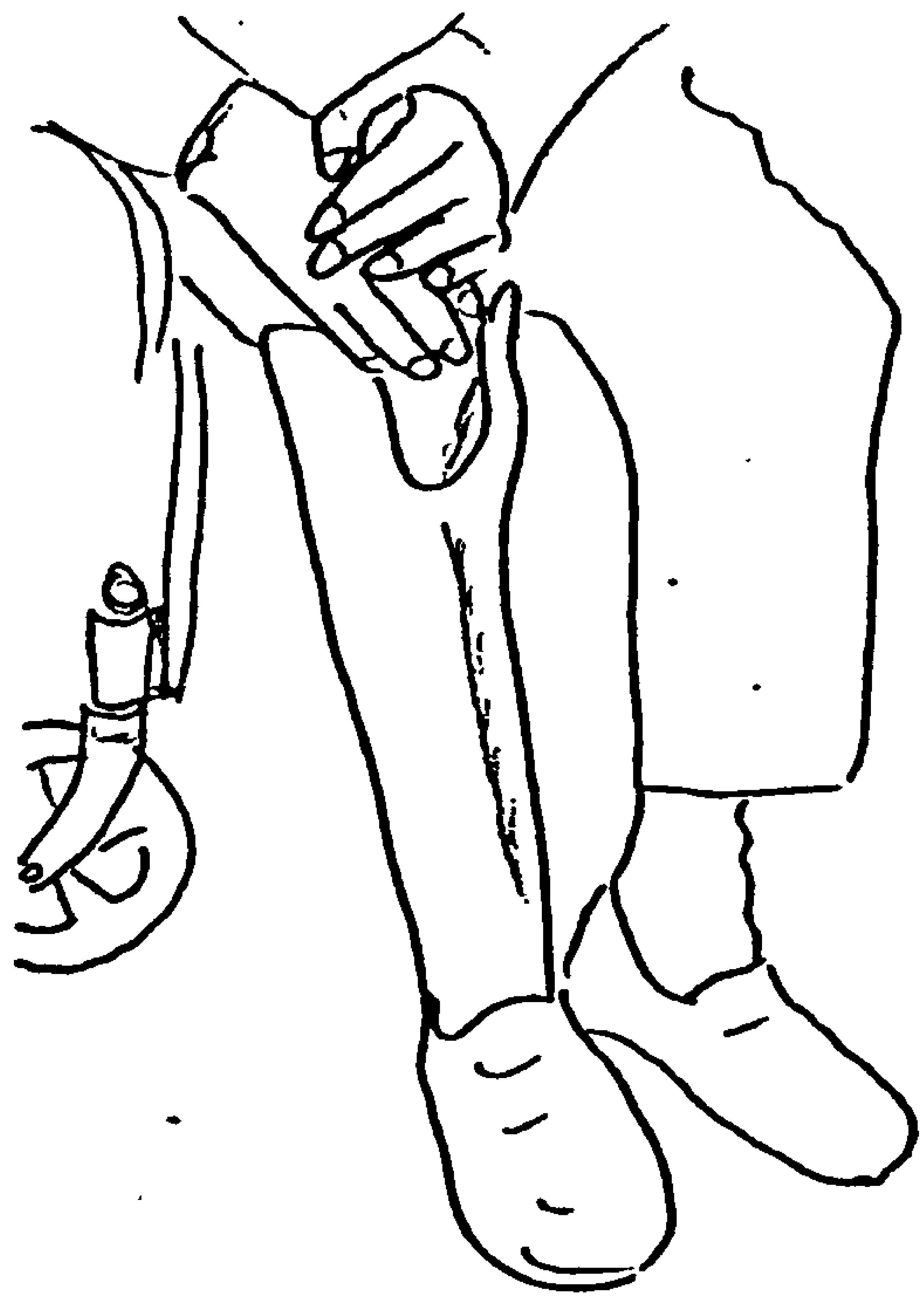


Figure II.44: The patient is pushing by his hands' heels so that no strength is needed in his fingers

11.II.5.1.1 Description and manufacture

The brim of the socket is composed of:

- a posterior horizontal edge that forms the ischial loading area on which the ischial tuberosity bears. It forms the main rest.

- a medio-sagittal edge that descends lower than the ischial rest area to leave a free pathway for the ischio-pubic ramus. Between the posterior and internal edge, the postero-medial angle is close to 90°.

- the front part of the brim is oblique upwards and outwards. It follows the direction of the inguinal fold and forms the area for counter-pressure. Between the anterior and internal edges, there is the anterio-internal angle, approximately 100 to 120°. It is slightly widened and leaves space for the adductor muscles.

- the external brim ascends high enough to include the great trochanter but this bony out - growth is too flat to be a locking for the socket.

In summary: four edges and two angles particularly well individualised as shown in figure II.49 and II.50.

The socket has therefore roughly a quadrilateral shape to ensure optimal stability of the stump in the horizontal plane. It is not easy to accept the fact that an above-knee residual limb has no true bony fit and that the femur is a unique central bone, around which muscular masses have not any muscular contracture possibility. It is therefore important to notice that the residual muscles degenerate into fatty-cellulofibrinous tissues. Rotations of both the socket and the residual mass around the femur shaft are difficult to prevent.

The socket becomes more circular in the inferior part at the wound level and the dressing zone. The bottom of the socket is largely open and it is necessary to have no stress at this level.

The equilibration of volume fluctuations of the stump is ensured by a modification of the stockinet thickness. There is no particular device.

The stability and the support in the vertical plane are achieved by a suspension strap that crosses the opposite shoulder like a sling. It is important to remind the therapist that if an axillo - femoral by - pass has been produced, there is a risk that the strap will damage it by contact with the collar bone. In this case and as a precaution, the belt must not cross neither the opposite shoulder nor the axillo-femoral by-pass. The strap must cross the ipsilateral shoulder with a horizontal abdominal belt to avoid the sliding of the strap.

Four metallic boards included in the gypsum of the socket provide a connection with the alignment device and, most often, a locked knee. The patient walks as if he has a knee arthrodesis and releases the bolt when he wants to bend his knee to sit. A telescopic metallic shank tube connects the knee and the foot to allow an effortless height adjustment, so that the shank tube has two diameters: 30 mm as external diameter in the upper part and 25 mm in lower part of the tube, just above the artificial ankle. This is very important because it will not otherwise be possible to use the removable pylon transducer easily (see figure II.88). In other words, the tests conducted later on transfemoral amputees will usually be made with definitive prostheses having an acrylic resin socket. A peg - leg is very exceptionally used. A monoaxial foot is mostly used that is similar to these shown for the transtibial plastered distal prosthesis (see above section II.3.2.1 and II.3.3.4).

The manufacture of the socket is undertaken with the patient lying down on the same special table previously described for below-knee amputees. The socket is made directly on the stump, without passing through any brim set (figure II.53). The posterior edge is cast by a piece of wood on which the patient rests. The medio - sagittal and the front part of the brim are moulded by hand by means of two thin small planks. A simple wool-made bonnet covers

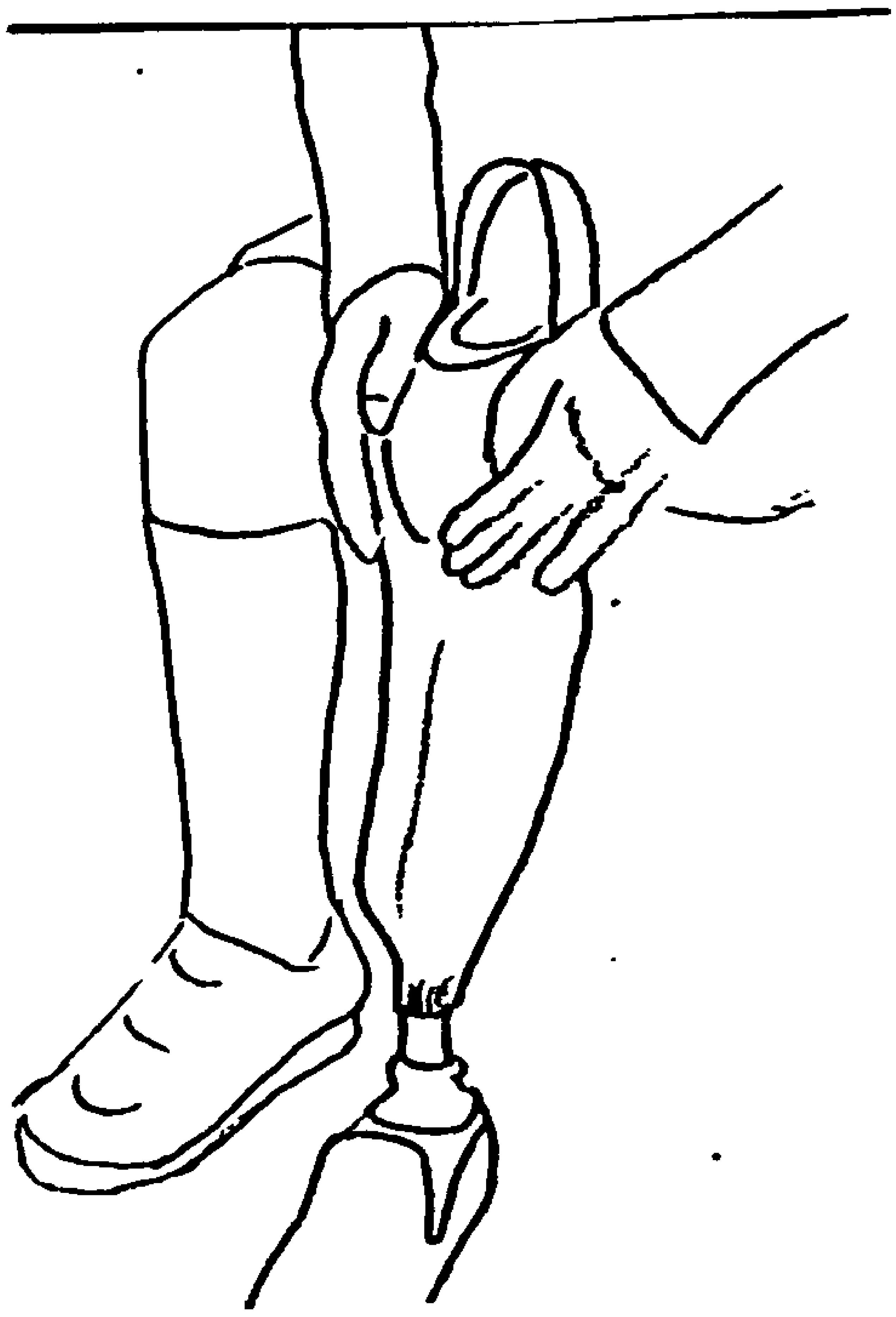


Figure II.45: The fitting is easier if the stump is not too long

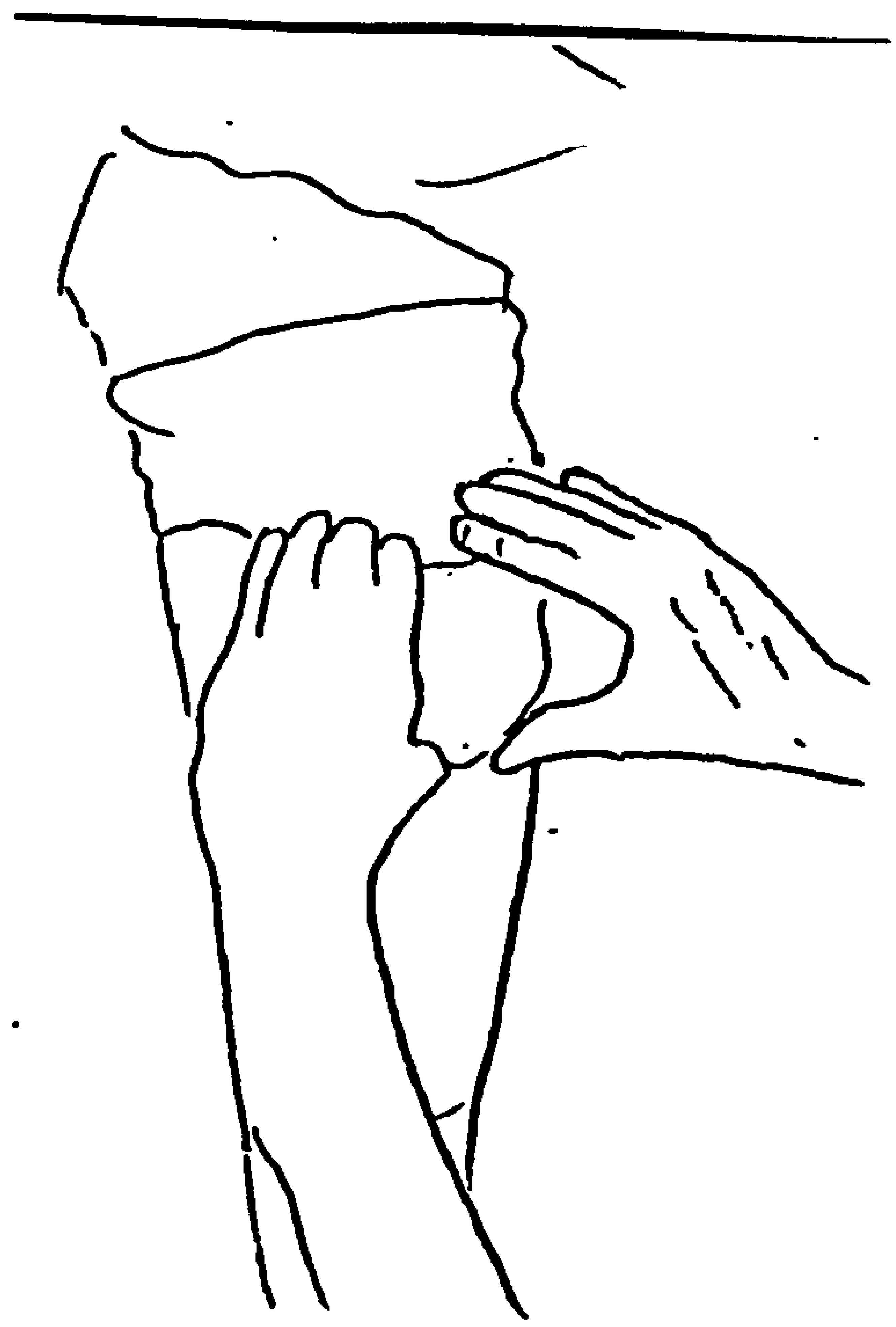


Figure II.46: The physiotherapist must check the fitting avoiding any pain or injury

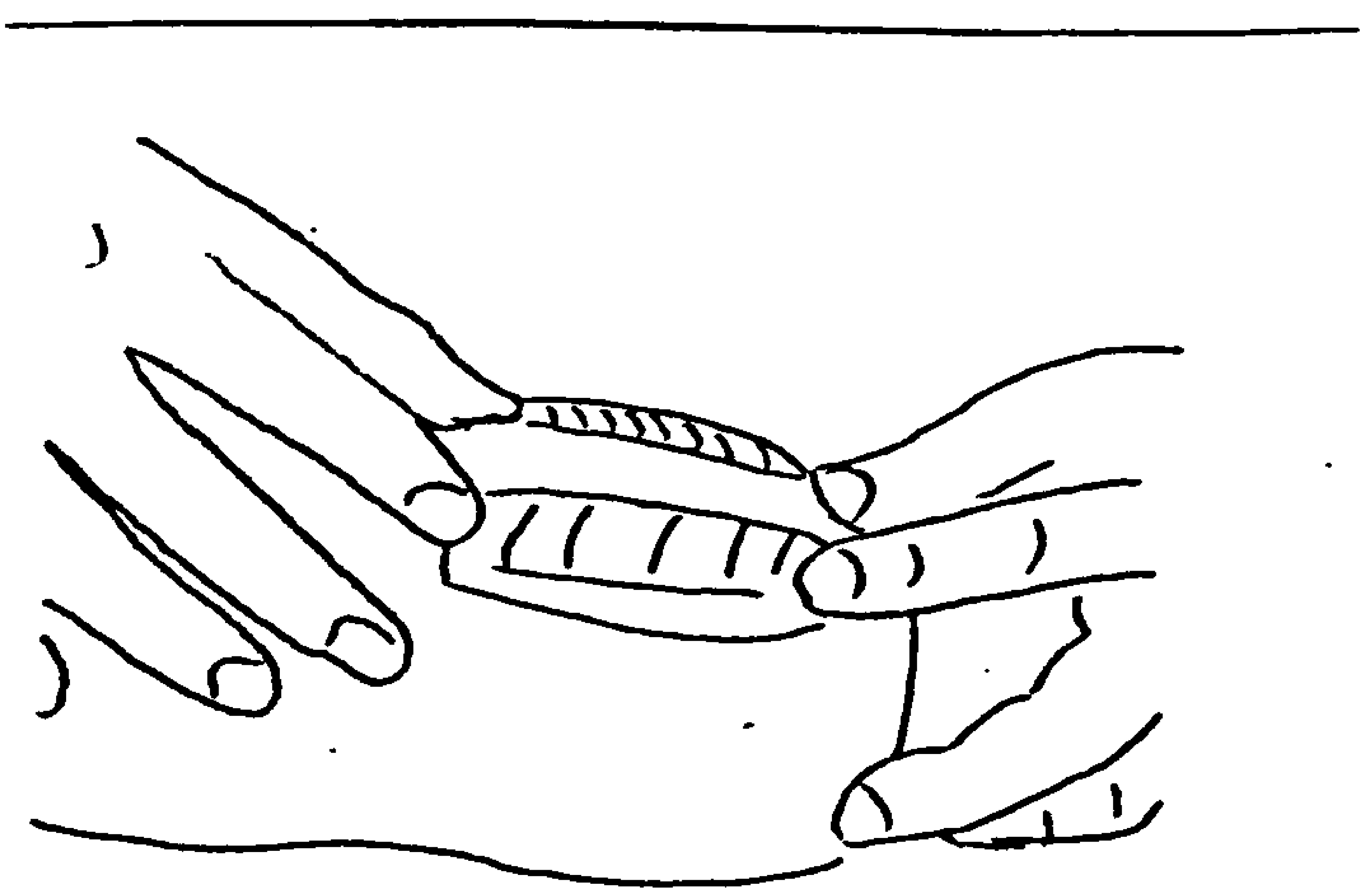


Figure II.47: Some overthicknesses above the dressing can be put to decrease some stresses on the tibial crest the stump making a comfortable interface between stump and socket. This position does not produce the shape and muscular bulk positioning which occurs in the vertical position. The modification induced by the stump position is easy to compensate. The position entails a pathway for the fatty-cellulofibrinous tissues posteriorly relative to the femur. On the other hand, it appears illusory to hope to keep elderly patients standing up on their contralateral lower limb for several minutes. The lying down position allows the patient to tolerate the manufacture of the device without strain and the prosthetist to work in good conditions. The construction time of an above-knee prosthesis is approximately forty-five minutes, it is shown in figures II.51 to II.54. The gypsum dries over - night and the first try on is made the following day.

11.II.5.1.2 Alignment

The static alignment is conventional:

frontal plane: a vertical line descending from the middle of the inguinal ligament (in front of the femoral artery pulse) passes by the centre of the prosthetic knee and the mid point between the malleoli. The socket, itself, has to be in valgus to put the femur shaft most nearly in its anatomical position. This locates the insertion of the hip abductors in the most distal position to minimise the horizontal dip of the pelvis when walking. In this case, the femur is applied along the external wall of the prosthesis. The ancient prosthetists said « to give an X shape at the prosthesis » (figure II.55, page 79A).

sagittal plane: a vertical line from the anterio - superior part of the great trochanter passing anterior to the knee joint centre (approximately one centimetre) to finish about one or two centimetres anterior to the bi-malleolus ankle axis. On the foot, it is at the union of the rear third and the front two-thirds of the foot (figure II.56).

horizontal plane: In the static position, the mechanical axis of the knee has to be situated in the frontal plane. This has no effect on the gait quality, since the knee is locked during walking, but it has an aesthetic effect in the sitting position when the knee is bent. The foot is in the same external rotation as the opposite foot, average 5 to 15° (toe-out angle).

Considering that the knee is fixed in the extended position during gait, the length of the prosthesis has to be about one to three centimetres shorter than the length of the opposite side to facilitate the swing phase. This shortening is increased in the first prosthesis aiming to favour the swing phase while maximising the axial load force during stance phase. The further the rehabilitation proceeds the more, this difference is decreased. This shortening allows avoidance of excessive elevation of the pelvis during the pendulum phase of the gait. These static alignments are theoretical. Nothing replaces the gait trial, the observation of a walking subject and a good patient, prosthetist and physiotherapist collaboration to have a good dynamic alignment. As for all prostheses, alignments have to be checked regularly as the re-education progresses, when the patient takes confidence in the device and that the apprenticeship of the use of the prosthesis is improving. The effect of prosthetic alignment on relative limb loading was studied by Pinzur *et al.* (1995), while other researchers found that several alignments were possible for the same amputee without any change in his gait behaviour (Zahedi *et al.* 1985 and 1986, for above - knee amputees only and Yang *et al.* 1991).

11.II.5.1.3 Indications

Indications are very wide since a single prosthesis model suffices to cover all our requirements. Some precautions during manufacture should be taken if the patient is wearing a by-pass crossing the Scarpa's triangle under the skin. Equally, it is necessary to pay attention to the tip of the femoral shaft that could threaten fragile skin jammed between the rigid femur and the rigid socket.

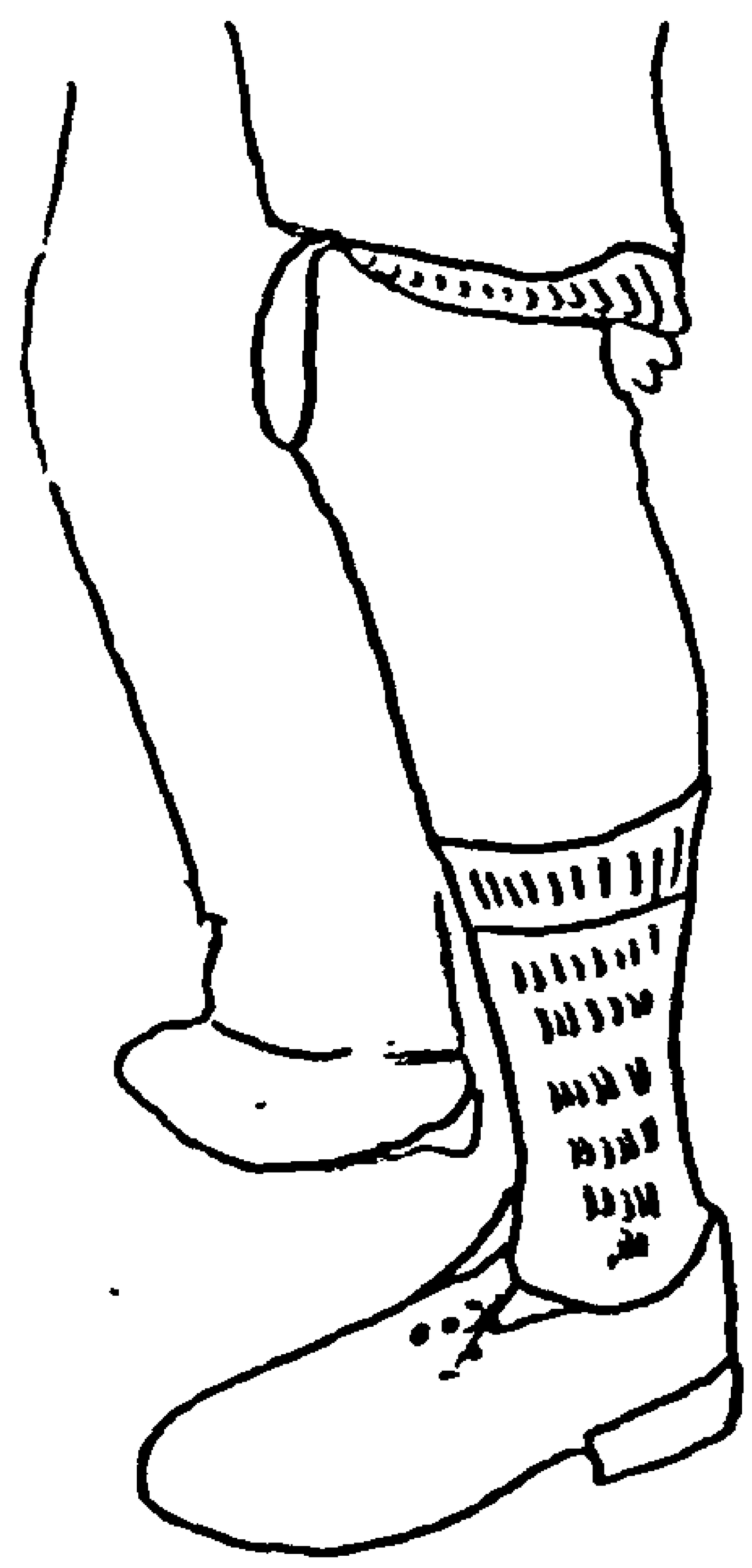


Figure II.48 : A definitive prosthesis covered with the fragile cosmesis foam and the patient's sock.

11.II.5.1.4 Donning and use

To put on a transfemoral prosthesis, a tubular stockinet is most often used (figure II.57). That allows the stump to slip into the socket (figure II.58). It is important to pull on the stockinet, which passes through the open bottom of the socket instead of leaving the patient pushing down his residual limb. This way of doing allows the stump to remain spindle like and makes the donning easier. It is necessary to verify manually the ischial - brim contact and the absence of a fold of skin or a flange of flesh at the internal edge level (figure II.59). This would be the origin of discomfort or even pain and at worst trophic disorders. This is particularly true for females. It is necessary to explain completely to the patient where the load is transmitted so that he can himself control the assembly of the prosthesis. The patient has to understand equally the necessity of this procedure so that he accepts some constraints. The stockinet is left in place.

The shoulder-belt is then fitted with an average tension. It is a compromise between the efficiency for the maintenance of the prosthesis and an excessive force on the shoulder pulling it down. It is necessary to be careful not to press the jugular vein. The strap must not be set directly on the skin and one of the patient's garments ensures a mobile interface as shown in figure II.60. For very thin patients whose skin is particularly fragile, a flexible comfort foam can be glued under the strap.

At this stage of the rehabilitation, it is the physiotherapist who puts the prosthesis on. This is done upright. The patient needs his hands to hold the parallel bars or the armrests of his wheelchair because of the precarious unipodal position. It will be seen later how the apprenticeship to the use of the femoral prosthesis by a patient is long and difficult.

Removing the prosthesis is done in the inverted order.

11.II.5.1.5 Advantages and disadvantages

As for the provisional below-knee prosthesis, the advantage of this apparatus relates to the material of the socket. Plaster of Paris is easy for working up and is a low cost material. It is well tolerated and the socket can be remade rapidly if necessary. The major disadvantage is the absence of a device allowing easy compensation for differences in stump volume.

A close surveillance of the prosthesis is necessary. If the patient is particularly active and / or heavy, this surveillance becomes indispensable (figure II.61). The plastered socket is thin for best comfort and the material has a tendency to disintegrate under constraints weakening the prosthesis.

As for transtibial amputees, it is necessary to be attentive to the cutaneous state of the stump. The main points to verify are:

the wound and its edges	the perineum area
the anterior tip of the femur shaft	the area where the ischium rests

11.II.5.2 THE DEFINITIVE TRANSFEMORAL PROSTHESIS

11.II.5.2.1 Description, manufacture and fitting

It is globally similar to the plastered provisional prosthesis. Only the material of the socket changes: layered acrylic resin. The manufacture is also different since it is necessary to go through the intermediary of a plaster cast. The negative is moulded on the stump with the patient in lying down position. A positive is cast to obtain a mould which is then retouched and rectified by the prosthetist according to requirements of the stump. The resin is injected under vacuum around this positive. Knee, shank tube and foot are identical to the provisional prosthesis.

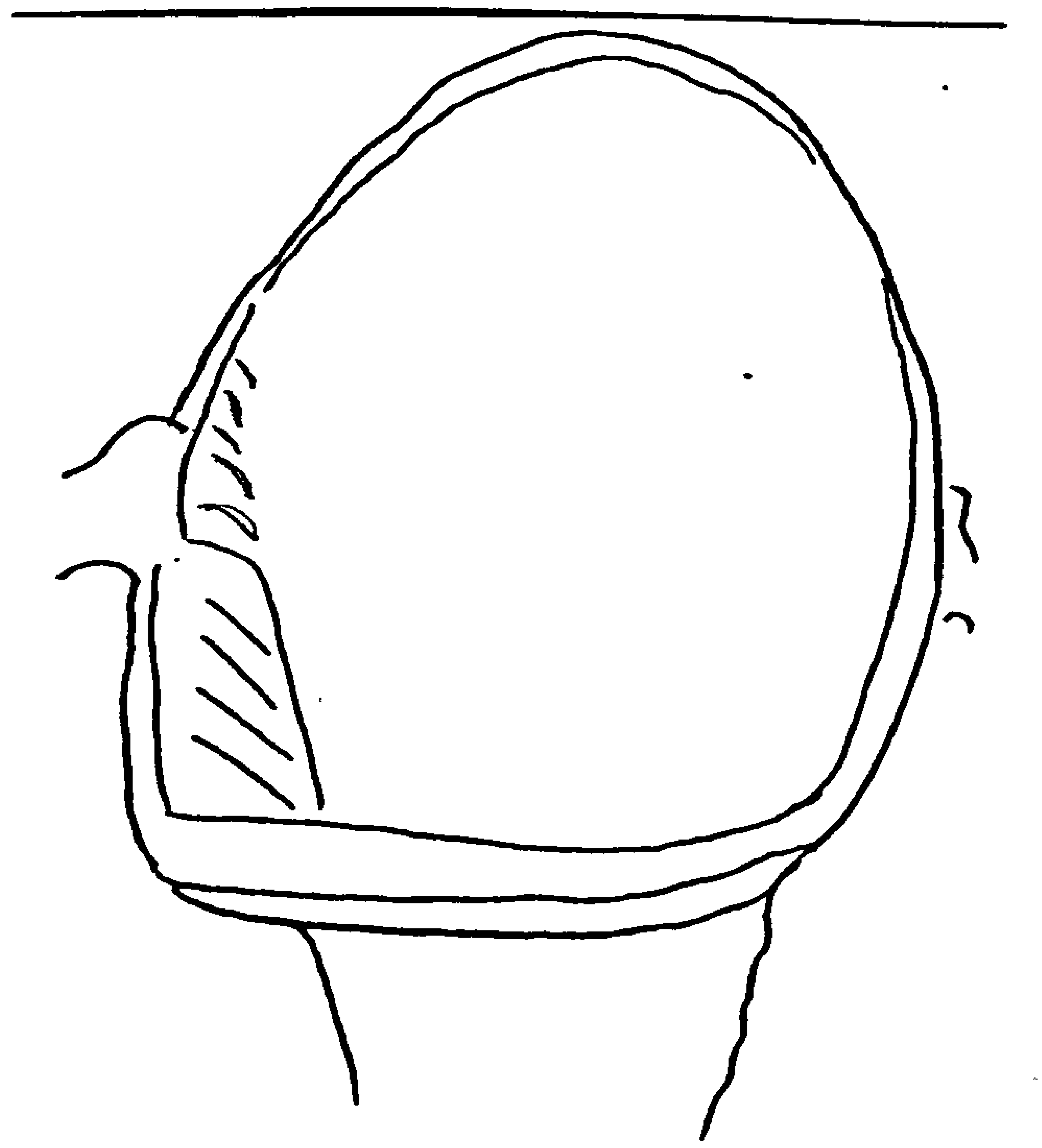


Figure II.49 : An overview of the quadrilateral brim of a transfemoral socket

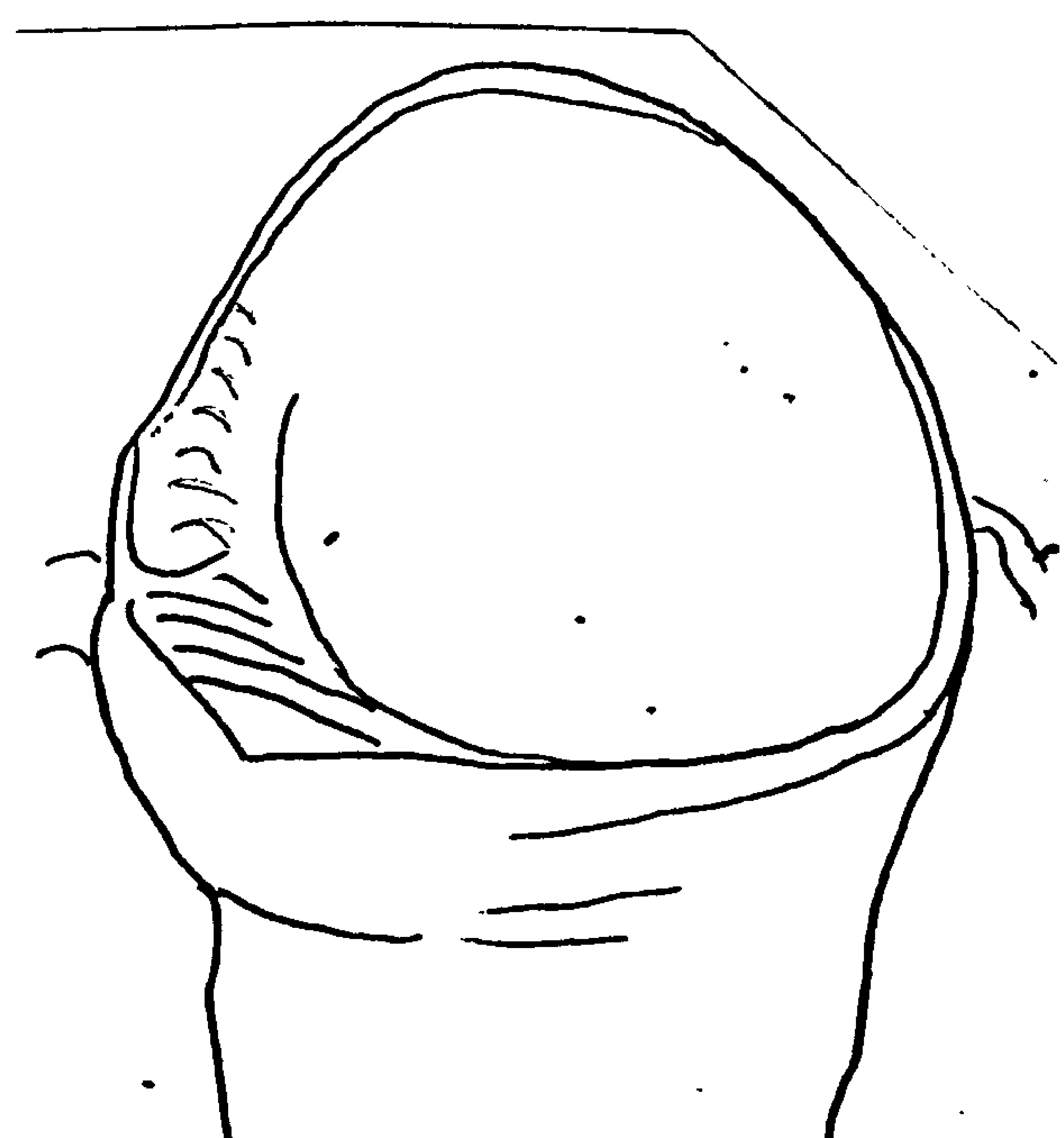


Figure II.50 : A medial view of the same brim in which the medial edge is well seen

The material used for the socket is the same thermo plastic as used for the definitive below-knee prosthesis. It is possible to heat it and extend it a little to adapt the volume changes of the contents. This is done only for localised problems. If all the stump increases its volume, it is necessary to make a new socket. If the stump slims, the amputee can use different thicknesses of stockinet or stump-cover bonnet. There is a limit to this, however a maximum of one wool-made bonnet and four thicknesses of stockinet.

The weight is about the same as for the plastered prosthesis. The socket is lighter but the main dynamic mass is represented by the knee, the foot and its shoe, which are common to the two prostheses. The shank tube is built in one part, so that there is only one diameter: 30 mm and therefore it shall be possible to use the removable pylon transducer described below. It is necessary to warn patients that the weights are similar. Indeed, they often think wrongly, that the prosthesis with plastic socket is lighter than the previous one. They hope it will give them a more efficient gait. Unfortunately, this is not true. Nevertheless, the definitive prosthesis is the most often better adapted and its improved interface enhances the comfort and the quality of the gait.

11.II.5.2.2 Indications

This prosthesis is prescribed and the manufacture started when the stump is stable after approximately three weeks. The objective criterion is that the same provisional prosthesis is used with the same number of stockinet thicknesses during all this period. It supposes also that the stump is sufficiently healed and that the patient has reached a certain skill in the handling of the prosthesis. The criteria are similar to these for a transtibial amputee. The daily wearing of the provisional prosthesis has to be enough and continued throughout the week. It is the experiment that dictates us these considerations: patients think often that the provisional prosthesis does not have to leave the re-education room. When they use the first definitive prosthesis, its daily use increases and the socket rapidly starts to be large.

11.II.5.2.3 Donning and use

The donning is identical to the provisional prosthesis. The stockinet is passed through a hole in the socket. This hole has to be infero-medial, so that the patient can easily pull on the stockinet with the contralateral hand while he holds the armchair with the other hand. The stockinet is left in place unless the socket is typically a contact one or an ischial contained one. In these two cases, the stockinet has to be completely removed. In case of necessity, the fitting can be made partly or totally sitting down. The patient increases comfort but loses accuracy in the checking that a good position of the ischium in front of the ischial loading point is achieved.

To put on the shoulder-belt requires a full range of motion at the upper limbs.

When the patient is in a Re-education Centre, the fitting of the prosthesis has to be made as soon as possible in the morning. The prosthesis most often has to be removed at lunch time to allow a rest and a sleep. Removing the artificial limb for toileting is also necessary (particularly female). The prosthesis is donned again in the beginning of the afternoon, and kept on as long as possible. At home, the fitting has to be made the morning before dressing but removing it, one or several times during the day, is more or less unavoidable. One sees that disadvantages and constraints are important: these relate more to the level of amputation and the anatomy of the thigh than to the limb fitting itself.

11.II.5.2.4 Advantages and disadvantages

This type of prosthesis is relatively well adapted to the vascular disease stump. Notable improvements could be effective. The fitting, standing up with a unilateral load on

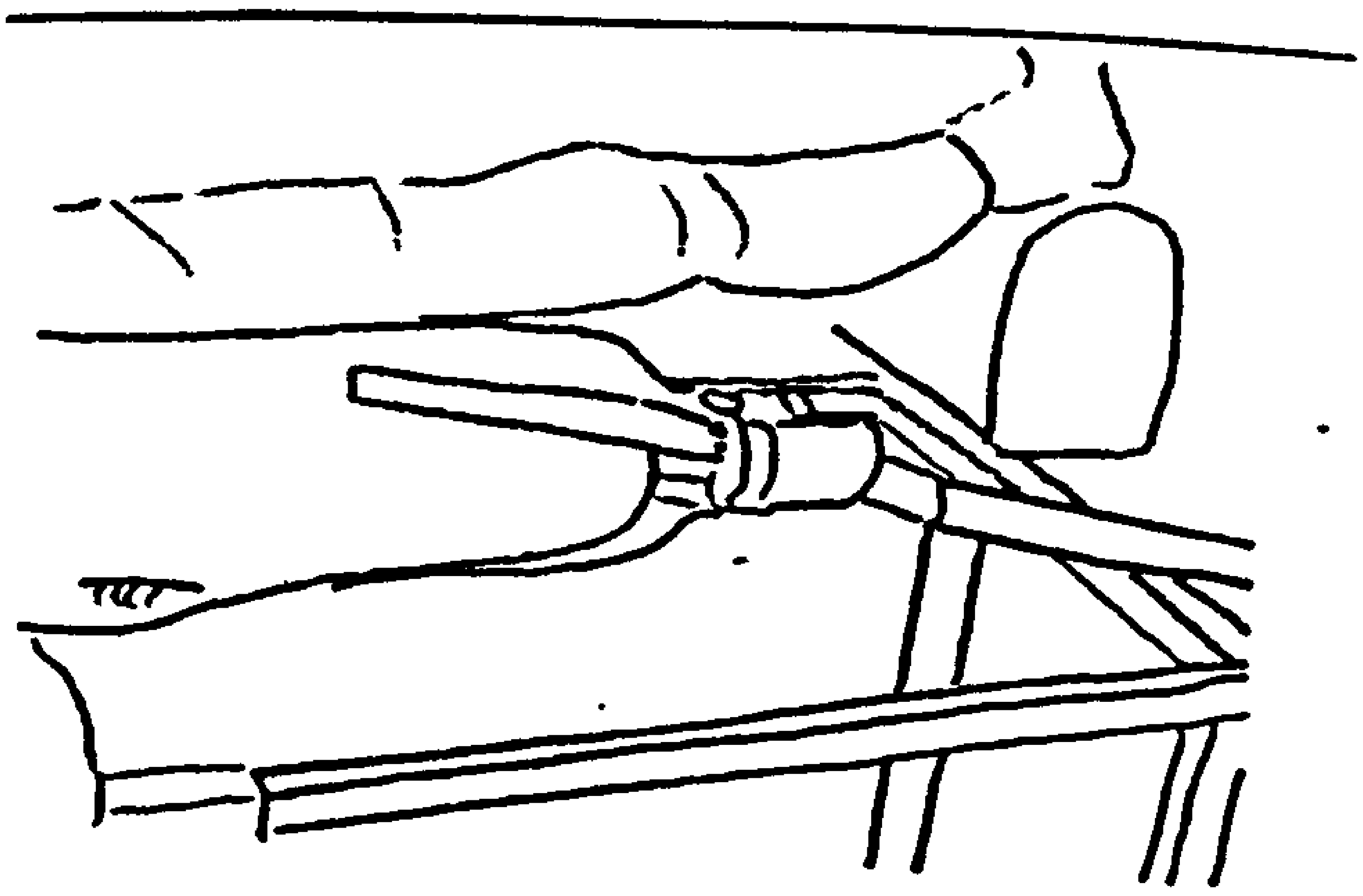


Figure II.51: During the transfemoral prosthesis fitting, the patient lies down a special table to allow the prosthetist to take his time

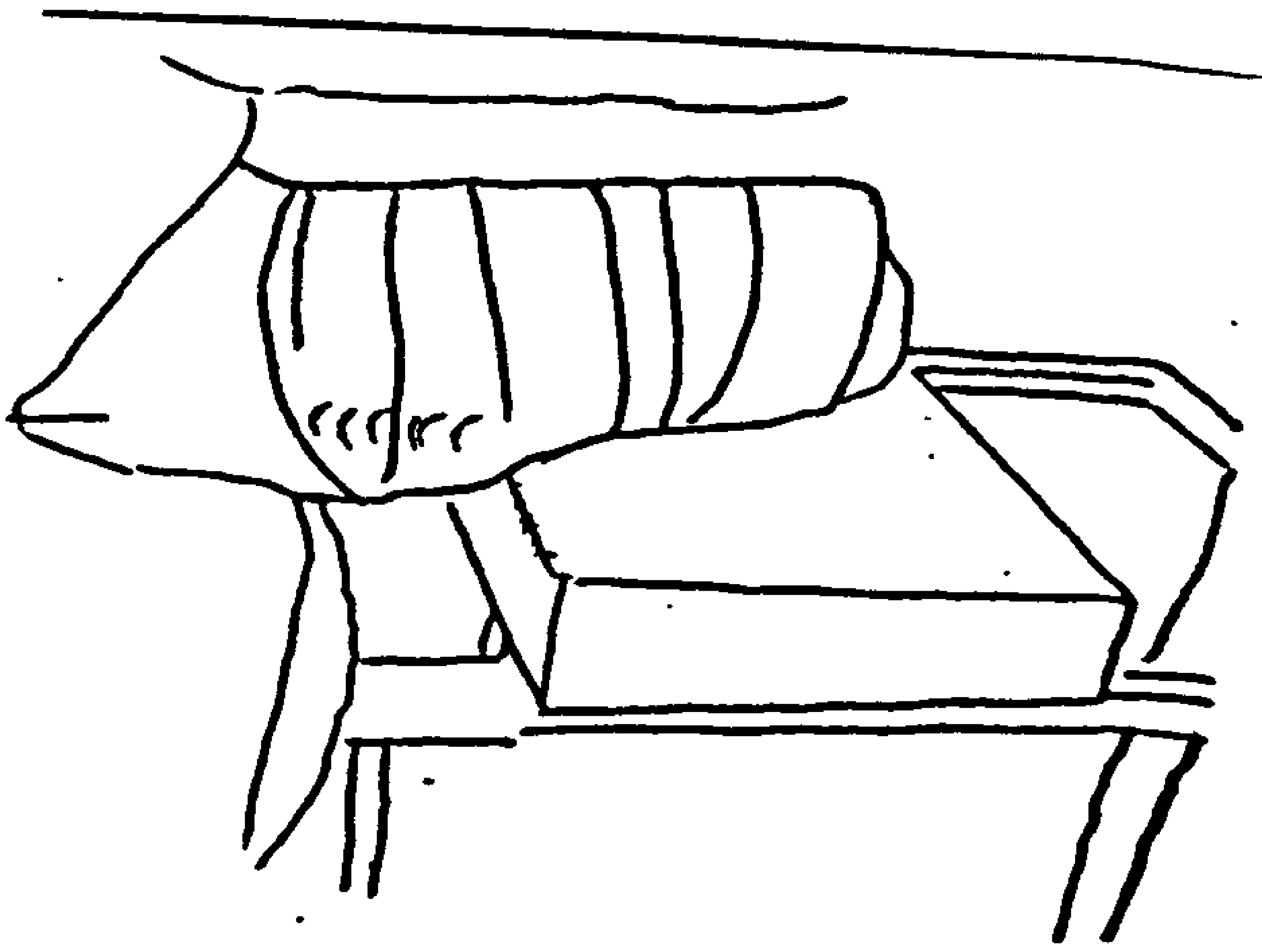


Figure II.52: The ischial part of the brim is cast by means of a piece of wood

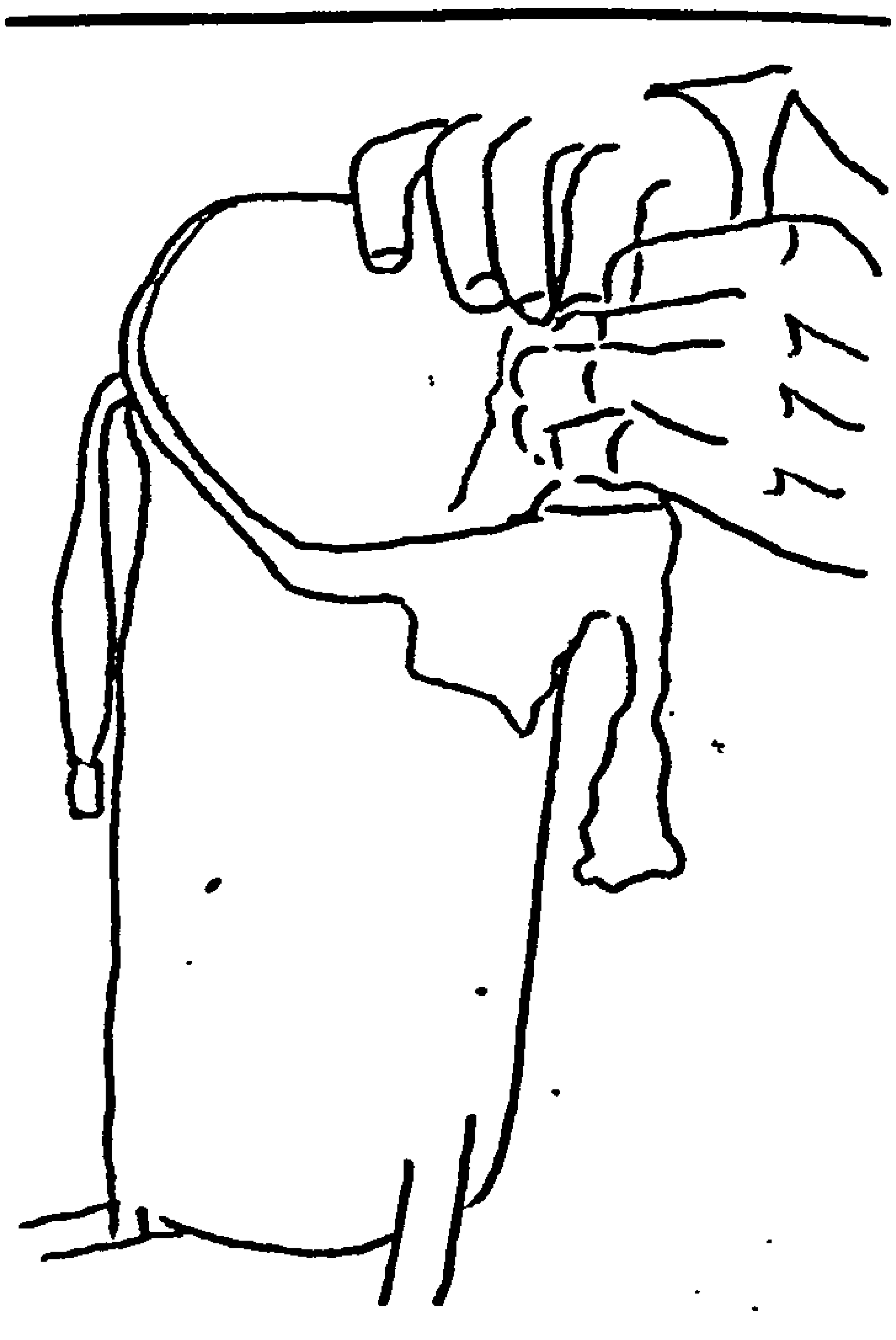


Figure II.53: The brim is manually reinforced by the prosthetist

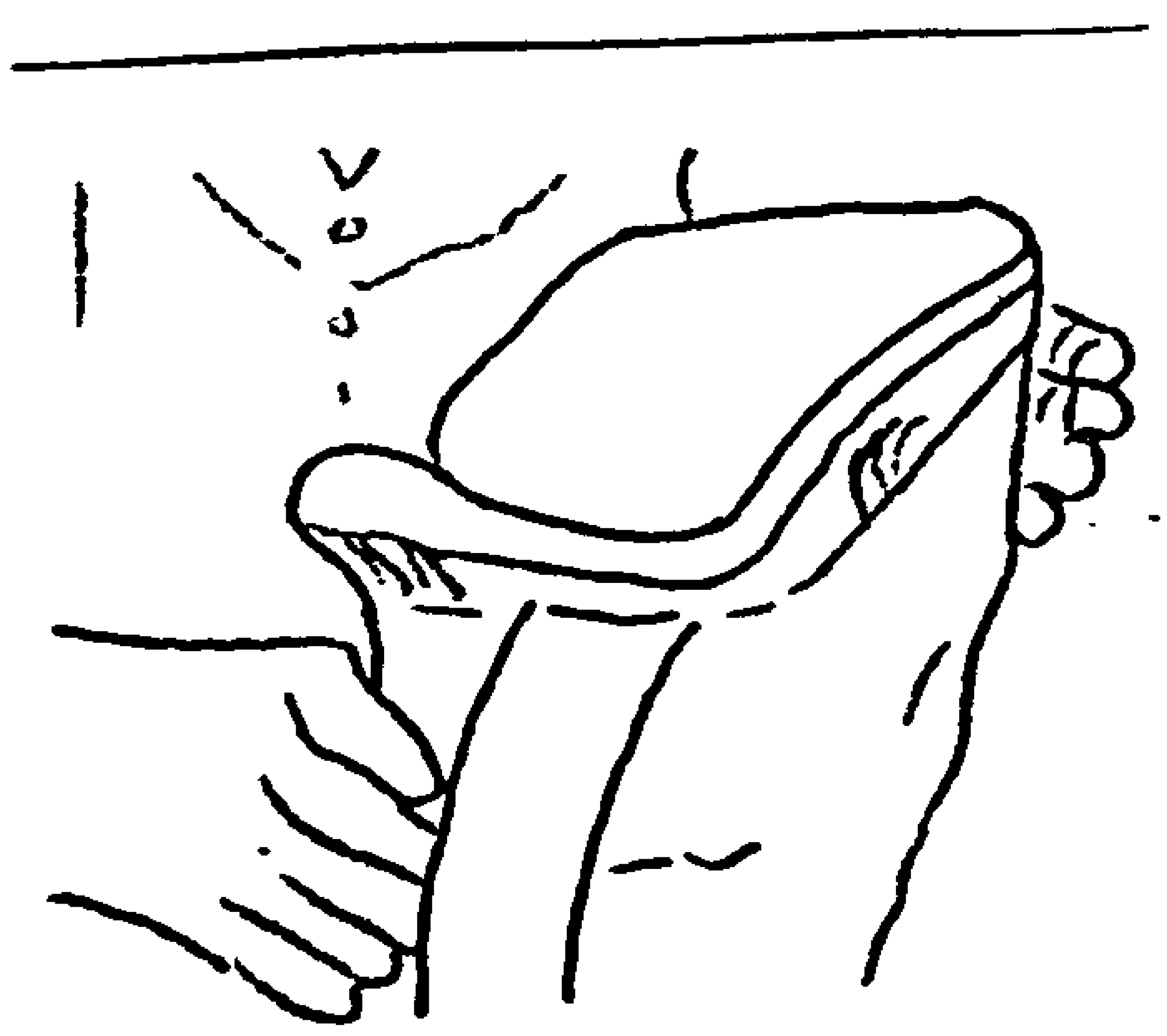


Figure II.54: The brim is finished, the socket must be dried before the first try on the contralateral limb, represents a hard exercise with a long apprenticeship (figures II.62 and II.63). If required, the fitting can be made in the sitting position, but with great disadvantages.

11.II.5.2.5 Variants

According to the age, the length, the tonicity of the stump and the activity level of the patient, it is possible exceptionally to put:

- a free flexion knee with stabilising brake (safety knee) or a four bar knee
- a contact quadrilateral socket if the rehabilitation staff are sure about the stability and the tonicity of the stump

We have, now, an other possibility of shape of socket called CAT-CAM or better ischial-contained socket.

11.II.5.2.6 Shape and description of the ischial-contained socket:

During the last few years, new ideas about sockets have been introduced to increase the comfort of the user as well as the quality of the gait.

The ischial-contained socket is a generic term that covers different shapes but the principle remains the same (Sabolich 1985). The prosthetist seeks to realise a double triangular restraint:

1. on the one hand in the horizontal plane between the ischial tuberosity, the posterior part of the ischial-pelvis ramus and the great trochanter to control rotation

2. on the other hand in the frontal plane between the ischial zone, the iliac fossa and the femur shaft to control the femoral adduction (figures II.64 and II.65).

This last point is the main one since the internal ischial stop prevents the slipping of the socket to the exterior during load bearing on the prosthesis (figures II.66 and II.67). Sub-trochanteric abutments and loads onto the femoral shaft maintain the position of the femur which aims to adduct as much as the opposite side. This position seeks to develop in the hip abductor muscles a physiological tension and therefore a possibility of more efficient work.

That goes with the prevention of ipsilateral limp during the load on the prosthesis habitually compensated by an increase of the polygonal support and therefore a raise of the energy cost during gait (figure II.68, extracted from Lehneis 1985). This frontal bony restraint is linked with a decrease of the transverse size and a raise of the anterio-posterior size (figure II.69, from Lehneis, 1985).

The presumed advantages are often subjective

1. improved comfort by eradication of the ischial load (Sabolich & Ortega, 1994)

2. a socket shape respecting the physiology of the thigh better

3. the quality of the gait due to better control of the prosthesis and a decrease in limping.

The most important disadvantage is the risk of maladjustment of the socket in relation to the stump whose volume is often in vascular disease, difficult and long to stabilise.

11.II.5.2.7 The prosthesis follow up and the role of the independent physiotherapist

Once returned home, the patient is taken in charge by his family general practician and often by a nurse and an independent physiotherapist. All of them have a major role in the

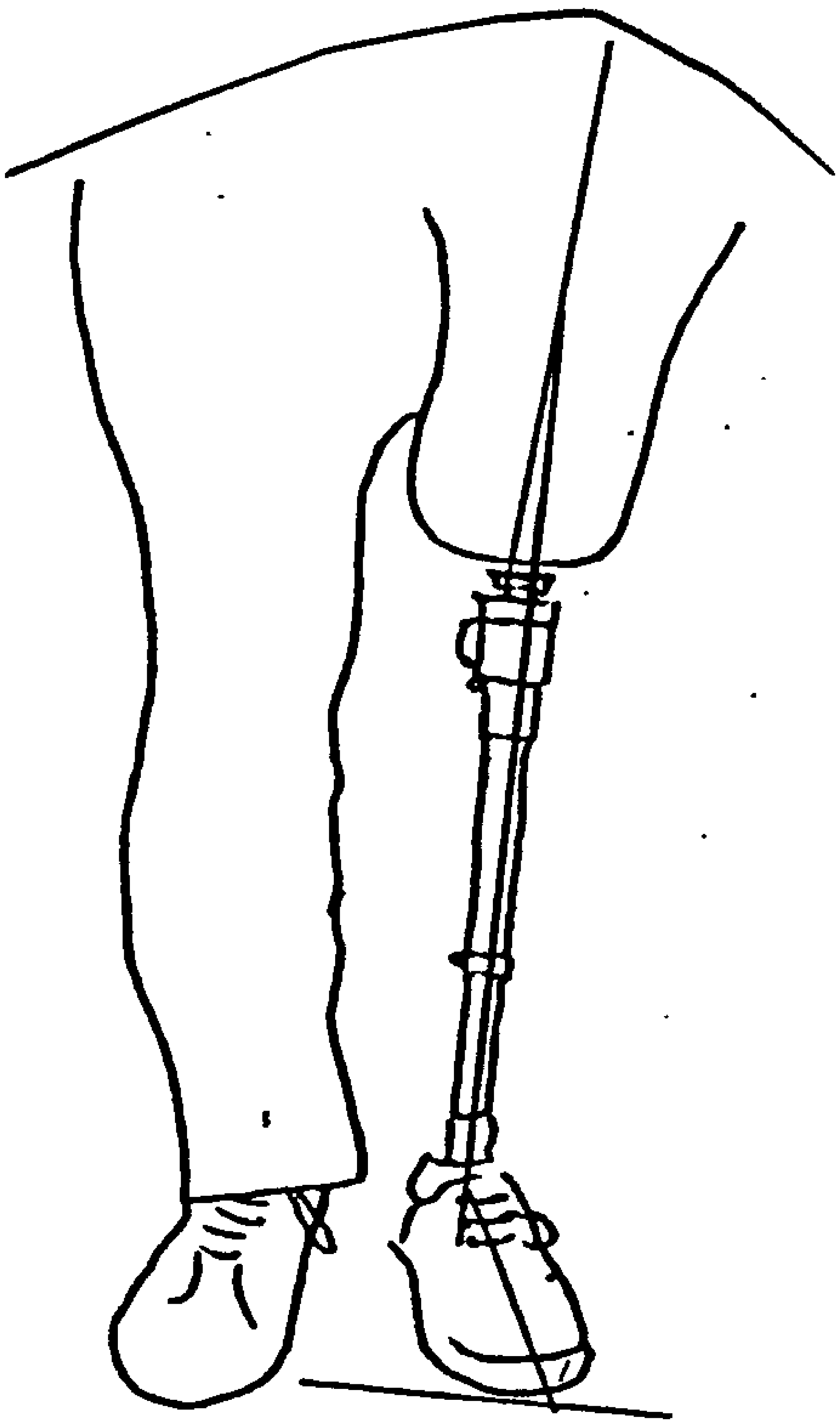


Figure II.55: The frontal and horizontal static alignment of a transfemoral prosthesis

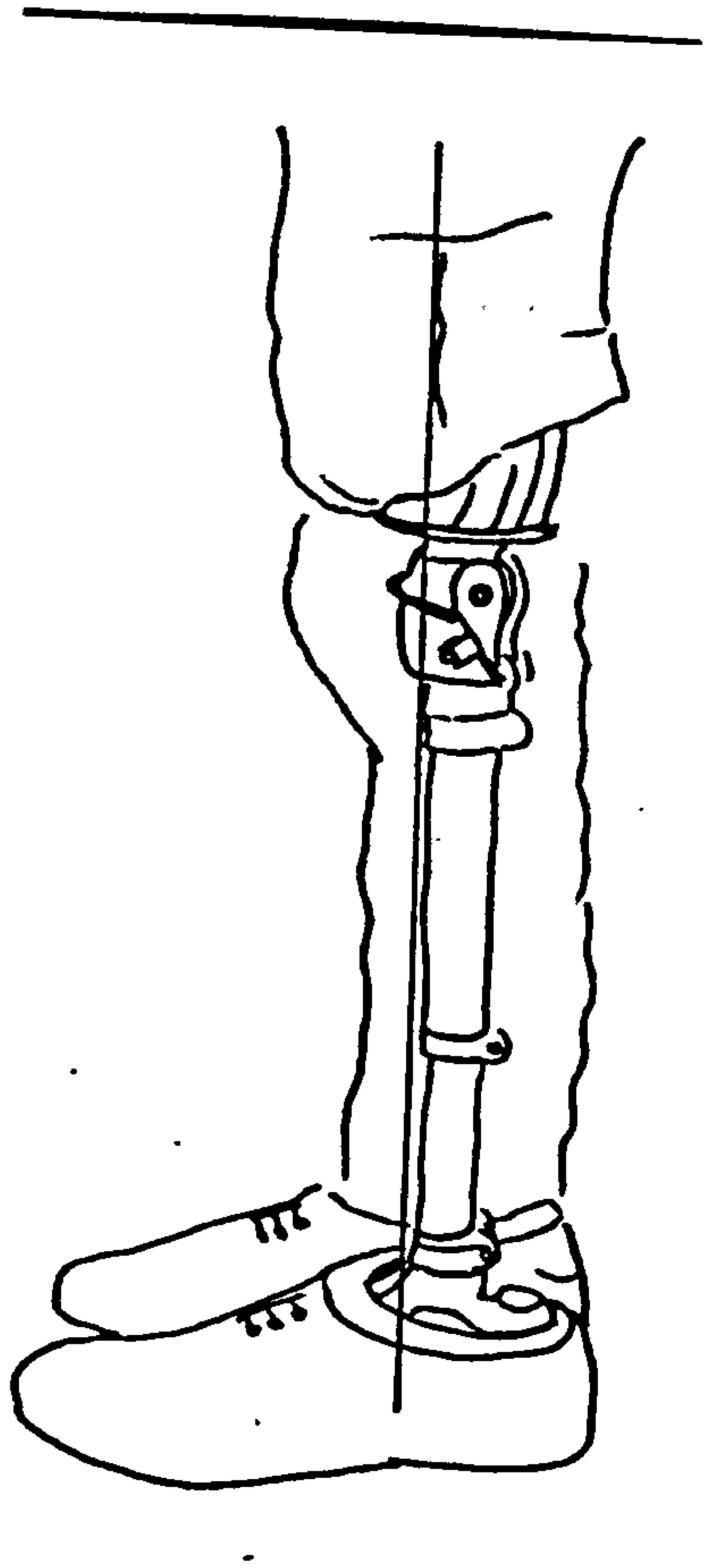


Figure II.56: The sagittal alignment

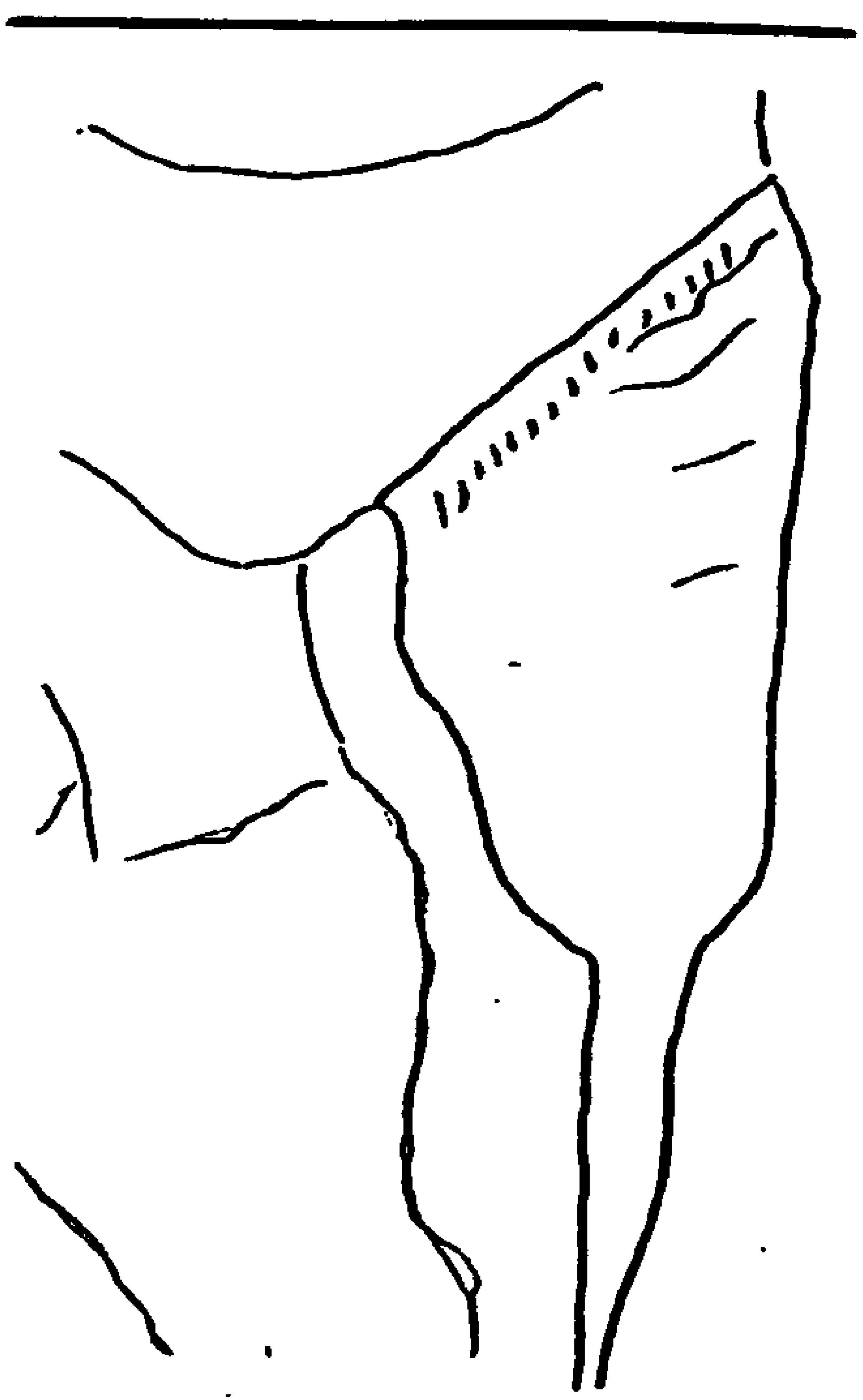


Figure II.57: A tubular stockinette made of cotton covers the residual limb

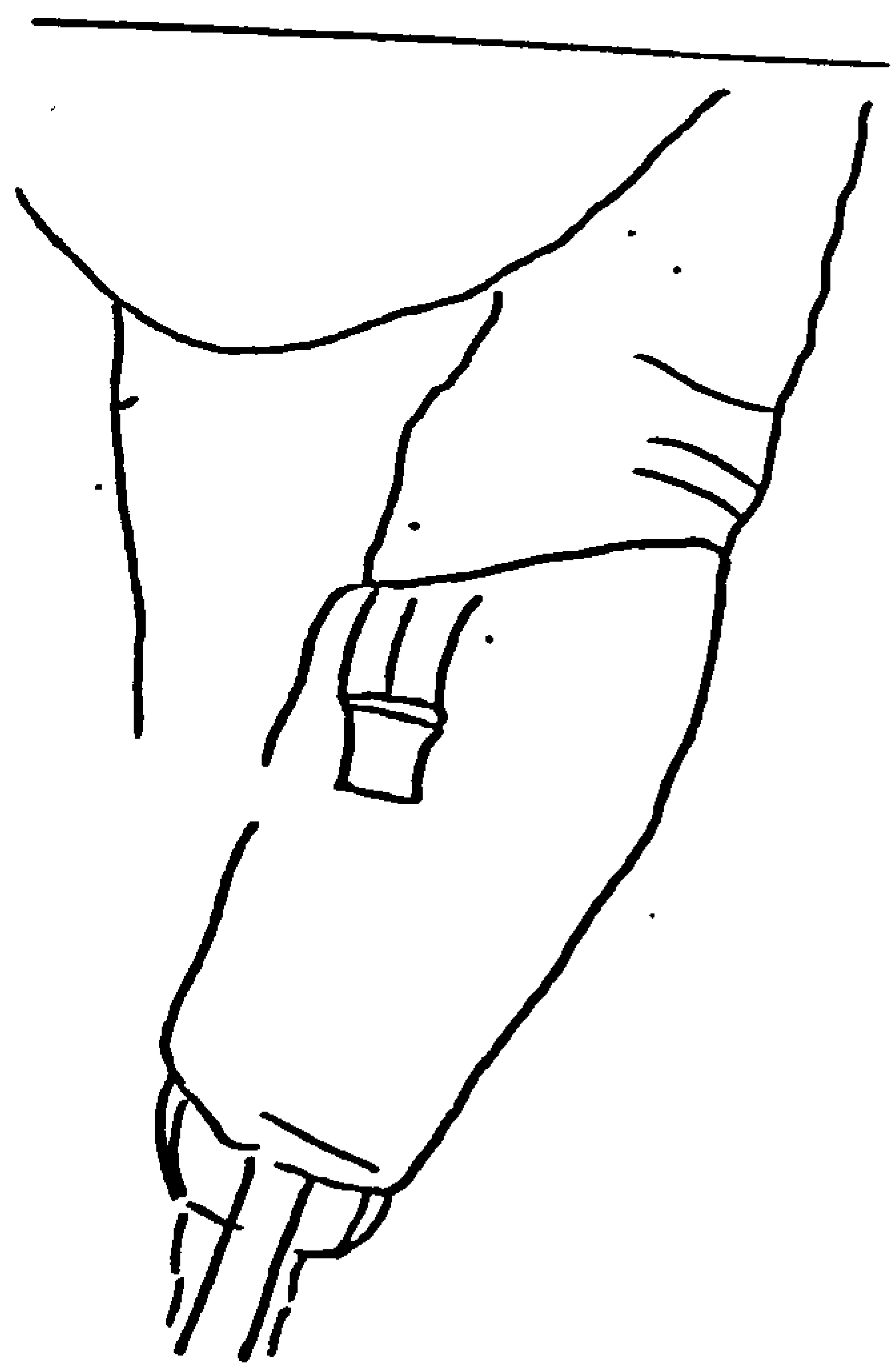


Figure II.58: The stump is introduced into the socket while the patient is standing up assistance and advice that they can give to the patient. If by using the prosthesis, the patient hurts or scratches his stump, the first and bad reflex is to forbid the use of the prosthesis waiting for the cutaneous repair, following the recommendations of Latour *et al.* (1989). Once this has happened, the stump, without any constraint, changes its shape and the prosthesis cannot be used. It is necessary to remake another one with periods of waiting, displacements and costs. What the medical and para-medical team has to say to the patient, at the first suspicion about a stump - socket conflict, is:

1. to continue to wear the prosthesis all day long;

2. stop walking or limit the gait time (this caution shows the importance of prescribing a wheelchair as well as a prosthesis);

3. to consult the prosthetist who has manufactured the prosthesis as soon as possible. In case of impossibility, to make an appointment with the closest prosthetic manufacturer. The material of the socket being thermo plastic, it is possible to change it locally and that is often sufficient to start walking again. If required, this consultation results in the ordering of a second device; thus, the patient has continued to walk, without maladjustment to the effort, without loss of any sort.

11.II.6 The peripheral vascular disease permanent bending knee

11.II.6.1 ORIGIN

It is the habit to give this name to a flexion contracture of the different joints that subsist after any amputation surgery. The most often, that is **a combined hip - knee permanent bending** which gives an early muscle lesion as validated by Kiuru *et al.* (1987)..

It is the most frequent: approximately one PVD transtibial amputee in four or five (figure II.70).

It is always an open stump and short stump complication.

Its constitution is complex but its dominant aetiology is:

ischaemic retraction , a phenomenon specific to vascular disease and well described since a long time (Eames & Lange, 1967)

One can distinguish:

1. the muscular schema: a badly vascular muscle, in chronic ischemia (as in the Volkmann's ischaemic contracture or the Lodge's syndrome) retracts, loses its extensibility and shortens sarcomere by sarcomere with a fibrosis of the myofibrils between them, as shown on cat's soleus by Tabary *et al.* (1972) and confirmed later by Tabary & Tardieu (1981). It results in a permanent flexion contracture. This phenomenon is reversible until the tendons have adapted their length to a shortened position.

2. motor nerve ischaemia, well individualised in the acute ischaemia sensory - motor picture.

As secondary causes of this permanent bending range of motions, one finds also:

3. an analgesic attitude of triple withdrawal (a strong pain is always present). As the natural tendency of each lower limb that suffers is to put it in flexion, this retraction affects only on the flexor muscles of the hip and the knee.

4. the usual gait lost before the amputation with abolishment of the sensory plantar efferent nerve impulse. This lack of sensory stimulation favours a modification in the proprioceptor adaptation of the relative tension between anterior and posterior muscles. It was well brought to the fore by Geurts & Muder (1992). This perturbation is made in favour of the flexors.

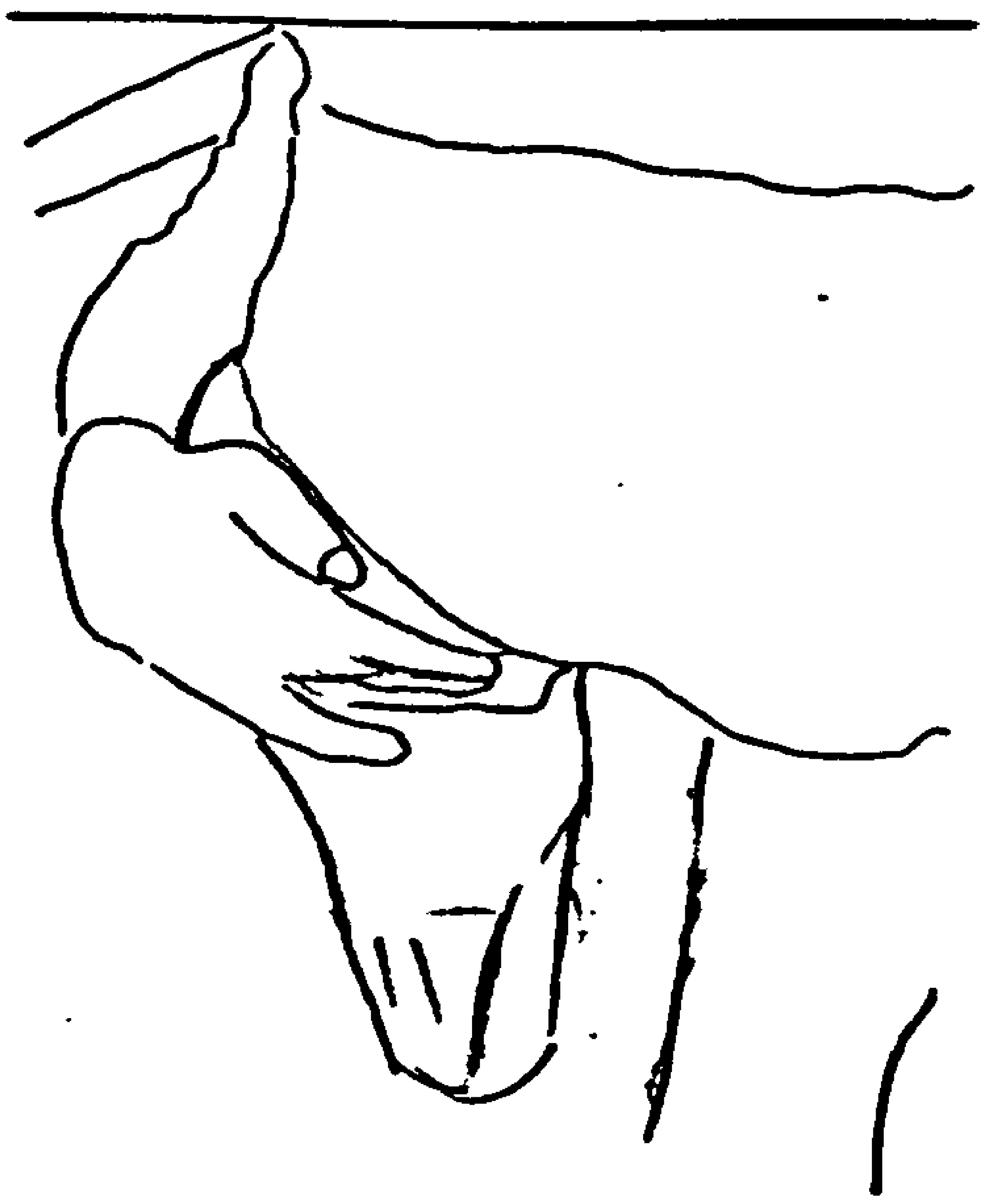


Figure II.59: The ischial brim load must be manually checked

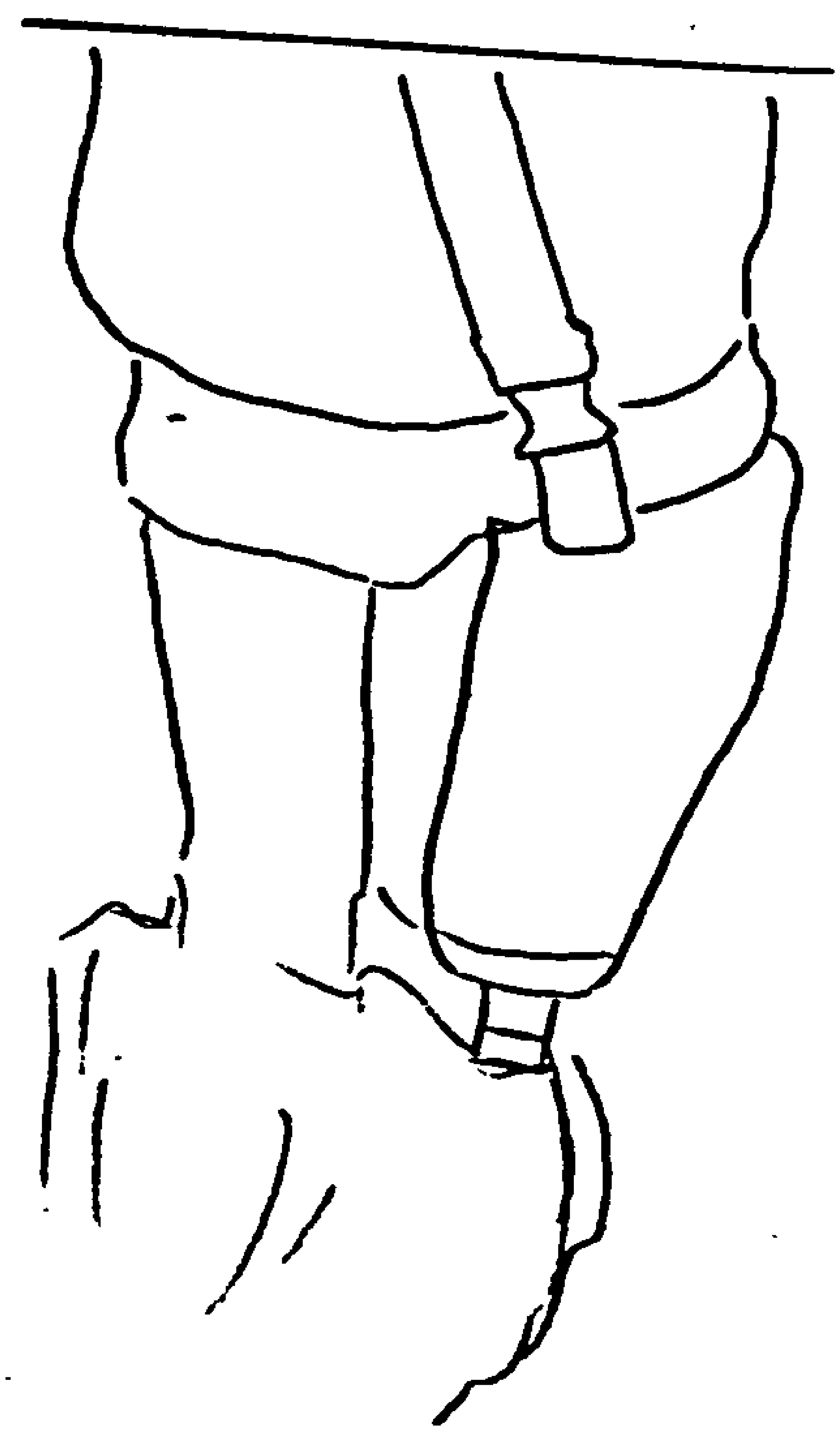


Figure II.60: The shoulder belt must have a moderate tension

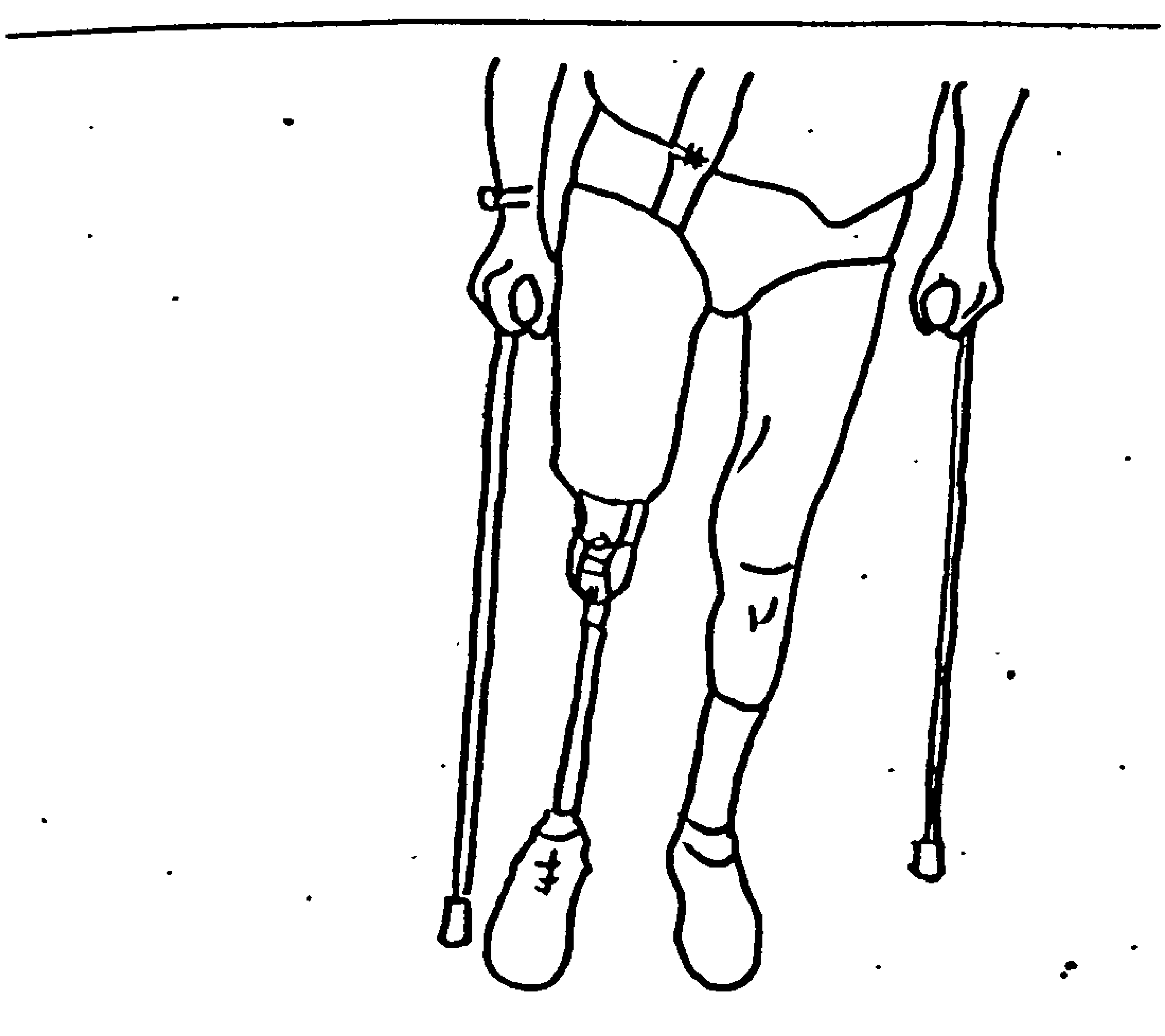


Figure II.61: An active patient, wearing a provisional prosthesis with a socket made of gypsum must have close surveillance from the therapist

5. a reflex neuro-sympathetic dystrophy linked to a micro - circulation disorder and to the loss of any load contact on the ground. Its decrease, following the age of the patient, has been thoroughly studied by Bilesimo *et al.* (1988).

6. bad orthopaedic position while joints are close to 9O°, relatively motionless (excess of sitting position, particularly in the wheelchair) which gives a tendon adaptation studied by Tardieu *et al.* (1984) in France and Williams & Goldspink in United States (1984).

This ischaemic retraction with these bends can pre-exist the amputation surgery and we will see that one can combat them with efficiency. It results that these bad pre-surgical attitudes must not be an indication to a transfemoral level segmentation.

It was previously said that the functional outcome of any transfemoral patient is always more bad than the one of any transtibial amputee, whatever is the quality of their stump or their knee. This assertion is well known and well accepted all over the world: Cormier (1988), in France, Kng *et al.* (1996), in United States.

These six causes are, probably, more or less mixed to the genesis of these permanent bending range of motions, without any easy possibility to dissociate them.

These bends are reversible, as shown by Pillu (1989). Therefore, we eliminate important non - extensible soft - tissue revisions. Nevertheless, in cases of a very short stump with a reduced range of motion, it is sometimes necessary to solve the problem by means of a kneeling prosthesis with a joint locked to 90° but this eventuality is extremely rare. This effect of stump length on the rehabilitation outcome was noticed by Subbarao & Bajoria (1995).

Bending angles of the hip and the knee are complementary and a decrease, in priority, of the hip bending, the most constricting for the limb fitting, will allow a decrease of the angle of the knee bending. The average ranges of motions that can be met are about sixty to eighty degrees for the knee and fifteen to thirty degrees for the hip.

In the rehabilitation check-up, it is important to notice all angles by separating passive and active; lying down, seated and upright positions. The results vary often from one position to the other. For example, the knee bending increases when the hip passes from flexion to extension while the logic of poly-articular muscles would indicate the opposite. There is no simple explanation so, probably, the placement in tension of the capsule of the coxo -femoral joint originates a reflex phenomenon.

11.II.6.2 TECHNIQUES OF RECOVERY

They are specific, because ordered by the vascular pathology.

11.II.6.2.1 Basic Principles

The cure is especially preventative by passive mobilisations of the knee and the hip joints before the amputation, associated with a good position of the patient lying down into his bed. Active heavy work of muscles is necessary. The most important are quadriceps femoris and gluteus maximus, i.e., the extensor muscles of knee and hip joints.

Unfortunately, ischaemia is always present and / or threatening. It is, therefore, difficult to control it and if there is a long history of lack of strong blood flow, the best physiotherapy is powerless. The existence of fixed flexion contracture is one of the complications of the vascular disease and not a lack of nursing.

More concerning is the impossibility of practicing postures. Indeed, all passive stretch entails an internal tension in all tissues, muscular among others. This is particularly true of intra - cellular spaces (because of unstretchable aponeurosis sheaths that enclose them) in which wander nutrient vessels that are then compressed. Therefore, the ischaemia has a tendency to be worsened.

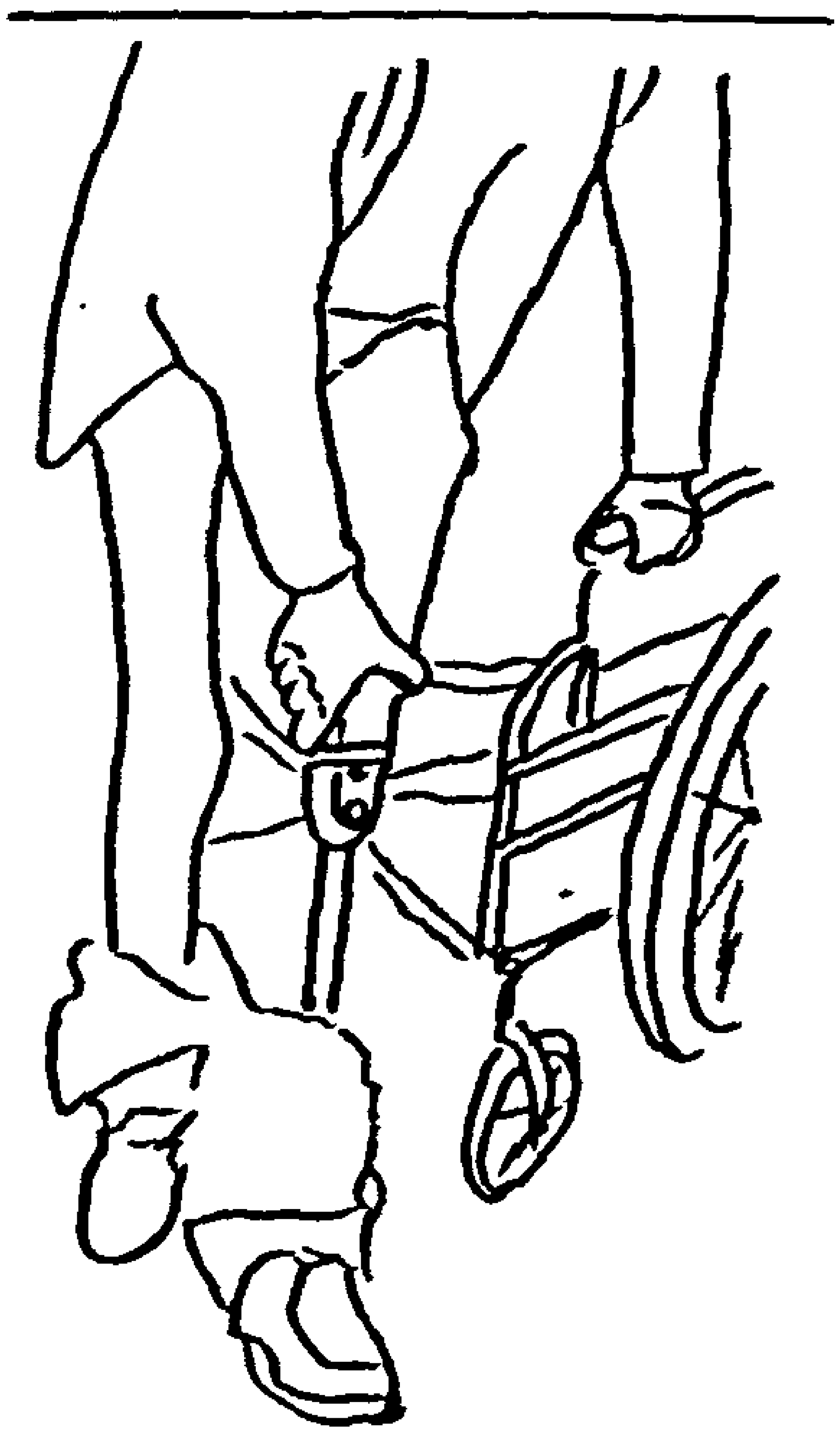


Figure II.62: The fitting of a transfemoral prosthesis is a difficult task for an elderly amputee

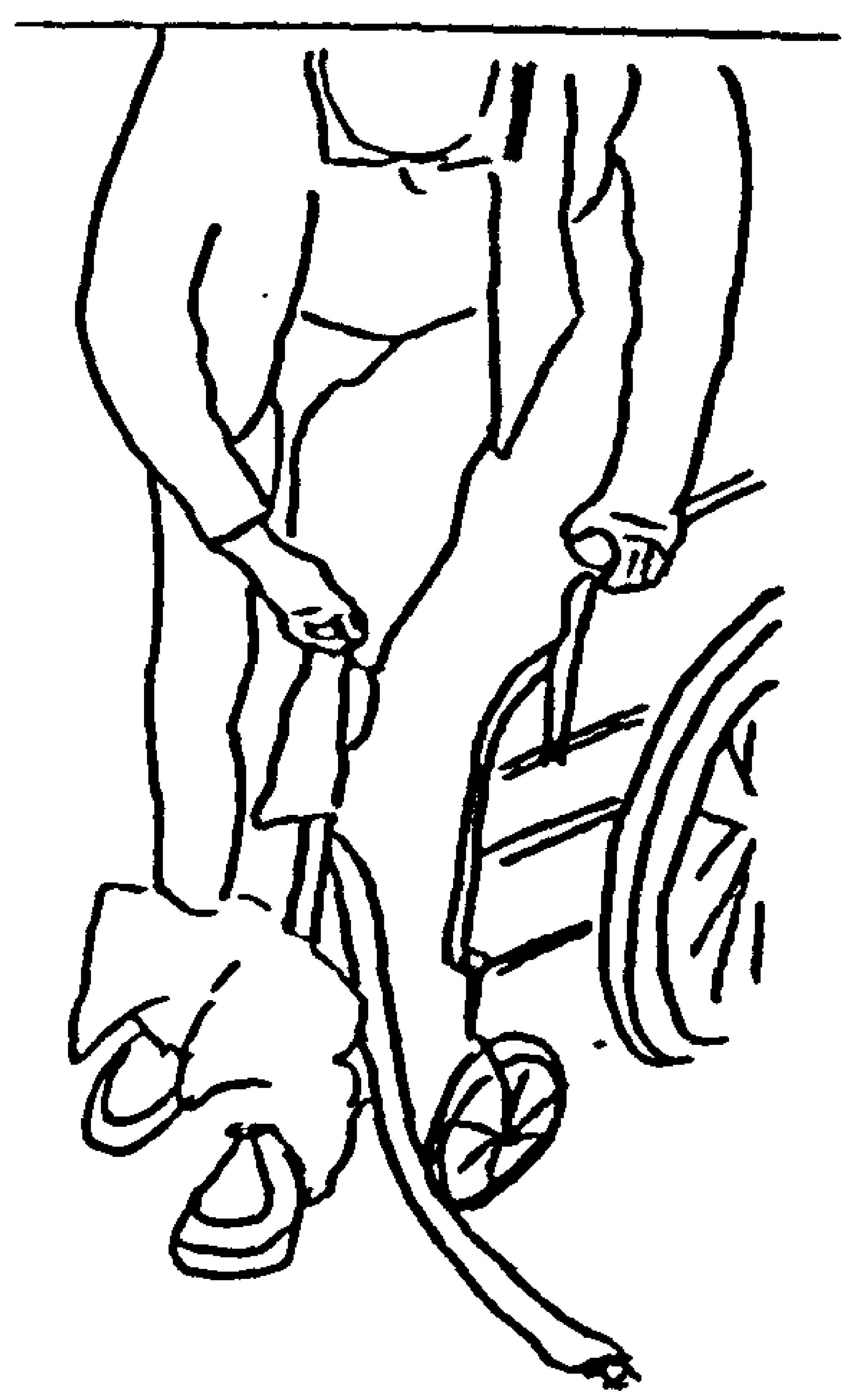


Figure II.63: The patient is standing up a long time on his sound limb

On other hand, the **Intermittent Dynamic Heavy Work** (IDHW) seen above allows re-vascularisation little by little of muscles and reverses the ischaemic retraction. Walking is therefore the major manner to recover these bends. Moreover, the gait will be made with specific prostheses that are a tool of work for the physiotherapist (Cauret, 1987).

11.II.6.2.2 Physiotherapy without any prosthesis

11.II.6.2.2.1 MASSAGE

Considering the importance of the pain in the picture of the ischaemic retraction, a direct contact massage at the start of a workday in association with relaxing manoeuvres is well appreciated by patients. Light and painless stretches of skin and hamstrings tendons seem to be beneficial. This task is conducted most often with the patient seated in his wheelchair and concerns essentially muscles of the thigh, the knee region and the upper part of the leg, far from the amputation wound. In any event, up to this stage, the dressing prevents access to the distal part of the stump.

During these manoeuvres, verbal exchange between the physiotherapist and the patient about the programme of the day and its objectives is indispensable. It is necessary to explain to the patient what causes his joint bending, their potential development, especially if tobacco poisoning persists (Chanu & Rouffy, 1988). The therapist may explain why a different range of motions is measured at different hours of the day and why they can vary considerably. The daily re-education work usually decreases the joint angles by about a third while the nocturnal decubitus, decreasing the distal blood flow, increases the bends. If not warned, the patient is at risk of discouraging himself.

It is necessary to couple these massages with a training of the muscular relaxation, as far as the pain will allow.

If it is possible, a session of relaxation, only can be beneficial. One can associate relaxing techniques with vibrated massage on the muscle and the tendons. As applied in respiration physiotherapy, vibration hand movements are used to relax the tendinous tissues and fascia of muscles. There is no explanation for the physiological process nor to proof of the efficiency of this technique but patients are happy and better.

11.II.6.2.2.2 PASSIVE WORK

After and during the massage, a minimal passive training is introduced, very brief, alternating tension and relaxation laying stress on knee extension. It is also necessary to attempt to mobilise the patella and to stretch passive elements round the knee joint. The hip should be mobilised in all planes of the space and in all available range of motions. For this task, the patient lies down, his lower limbs at the end of the table. The distal tip of the stump is off the table to allow maximal hip extension. If required, a placement in lateral decubitus on the non amputated side is possible. It is necessary to apply low forces and short duration because of the danger to apply dangerous postures, having the risk to decrease or to stop the blood flow..

Matters noticed in the assessment should not be overlooked, for example: femoro-tibial distal by-pass crossing the popliteus hole (necessity of a medical notice before any maximum knee extension), ilio-femoral by-pass crossing the hip, scars more or less retractile because of old surgery in front of the Scarpa's triangle.

The ventral decubitus is always badly tolerated (respiratory and /or cardiac problems) for arterial elderly patients even if the plan of work can be ruled to spare minimal amplitudes.

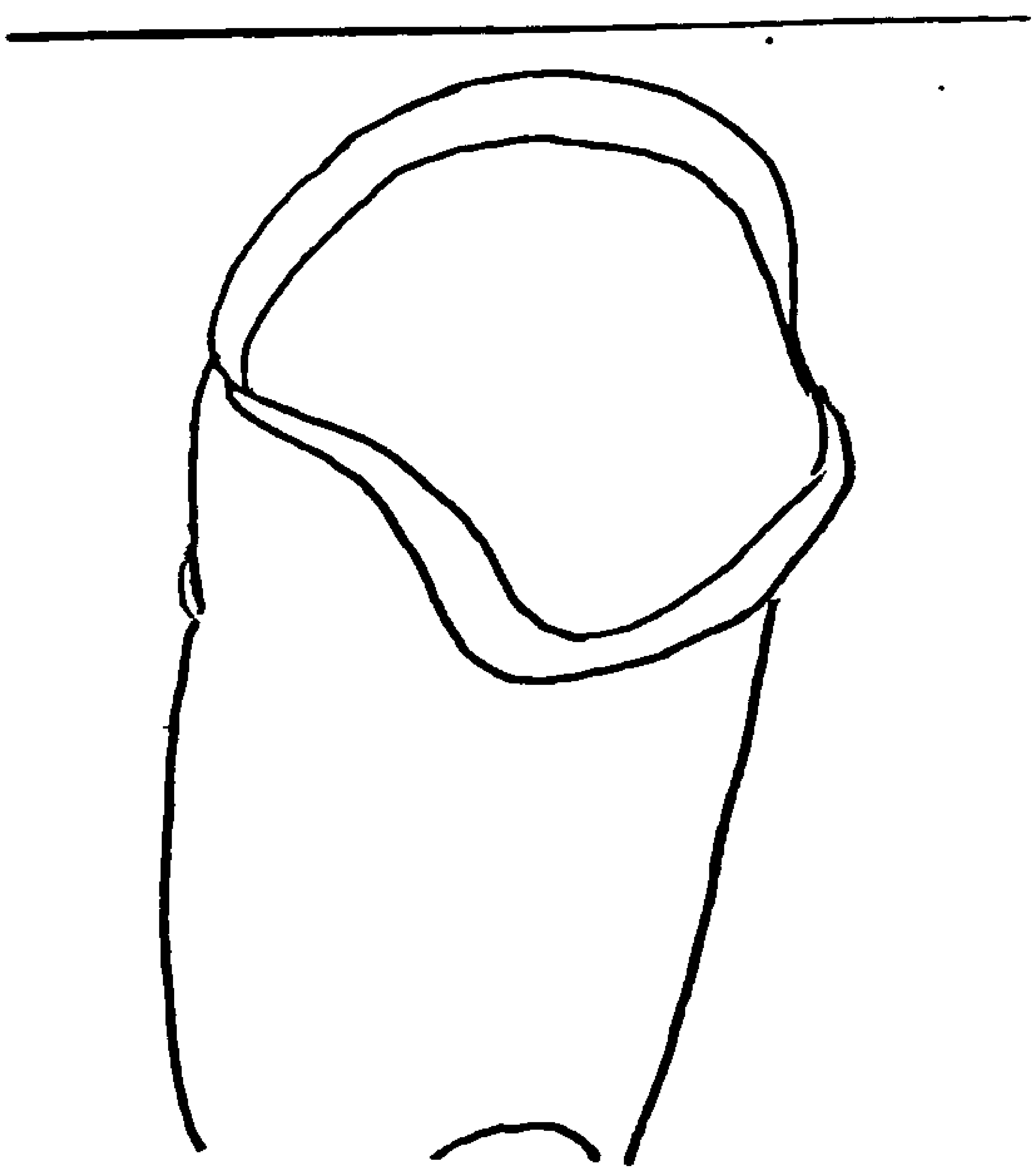


Figure II.64: An ischial - contained brim in a medial view

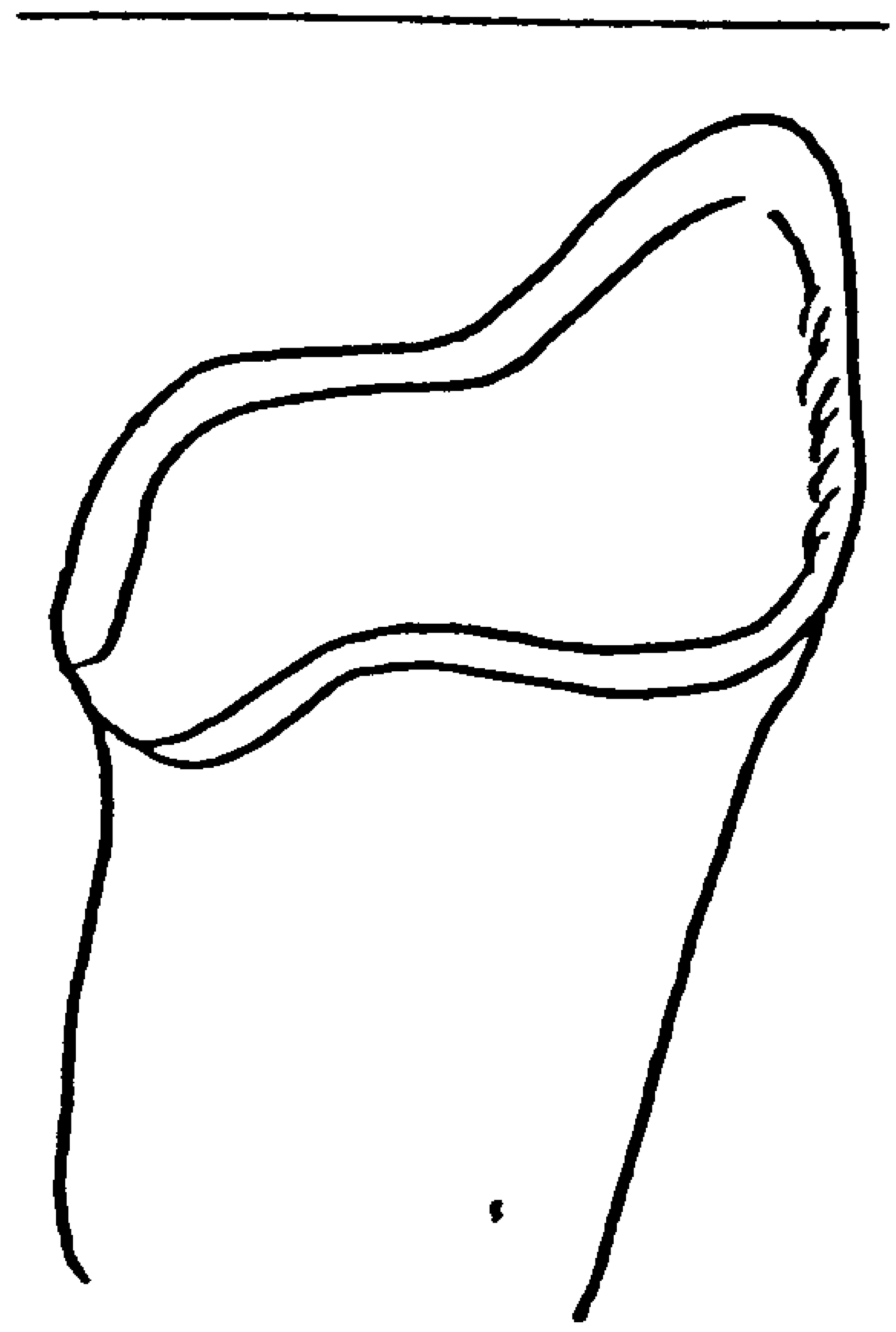


Figure II.65: The same brim in a posterior view

Figure II.66: The ischial - contained socket in a superior front view with a knee-lock lever and the fitting hole

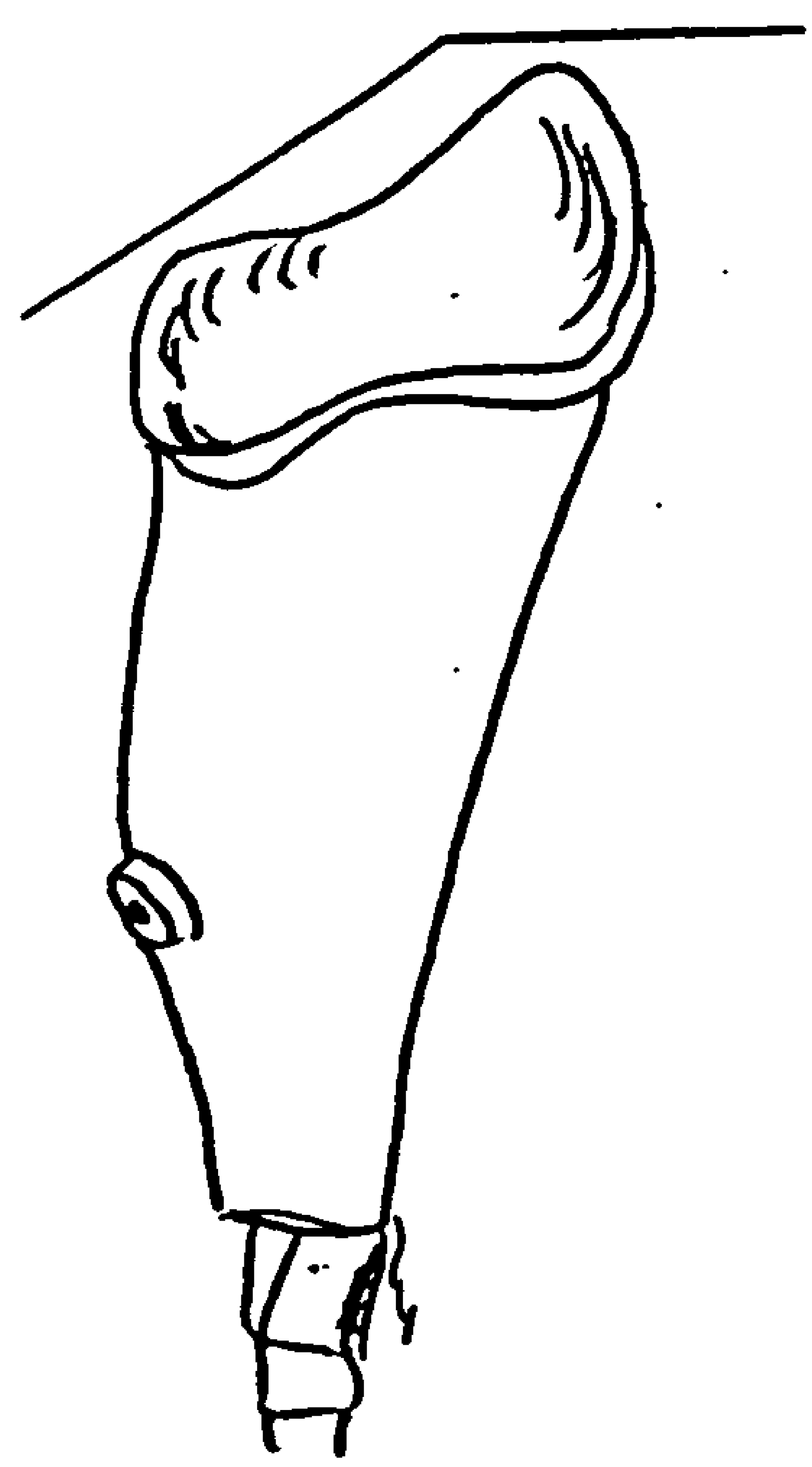


Figure II.67: A medial view of a similar socket with a locked knee

11.II.6.2.2.3 ACTIVE WORK

Active muscular work is essential for vascularisation. This is usually manual work, strictly dynamic and the most often concentric. Muscular units are alternated to give enough times of rest between each series of contractions.

Assisted active heavy work usually straightens in extension. When the peri-joint extensibility and the muscular heating are obtained, concentric active work acting is introduced. The resistance is weak. It is more the repetition of the same gesture that is important rather than the instantaneous power. At the end of the series, some eccentric work is introduced.

Since it is repetitive, an assembly of pulley-therapy is usual. The work is alternating concentric - eccentric, isodynamic, with lightweights. The restraining pegs should be positioned to allow some patients rest periods in a good position. We work agonist muscles as well as antagonist of the bent joint. One of the difficulties is to attach straps on a stump which is too short or fusiform. One solution is to fix a pulley-therapy hook with some adhesive strap like Hypafix® if the texture of the skin allows it.

In parallel bars, the patient trains for a simulated mid-stance to toe-off step. With the patient standing up, he is asked to undertake a hip and a knee full extension of the amputated lower limb. This exercise is some times associated with a triple contralateral flexion insuring the stability of the patient by means of an upper limb flexion.

11.II.6.2.2.4 CONTRACT - RELAX

The contraction - relaxation technique is frequently used. This way of doing uses a muscle contraction close to the maximum of the agonist muscle (here it is the quadriceps femoris). The result is hyperextensibility of the hamstrings thanks to the crossed innervation. It looks like a static powerful work close to the maximum, which is opposite to principles given above, but the duration is brief (classically six seconds). The technique is slightly changed by decreasing the duration of the contraction (maximum four seconds) and by lengthening the rest time between each movement (approximately twelve seconds). The importance of this muscular training was brought to the fore by Tardieu *et al.* (1982) who considered the adaptation of connective tissue length to immobilisation in the lengthened and shortened position in cat soleus muscle.

11.II.6.2.2.5 HOLD - RELAX

The hold - relax situation is additional to the contract - relax; it uses the antagonist (here the hamstrings) and its period of hyperextensibility by an inhibition following a maximal contraction (same principles as above about time).

11.II.6.2.2.6 ELECTROTHERAPY

Motor-stimulating electrotherapy on the extensor muscles of the knee is useful. Two small electrodes (3 cm x 3 cm) are placed on the vastus medialis and the vastus lateralis; a third one with a size twice the previous is placed above in front of the rectus femoris. The power has a null average charge to avoid any skin burning and its frequency is 75 Hz with a wave of rectangular shape, duration 100 μs. The intensity must be comfortable for the patient. The active participation of the patient is important. In this point of view, we complete this electrotherapy by an extensive use of bio - feedback.

11.II.6.2.2.7 ARTHROCAME

The Arthrocame® is an excellent additional adjuvant to all these techniques. The apparatus gives an alternate passive tension / relaxation into the joint capsule and passive

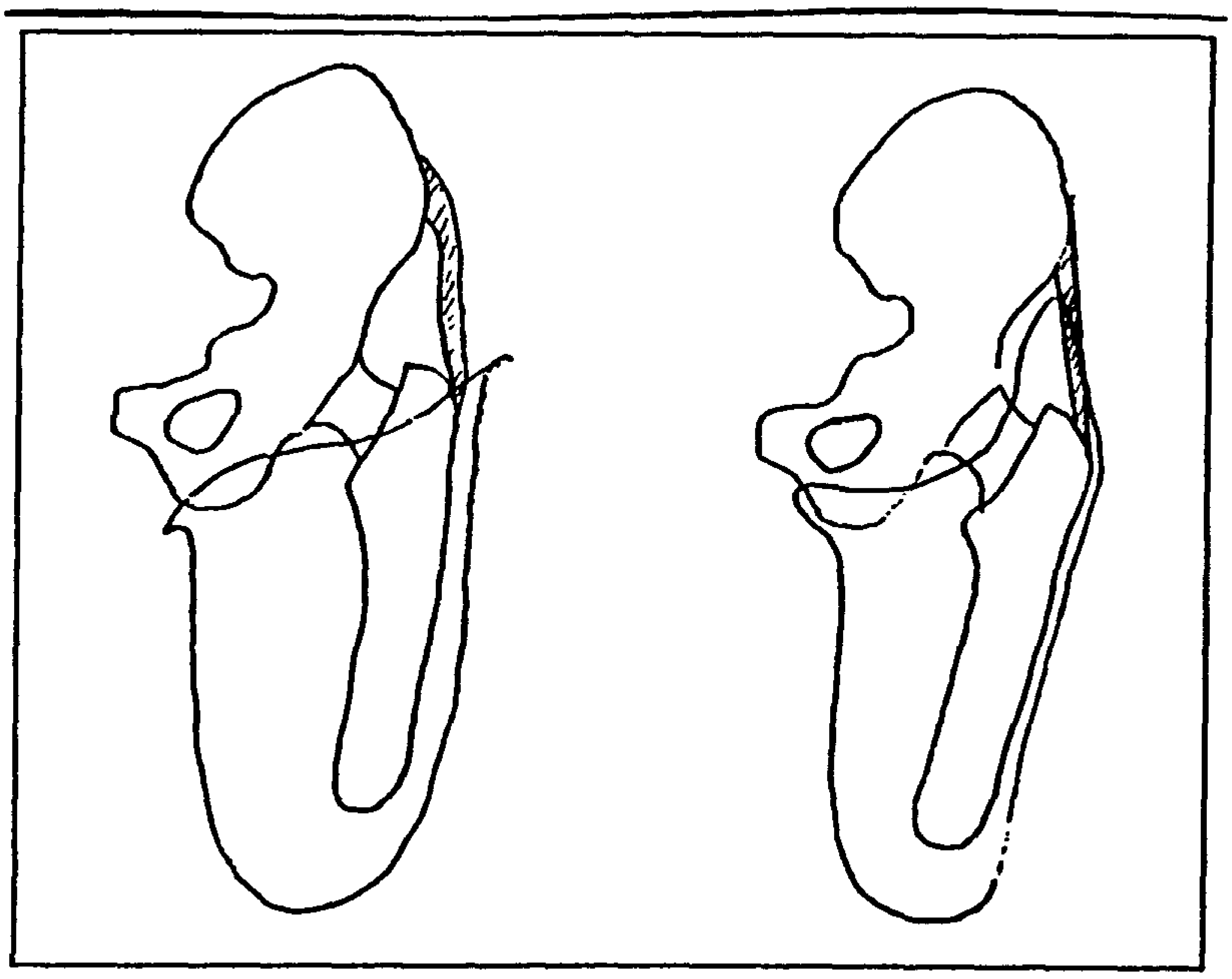


Figure II.68:
Left : quadrilateral socket with a bad control of the femur
Right : ischial - contained socket with a better control of the femur bone during the stance phase of the gait
(extracted from Lehneis, 1985)

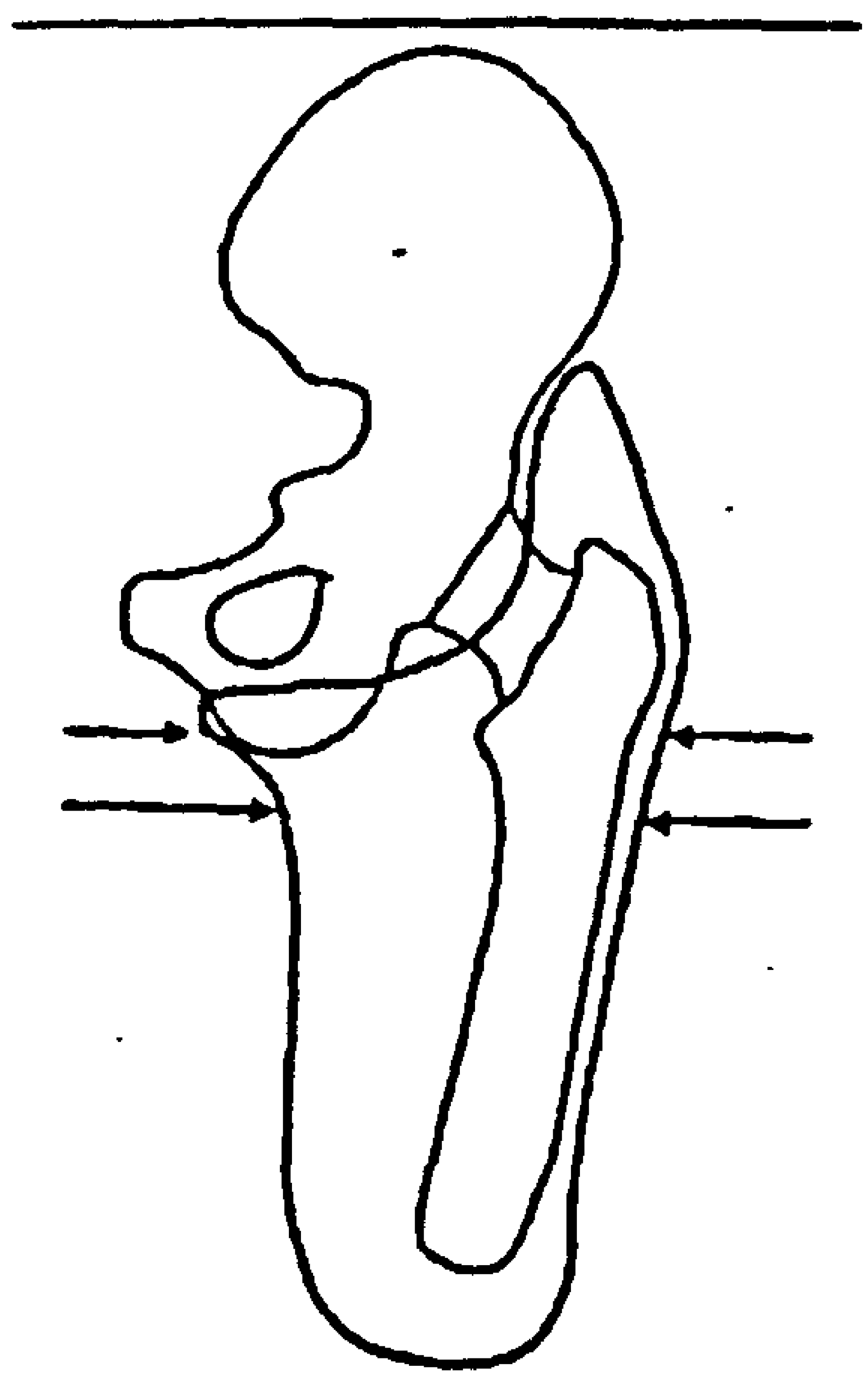


Figure II.69: The frontal nip of the ischial - contained socket
(extracted from Lehneis, 1985)

elements round the knee. Its efficiency has been already highlighted (Pillu 1989). The main problem is to link the hook with the stump and its very fragile skin. One solution exists: adhesive strap or elastic bandages of electrotherapy.

All these techniques are wholly explained in Dechamps & Pillu (1994).

11.II.6.2.3 PHYSIOTHERAPY WITH PROSTHESIS

11.II.6.2.3.1 THE OFF - LOAD ISCHIAL BEARING PROSTHESIS

We have seen, several times, that an early, controlled and programmed gait recovery is essential. It is possible thanks to a specific device: **off - load ischial bearing prosthesis,** described previously.

It allows the decrease of the permanent bending of the hip, the most constricting, but it goes backs the most easily because of

- the nature of the hip joint and its muscles: near the limb root, peri-joints elements and muscles are better vascularised than those distally situated
- great lever arm for the extension of hip during the second part of a step: mid stance to toe off.

This prosthesis is a tool for the physiotherapist.

11.II.6.2.3.2 DONNING AND USE

The ischial bearing prosthesis described previously most often has a vertically split socket to allow an easy pathway for the bending knee for donning the prosthesis. Once the thigh is into the flange, the socket is closed by an unstretchable crepe bandage. Then the patient is asked to stand and the position of the ischial bearing, is adjusted and checked with a perfectly vertical prosthesis. After that, the physiotherapist pushes backward the thigh segment of the patient just above his knee to place the hip at its maximum extension, without forcing nor pain. With his other hand, the physiotherapist verifies that the pelvis does not antevert and that the patient does not compensate by bending forward his lumbar spine. The physiotherapist then binds the thigh by means of unstretchable strips around the prosthesis. The femoral condyles are protected by an interface of foam. The shoulder-belt is now put on. The presence of an axillo-femoral by-pass requires that the belt be placed on the same side as the prosthesis.. The patient can begin to walk by **ensuring that the hip is in full extension,** at each step during the second part of it: mid stance to toe off.

The procedure is more efficient if the **daily gait duration is sufficient.**

It is necessary that patients have a physical activity close to their maximum. Having enough muscular exercises is vital because there is a change in sarcomere length and physiological property in immobilised muscle as shown by Williams & Goldspink (1984). All the features of the examination data-base are re-checked to determine this maximum level by the medical team. The criterion for stopping is a local muscular fatigue, without any pain, as described by Theys *et al.* (1982). The patients' will must not be stimulated too much. This maximum is eminently variable according to days, hours of the day, in the week. This is why a careful follow up of the patient by his physiotherapist, always the same one if possible is of a first importance. If all these criteria are obtained, a significant decrease of the permanent bending of the hip is obtained in approximately three weeks to one month of re-education.

The efficiency of the prosthesis is independent of the gait assistive devices used: in parallel bars as well as with one cane - one bar or two walking sticks. The duration alone counts. A patient who walks inadequately, by passing the major part of the day in his

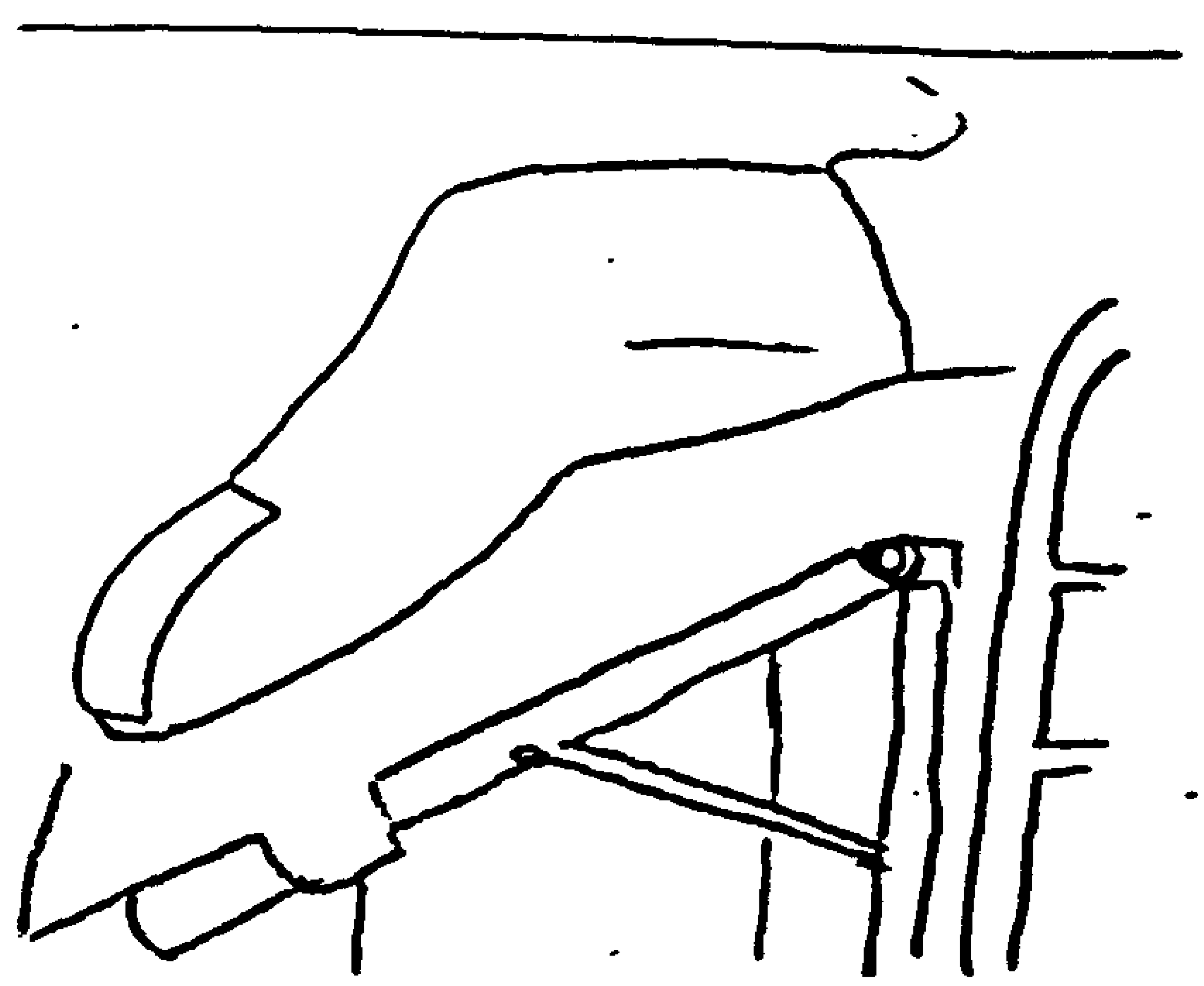


Figure II.70: A permanent knee bending of a patient sitting in his wheel - chair wheelchair while worsening his ischaemia with tobacco, will not recover or will only very partially improve the deformity.

If possible, a tread - mill is used as a stimulant of the extension of the hip (see above figure II.18) and it was possible to study the gait symmetry using the force measuring tread - mill, as described by Tucker & Lin (1996).

As the prosthesis is put on twice a day by the physiotherapist, it is always well fitted and it allows an accurate positioning of the hip, having a permanent flexion contracture. As the recovery of the hip extension continues, the permanent knee bending decreases automatically, without any physiotherapist's act. One can advance several reasons for this:

- poly - joint muscles;
- the Intermittent Dynamic Heavy Work (IDHW) that has already allowed a better vascularisation of peri - joint elements and muscles of the knee;
- the decreasing of the pain, both because the post-surgical period is far away and thanks to the improvement of the vascularisation;
- the gait motor nerve diagram that has allowed, in the swing phase of the gait, movement of the knee towards extension plus a stop at the maximum possible extension at each end of the swing phase, when heel strike occurs.

This list is not restrictive and the order of importance of these factors is different for each patient according to the history of his amputation, the location of lesions and the pathology.

Generally, in a few weeks, the flexion of the hip has regressed. It does not disappear completely, some degrees remain. They are not important. Over a certain age in the standard population, extension of the hip disappears. Living with five to ten degrees of hip flexion contracture is easily possible. It is therefore possible to go to the next stage. Also, during the use of the ischial bearing prosthesis, not only the associated hip and knee bending have decreased but the wound of the stump has begun its healing, pain has decreased, the general shape of the stump has improved as well as the general state of the patient.

11.II.6.2.3.3 THE SECTOR PROSTHESIS

The type of prosthesis following looks like the definitive prosthesis with the same weight - bearing areas and the same support as shown in figure II.36. The socket is in acrylic resin. This new tool for the physiotherapist is called the distal sector prosthesis. It allows recovery of the permanent bending of the knee by means of:

an extension loading at each step

thanks to an assembly in some plantarflexion degrees (inferior to 5°) of a rigid monoaxial foot. This extension is maximal during the second part of the stance phase of the gait and depends mainly on the value of the axial force on the ground. A similar prosthetic tool was also described by Hays *et al.* 1992.

At heel off, the ground reactions tend to be posterior to the hip causing an extending moment and anterior to the knee causing an extending moment. These ground reactions are also anterior to the ankle joint tending to dorsiflex the artificial foot while loading onto its front ring. All of these forces and moments are shown in figure II.71.

This prosthesis is equally a tool for rehabilitation.

11.II.6.2.3.4 DESCRIPTION AND ADJUSTMENT

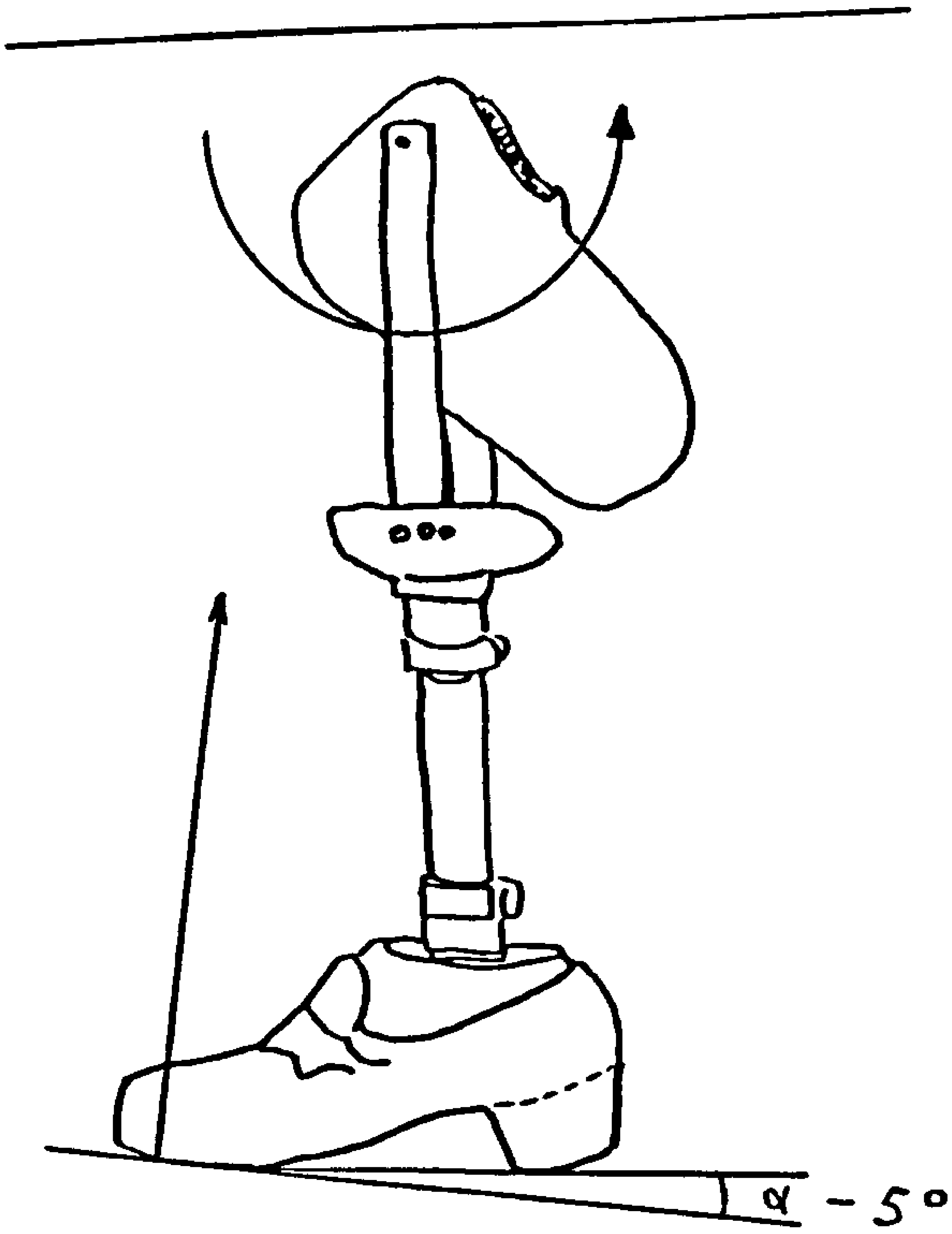


Figure II.71: All forces and moments applied on the sector prosthesis to minimise permanent knee bending (the plantarflexion angle is 5 to 10 degrees)

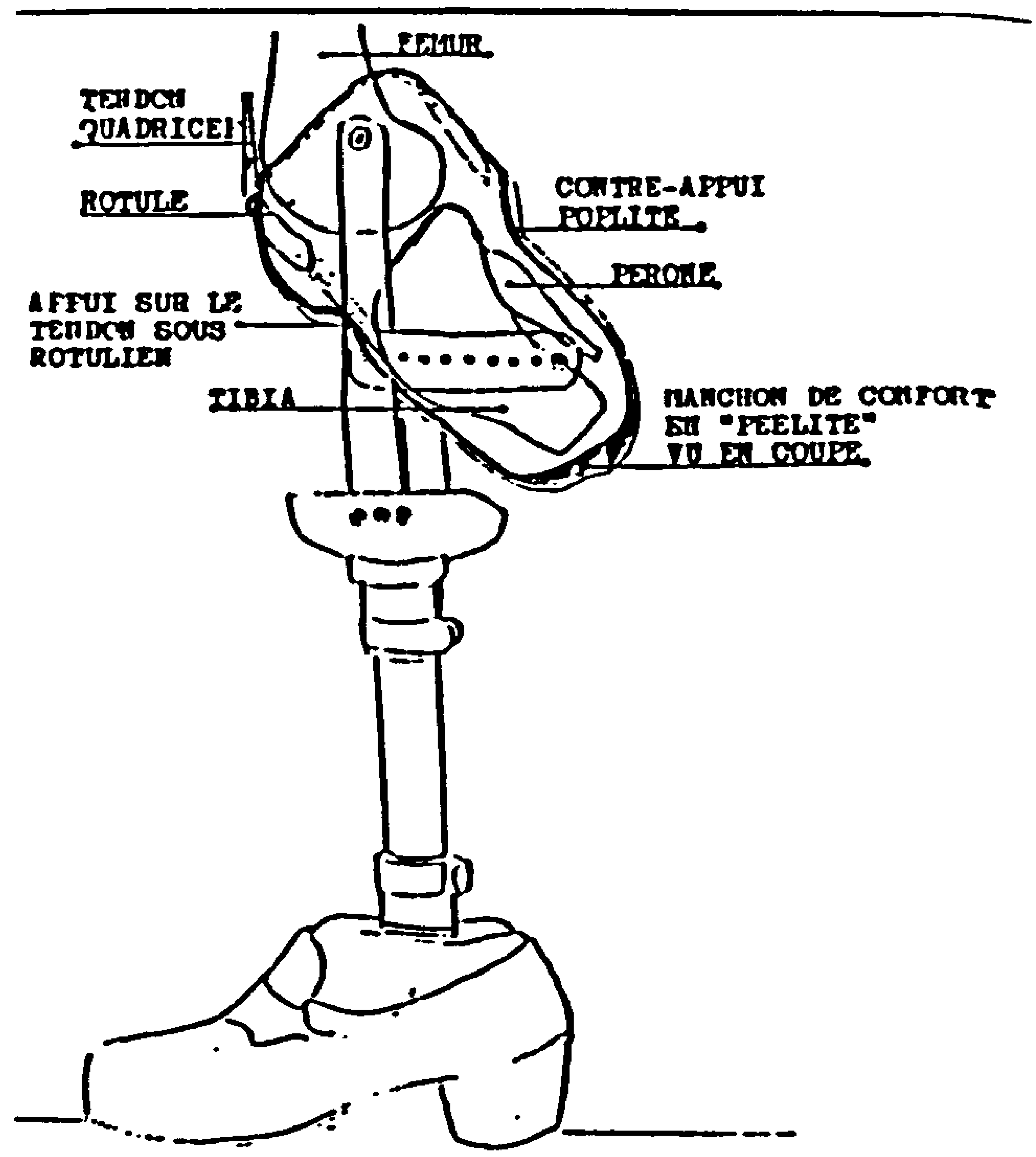


Figure II.72: A sagittal view of the sector prosthesis with the stump's bones

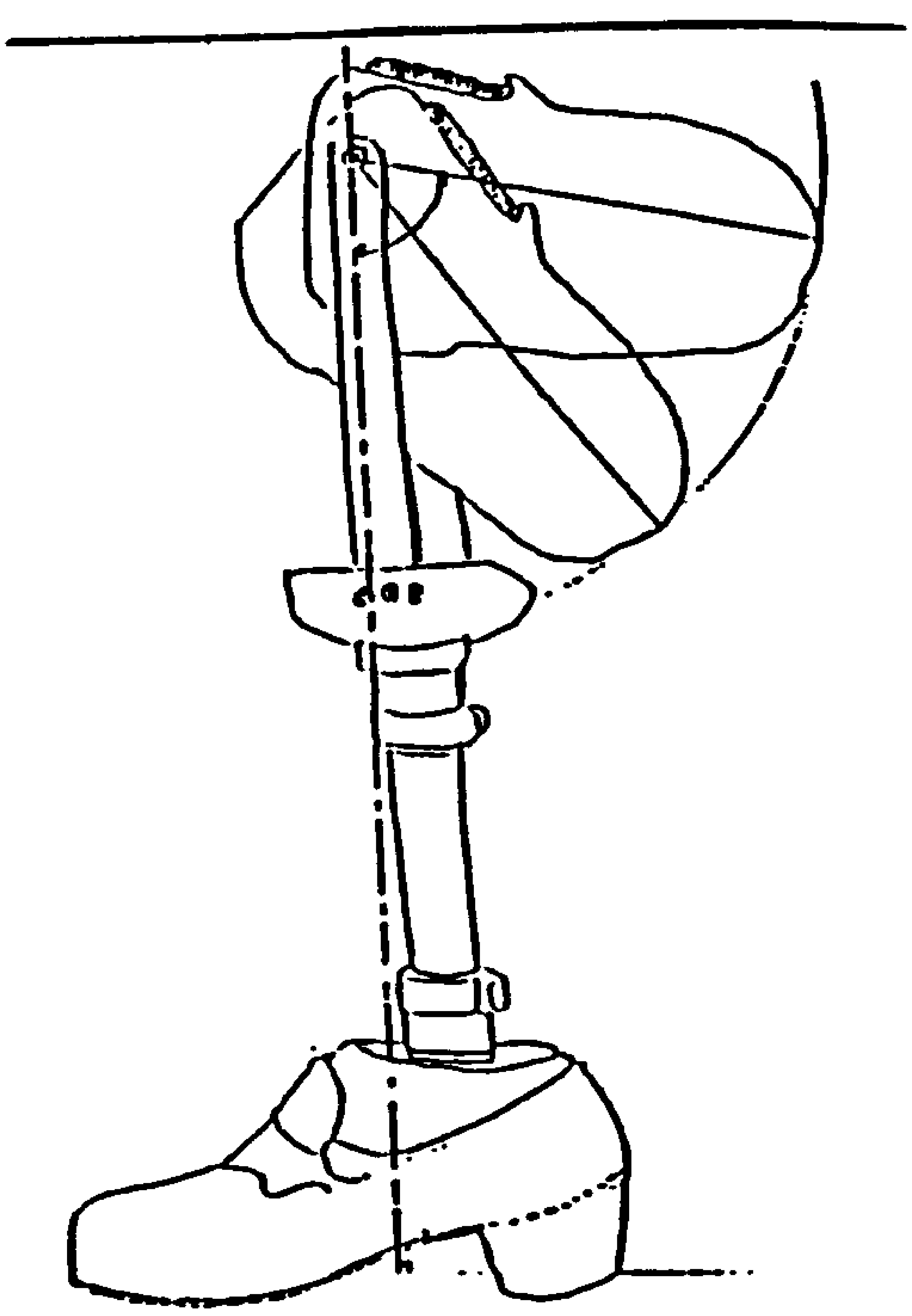


Figure II.73: The socket of the sector prosthesis turning about the knee joint axis

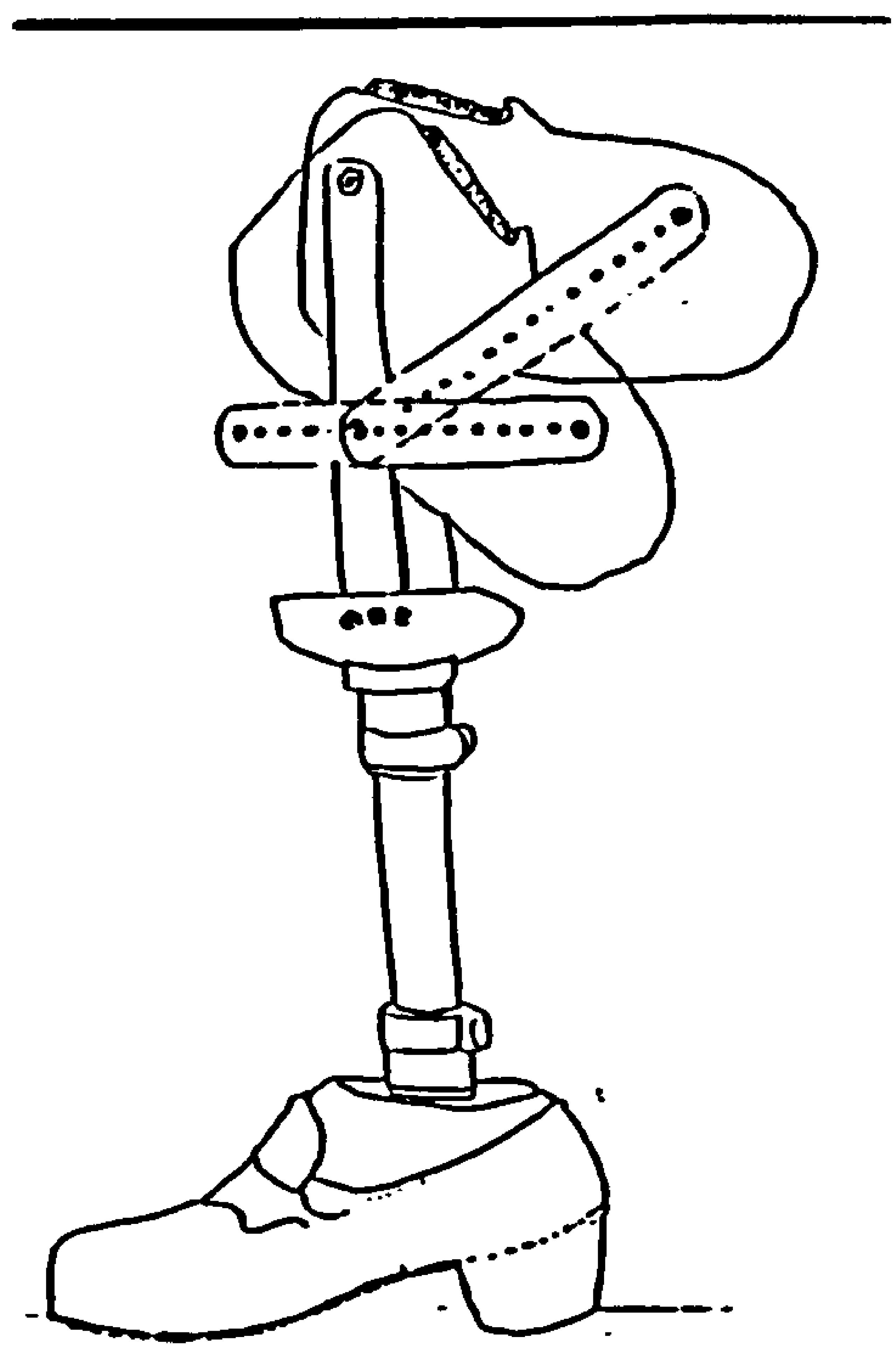


Figure II.74: The sector prosthesis with the two lateral splints turning about its axis in two different knee joint angles

On a tibialis socket contact, as described previously, two holes are drilled through the two condylar wings. These holes are in the average position of the flexion - extension axis of the knee (figure II.72). Two vertical dural splints fixed in the two holes of the socket support it and the shank tube by the intermediary of a dish of adjustment (figure II.73). On the figure, the socket is rotated around its axis by sweeping a sector of a circle while preserving the vertical alignment in the sagittal plane whatever the angulation of the knee is. To fix the socket in this swept sector, two lateral splints (figure II.74) or a single central one (when the stump is short enough) are pierced at every centimetre and form the chord of the sector of a circle as shown in figures II.75, II.76, II.77 and II.78.

The monoaxial foot with its front rigid stop ring is firm enough in dorsi - flexion.

The assembly in plantarflexion of ≈ 5 degrees (for checking, the height of a standard biro is used between the mid footwear heel and the floor) is checked while the patient is standing up, immobile. The prosthetist exerts a thrust in the sagittal plane forwards on the pelvis and one counter thrust backwards on the anterio - inferior part of the thigh, aiming to put the hip and the knee in the most possible passive extension (figures II.79 and II.80).

If the prosthesis is fitted correctly for optimal efficiency, the indispensable plantarflexion corresponds to a heel raise of about approximately one centimetre.

If the prosthesis is badly fitted, two cases appear:

1. too much dorsiflexion: the prosthesis is too bent, the patient has decreased his knee angle. The line of body weight extending down from the centre of gravity G passes posterior to the bi-malleolar axis. The angle between the socket and the shank tube has to be decreased by shortening the two lateral splints to find a new optimum plantarflexion (figure II.81).

2. too much plantarflexion: the prosthesis does not bend enough. The line of body weight extends down from G passes anteriorly to the tip of the foot. The angle between the socket and the shank tube has to be increased by lengthening the two lateral splints. This condition is often met because the patient hoping to save hospitalisation time and / or for aesthetic reasons insists that the prosthetist straighten the bend of knee exaggeratedly. This induced an artificial increase of the hip bending (figure II.82).

11.II.6.2.3.5 DONNING AND USE

The donning of the sector prosthesis is identical to that of the definitive prosthesis. The soft - socket and the stockinet are used in the same manner. It is simply necessary to take care to put the stump in flexion of about 80° to 90°, on the socket axis. For complementary angle reasons, this device is cumbersome in the sitting position and exceeds the footrest of the wheelchair.

The optimum use of this prosthesis involves three criteria:

1. maximal axial load acting on the prosthesis from mid stance to toe off
2. a full knee extension at heel strike
3. sufficient gait duration throughout the day.

With this prosthesis, the patient has to make a static effort on hip extension: the patient is asked to place the tip of the artificial foot as far backwards as possible from his frontal plane. The patient then tries to produce heel strike on the ground by pushing the knee in extension while avoiding anterior flexion of the trunk.

Gait exercises are common: correct attack at heel strike, good progress of the step, walking backwards notably on the treadmill if the patient can accomplish it.

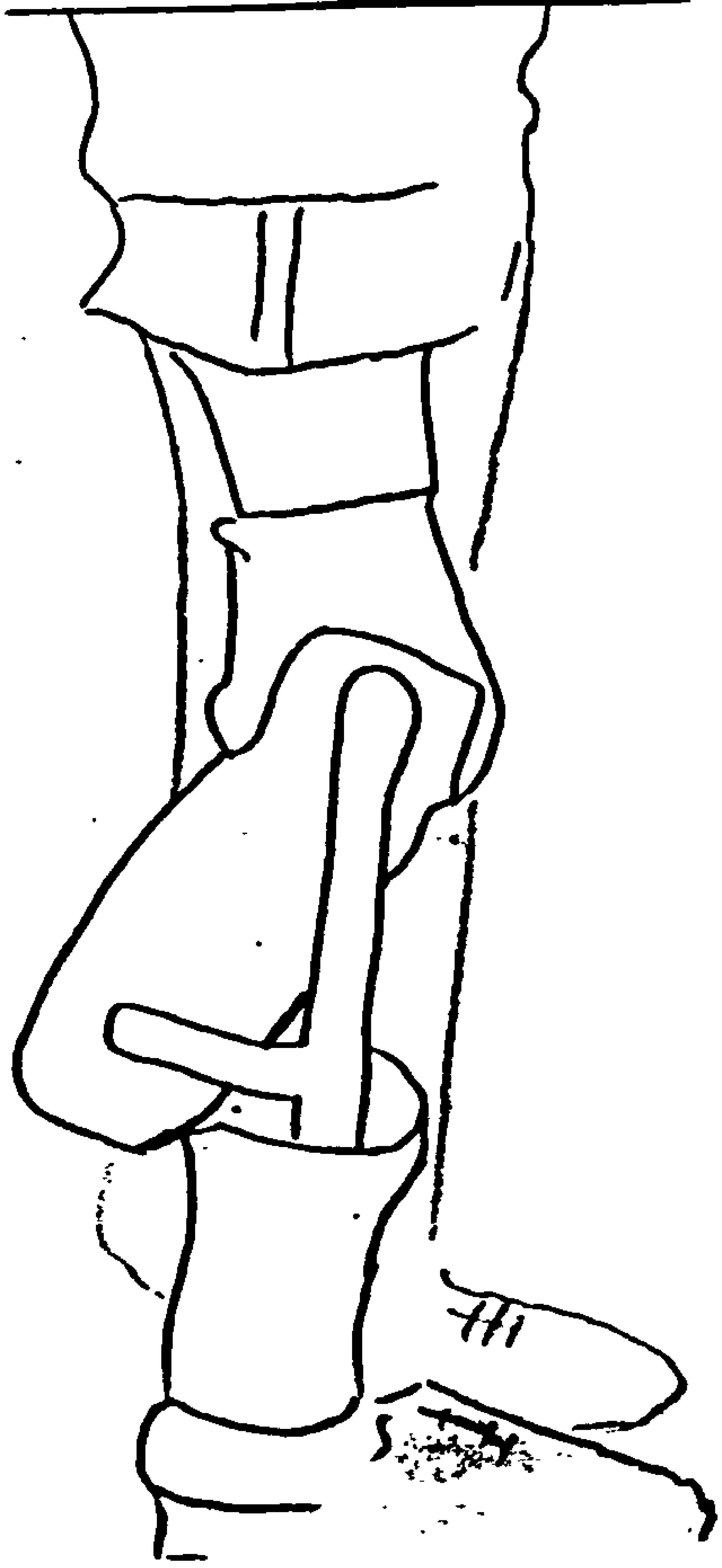


Figure II.75: A sagittal view of a sector prosthesis for the same patient as figure II.70. The device is covered by a cosmetic foam, the patient is soon going back home.

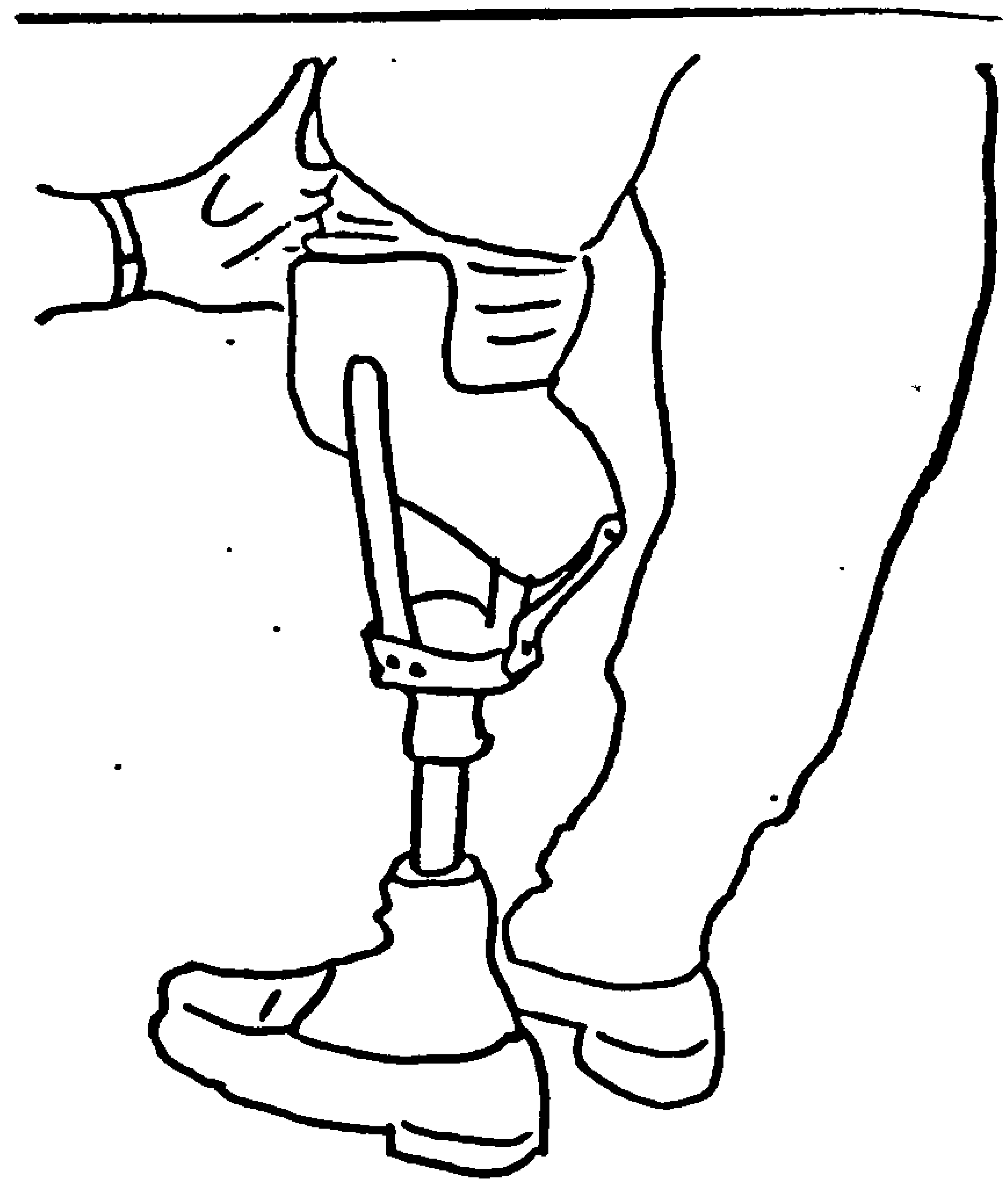


Figure II.76: A lateral - rear view of a sector prosthesis with a single splint for a short stump

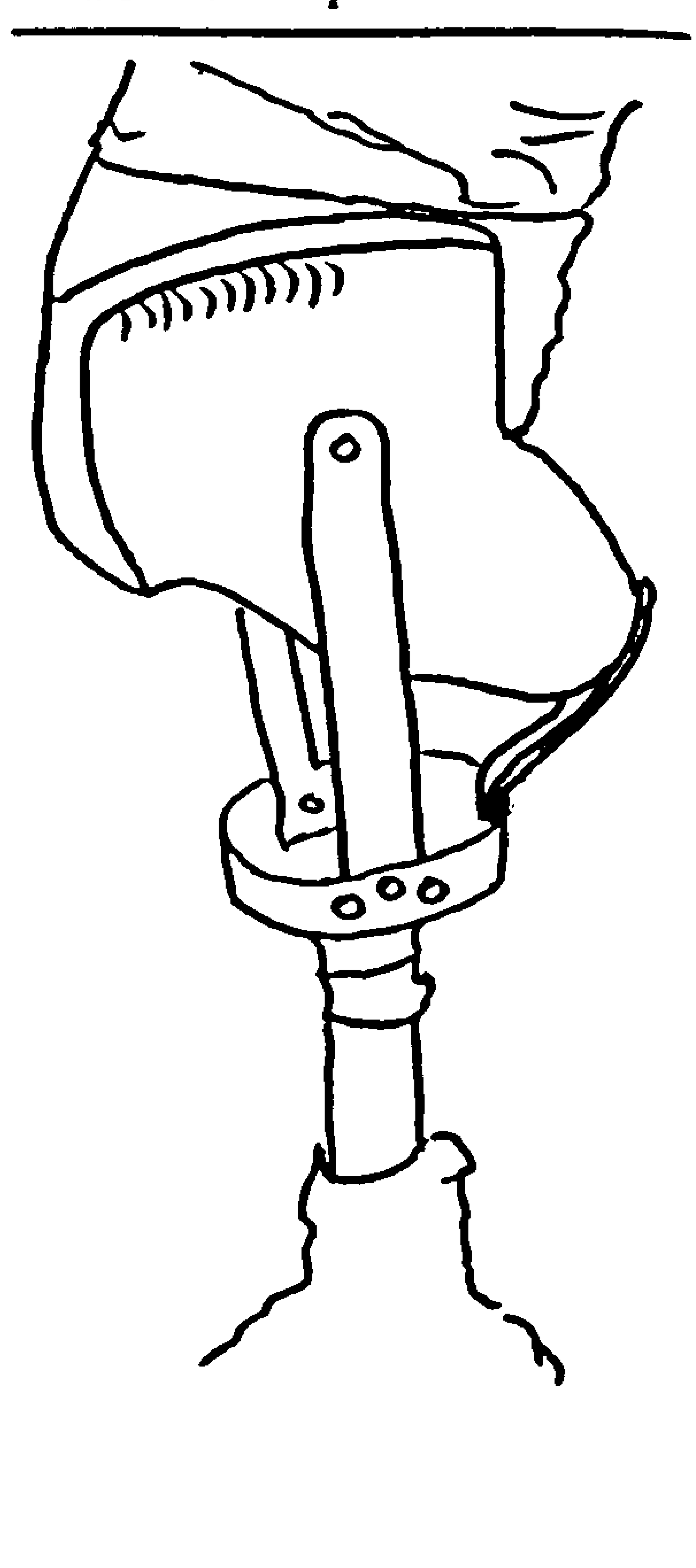


Figure II.77: The same device as figure II.76 in a sagittal plane

It was possible to demonstrate that the more the knee angulation decreased, the more efficient the prosthesis becomes and the more rapid the decreasing of the bending (Pillu, 1988). The importance is to start this decrease by any analytic physiotherapy, plus the training with the ischial bearing prosthesis, by the sedation of pain and a good general and nutritional state of the patient.

If these three conditions are met, one can hope to reduce all the contraction in a reasonable time. These periods are very variable and to give figures is difficult, nevertheless a period about two to three months is usual; until a remnant knee angle of fifteen degrees that is entirely compatible with an aesthetic limb fitting.

Nevertheless, if the reduction of the bends would prolong the stay of the patient in the Rehabilitation Centre too much with all psychological and economical prejudices that one imagines, it is possible to dress the sector prosthesis by means of a cosmesis foam and to allow the patient to go back home. A review, at least each fortnight, is organised to verify the prosthetic alignment. A psychological preparation of the patient and his surroundings is important for three reasons:

1. the prosthesis must be used properly;
2. its temporary but bad aesthetic aspect;
3. its extra - mass of about 0.5 kg.

The prosthesis must be well accepted. When the knee bending has returned to a reasonable angle and if it has tendency to stop reducing, a second prosthesis is manufactured without the bending adjusting device.

11.II.6.2.3.6 DISADVANTAGES

Besides the aesthetics and the weight (slightly higher that a plain prosthesis), the important disadvantage to note is in the sitting position as shown in figure II.83. With a knee joint having a flexion of 110° which is the maximum permitted, without any disadvantage nor discomfort, due to the popliteus counter - load, both the socket and the shank tube of the prosthesis cannot flex. That is, with a rigid artificial ankle, having a straight angle with the prosthetic shank tube, is anaesthetic, cumbersome in a small space as a car. The prosthesis also exceeds largely the footrest pallets width of wheelchairs.

11.II.6.2.4 Summary

There are therefore two criteria so that these tools of re-education are efficient:

ischial bearing prosthesis	sufficient daily use mid stance to toe off time as long as possible
sector prosthesis	sufficient daily use biggest axial load mid stance to toe off time as long as possible

We can summarise the use of these prosthesis - tools on a diagram that represents the same patient, shown in profile, at two stages of re-education as shown in figure II.84a and II.84b.

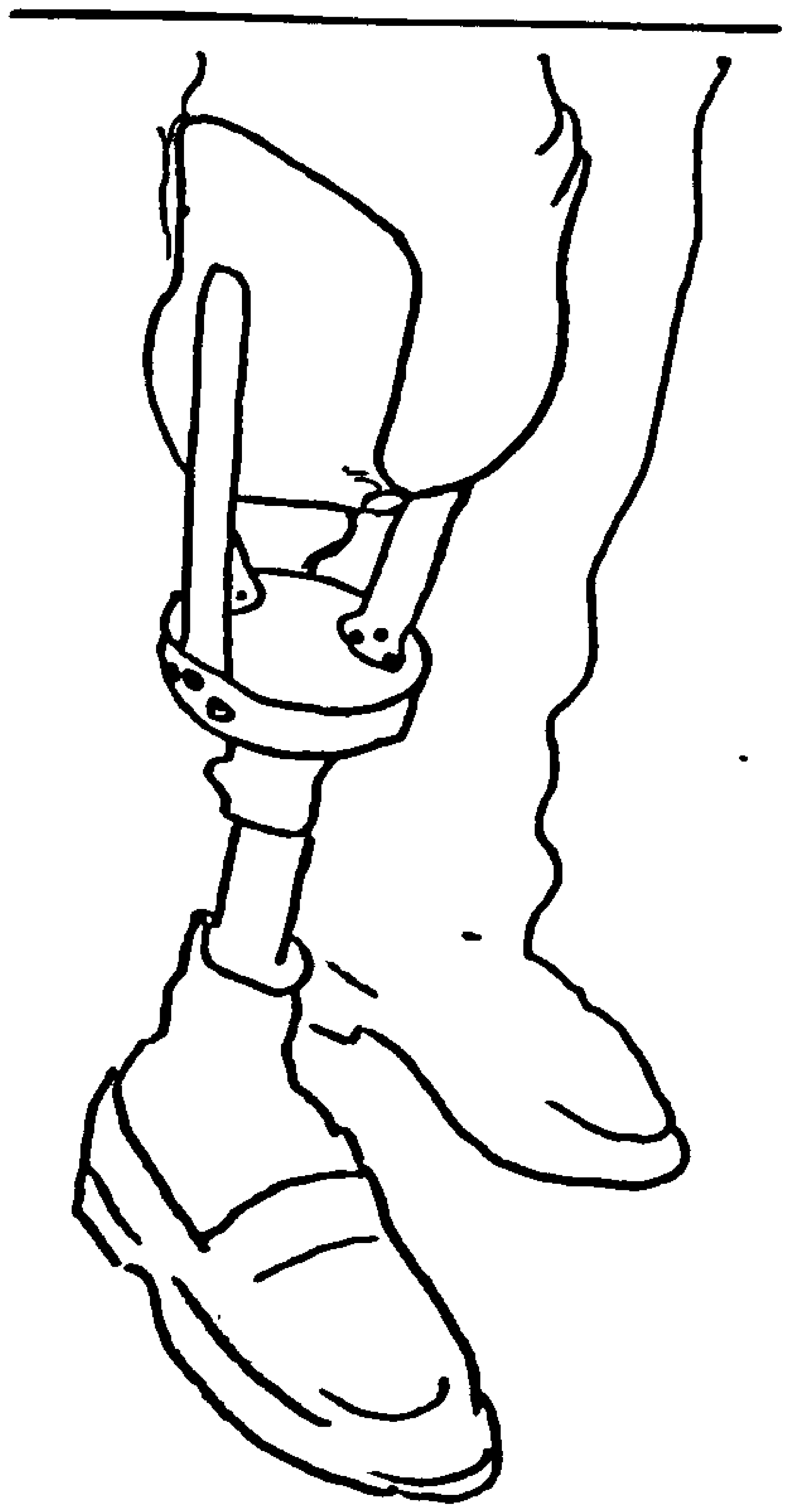


Figure II.78: A lateral front view of a sector prosthesis for the same patient as figure II.76

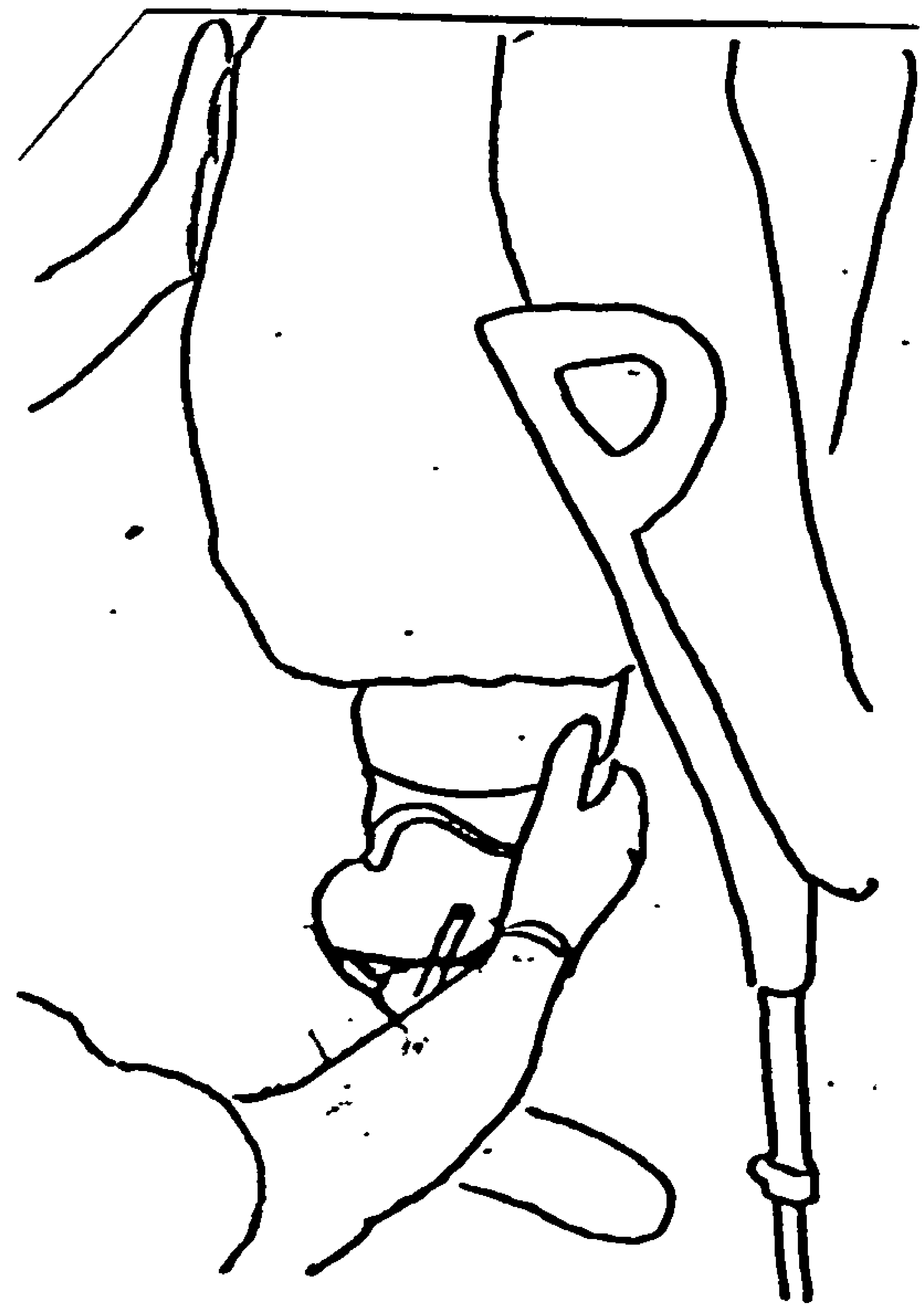


Figure II.79: Checking of the alignment of the sector prosthesis

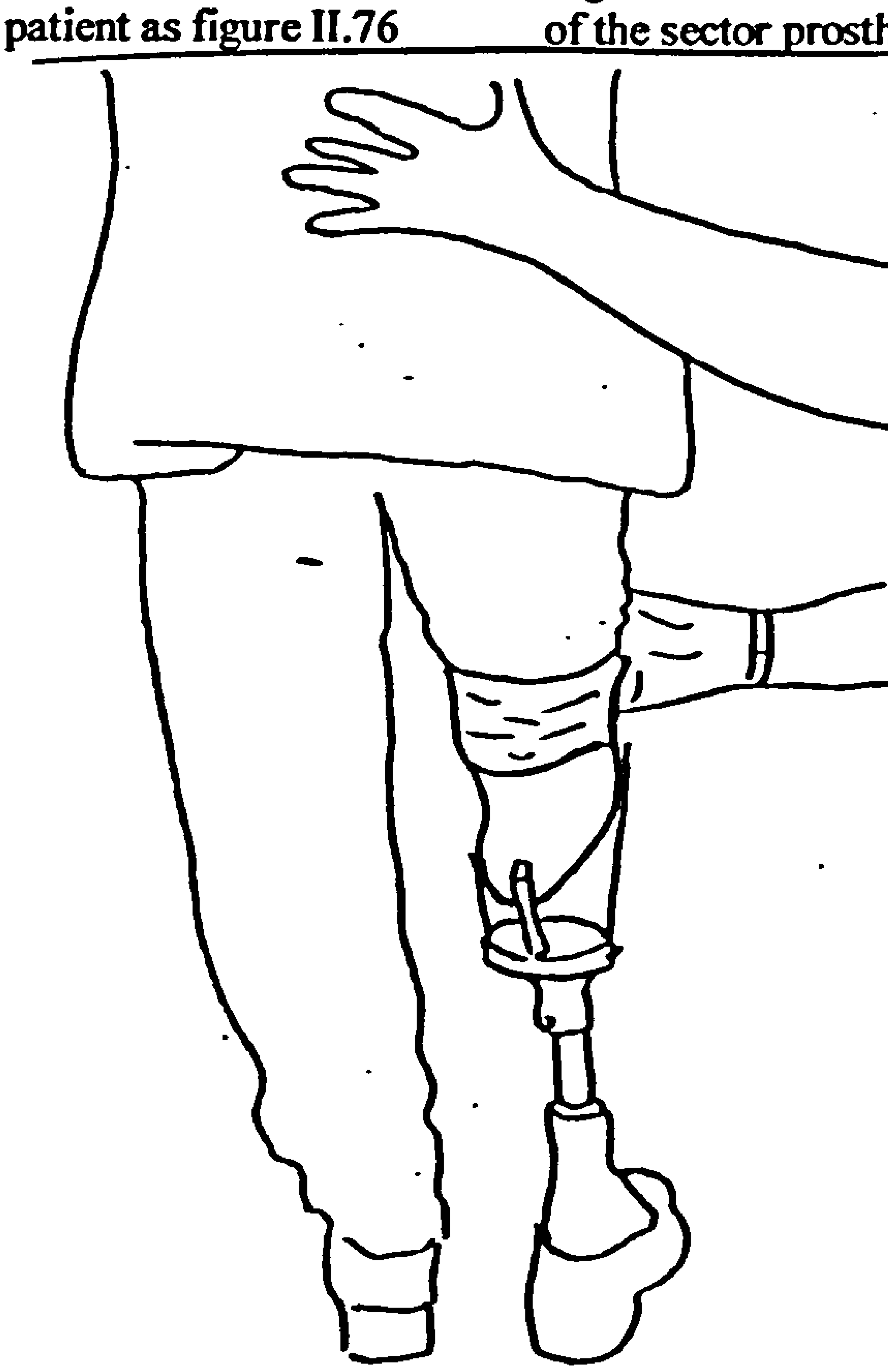


Figure II.80: Verification of the alignment, it is possible to see the 5° plantarflexion

11.II.7 The usual progress of an in - patient at Villiers-Saint-Denis Rehabilitation Centre

As was reported in chapter 1, the patients are amputated in a vascular surgery department, most of them in Paris or in its surroundings. Unfortunately, few of them have an early re - education programme recommended by many authors such as Paquin *et al.* (1989), Bruckner (1992), Eneroth & Persson (1993). Usually the patients are transferred to the Rehabilitation Centre within two or three weeks after surgery. They have an amputation wound not yet healed as shown in figure II.85 and wear a soft bulky dressing. An immediate postsurgical rigid dressing is never used despite its several advantages given by Wu & Krick (1992). Despite this fragile and painful stump, an early ambulation programme is started when the medical doctor agrees it. Cutson *et al.* (1994) among several authors noticed that an early co-ordinated post-amputation rehabilitation programme reduces the risk of complications such as thrombo-embolism, pneumonia and de - conditioning of elderly patients enhances remaining life. Wikoff (1994) laid stress on strengthening, endurance and range - of - motion exercises. They are of paramount importance for any new amputee. Declines in both strength and endurance are well known after - effects of bed - rest: immobility has been shown to cause strength reduction of 1 to 5 % per day, depending on the underlying pathology (Muller 1970, quoted by Wikoff 1994). Scremin *et al.* (1993) emphasised the effect of age on progression through temporary prostheses after trans-tibial amputation. Moreover, one of the factors influencing rehabilitation of arteriosclerotic lower limb amputees is an early gait programme as shown by Siriwardena & Bertrand (1991). This early ambulation is done by means of a special prosthesis called: an off-loading prosthesis with ischial bearing for transtibial amputees or a usual quadrilateral socket for transfemoral amputees (see description in II.3.1 and II.4.1). The use of these two prostheses does not affect the wound and the residual limb care which it is important as reported by Lachmann (1994).

11.II.7.1 GAIT TRAINING

It is well known all over the world that an early gait therapy programme is fundamental. Didier *et al.* (1982) and Bilisko (1986) in France, Cutson *et al.* (1994) and Wikof (1994) in United States, Engstrom and Van de Ven (1993 pp. 93-97) in Britain, all of these authors emphasised it and the effect of prosthetic rehabilitation in lower limb amputees was investigated by Christensen *et al.* (1995).

Our ancestors « homo erectus » had already well integrated, in their motor pattern, the interest of the standing up position for walking. As for the main aim in vascular disease as was seen previously, the essential is to trigger off a vasodilatation of the whole arterial tree of the two lower limbs by the intermediary of global muscular work, dynamic and intermittent.

11.II.7.1.1 In parallel bars

It is the first contact of the amputee with his new prosthetic reality. It is frequently at this stage that the patient takes mind of his irreversible handicap. The amputee is often adversely impressed by his first prosthesis that emphasised function rather than the aesthetic. Fauvet *et al.* (1985), Balmelle (1988) and Weil (1991) show how the mourning process of the lower limb loss by the patient must go through a succession of different stages. In this point of view, the first prosthetic contact is very important and all the rehabilitation team must be prepared to answer many questions from the patient.

The two main levels of amputation must be highlighted. The problems are not similar.

11.II.7.1.1.1 transtibial level with an off - loading ischial bearing prosthesis

At this stage, approximately 21 days from amputation surgery, the main difficulties are by decreasing order:

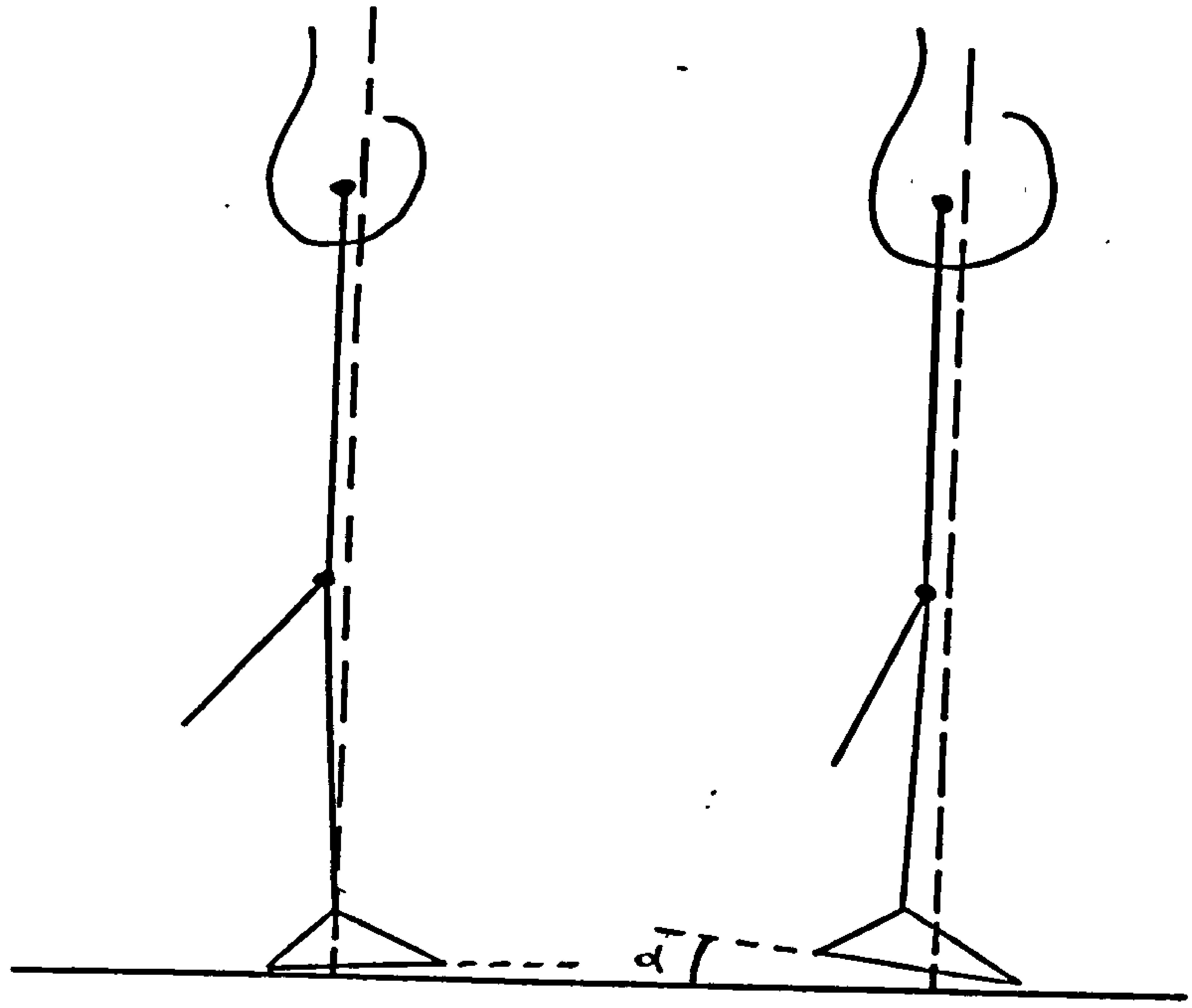


Figure II.81: There is too much dorsiflexion, the permanent bending has decreased

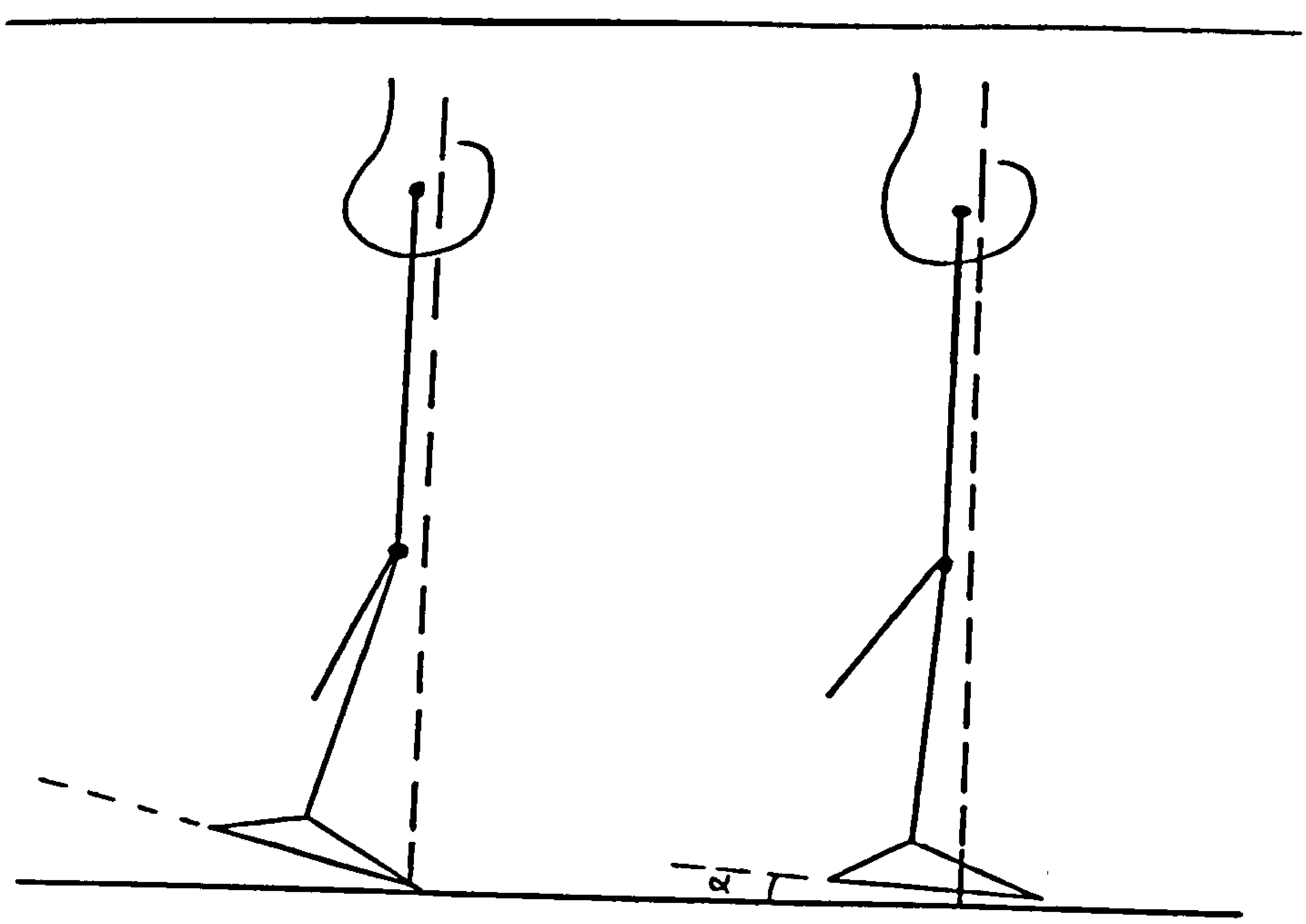


Figure II.82: There is too much plantarflexion, the permanent bending has increased

1. an incorrect general body position with often a shortcoming of the musculature of the trunk and abdomen (Barrault *et al.* 1989);

2. a maladjustment in the standing up position, to the standing balance and to efforts in general without enough power in the sound lower limb (Pinzur *et al.* 1991);

3. a difficult swing phase with the artificial limb: insufficiency of the abductor muscles of the opposite lower limb;

4. the weak strength of the upper limbs: patients lean on parallel bars with his whole forearm (Davidoff *et al.* 1992);

5. a sudden increase of the stump pain because of the swift standing up position with distal rush of blood;

6. discomfort at the ischial bearing area and at the anterio - medial part of the prosthetic brim because of the thinness of the skin at the limb's root or by the presence of ancient scars in front of the inguinal fold;

7. anxiety about efforts and mechanical stresses on the stump, even minimal as they are. The patient is afraid that they could compromise or delay the wound healing. This is particularly true if there is some blood going through the dressing.

One sees that difficulties are numerous, they are increased by:

- a general status of the patient markedly compromised with undernourishment. Pedersen & Pedersen (1992) noticed that normal wound healing depends on adequate nutritional intake and utilisation. Malnourished patients have an increased risk of postoperative cardiopulmonary and septic complications.
- a global muscular insufficiency of both opposite lower and upper limbs
- some pains raised by a precarious mental condition (Davis 1993)

All the patient's pains, although they are some times very severe, are not such as to require use spinal cord stimulation as described by Van Dongen & Liem (1995).

It is evident that this gloomy description is not inevitable. For all patients, a thorough assessment is essential before starting any early ambulation re-education programme.

Before the limb fitting, thanks to an analytic physiotherapy, the « struggle » against pain and the development of the muscular strength has already begun. The gait training must be included in this programme. According to the evaluation of each subject, the habit is to begin with short and simple standing up without any steps. After the prosthesis is put on, the patient needs some help from the physiotherapist to go from sitting position to standing. Once the adaptation to the vertical with a prosthesis loaded on the ground is obtained, it is possible to start walking for a few steps, without any correction of the gait pattern of the patient during this first stage. This is done to give him confidence. The therapist can help the subject manually to move forward the prosthesis during swing phase. Returning to the wheelchair requires an about - turn in bars or reverse walking, which is, paradoxically often easier. An about - turn needs balance and strength in the upper limbs.

Between each gait sequence, rest time has to be sufficient to regenerate the organism's food and force reserves. The duration of these rests varies not only according to the different patients but also for the same patient according to the hours of the day or days of the week. These moments of relaxation are put to benefit for a top quality level of dialogue between therapists and patients, to take the drama out of the handicap. This role of the therapist has the highest importance. The patient has to feel himself well in the physiotherapy-room. He will have to stay in it some long daily hours with pleasure and fruitful morally and physically. Much effort is devoted to elderly patients; they are forced to a discipline and constraint of which they have lost the habit. The communicative dynamism and the sense of contact of the physiotherapist with the patient are paramount for any re-education in the geriatric field. All these points were highlighted by Eghiayan (1993).

It is also necessary to encourage some talks between patients and to use each of them to stimulate other patients. A good dynamic behaviour in a physiotherapy-room is an invaluable advantage in a re-education hall full of elderly amputated patients.

As fast as the time passes, and, with patience, both of these notions are obvious and the recovery is visible. It is often made by steps, intersected by periods while the improvement seems null. These are phases of consolidations of the previous increase. The patient has to be warned and persuaded not to become discouraged and worried.

The progression is to increase the number of circuits and pull-backs in parallel bars at each sequence of walk and to enlarge their numbers, while decreasing the rest time. It is important to remember that it is more profitable for the arterial system to propose many short trials to the patient rather than a single longer one which would take him to the limit of performance and require for him to stop more quickly.

Throughout the recovery of the patient and before any bad habits are established, correction of gait patterns is begun.

The main problem at this stage is the absence of mid posterior stance phase of the amputated leg that it is necessary to correct. The leading causes are:

- the abuse of sitting position that leads to a reduced extensibility of the hip flexor muscles
- a hoary scar more or less able to be in tension due to the vascular surgery of the femoral artery and crossing over the hip flexion line, in front of the Scarpa's triangle.

It is therefore necessary to insist on a backward length equal to the opposite anterior stance phase:

1. at early stance phase, the contralateral foot has to come about thirty centimetres forwards of the peg - leg of the ischial bearing prosthesis.
2. at the end of the stance phase, the peg - leg must be placed at the level of the anterior tip of the contralateral foot as is shown in figure II.17.

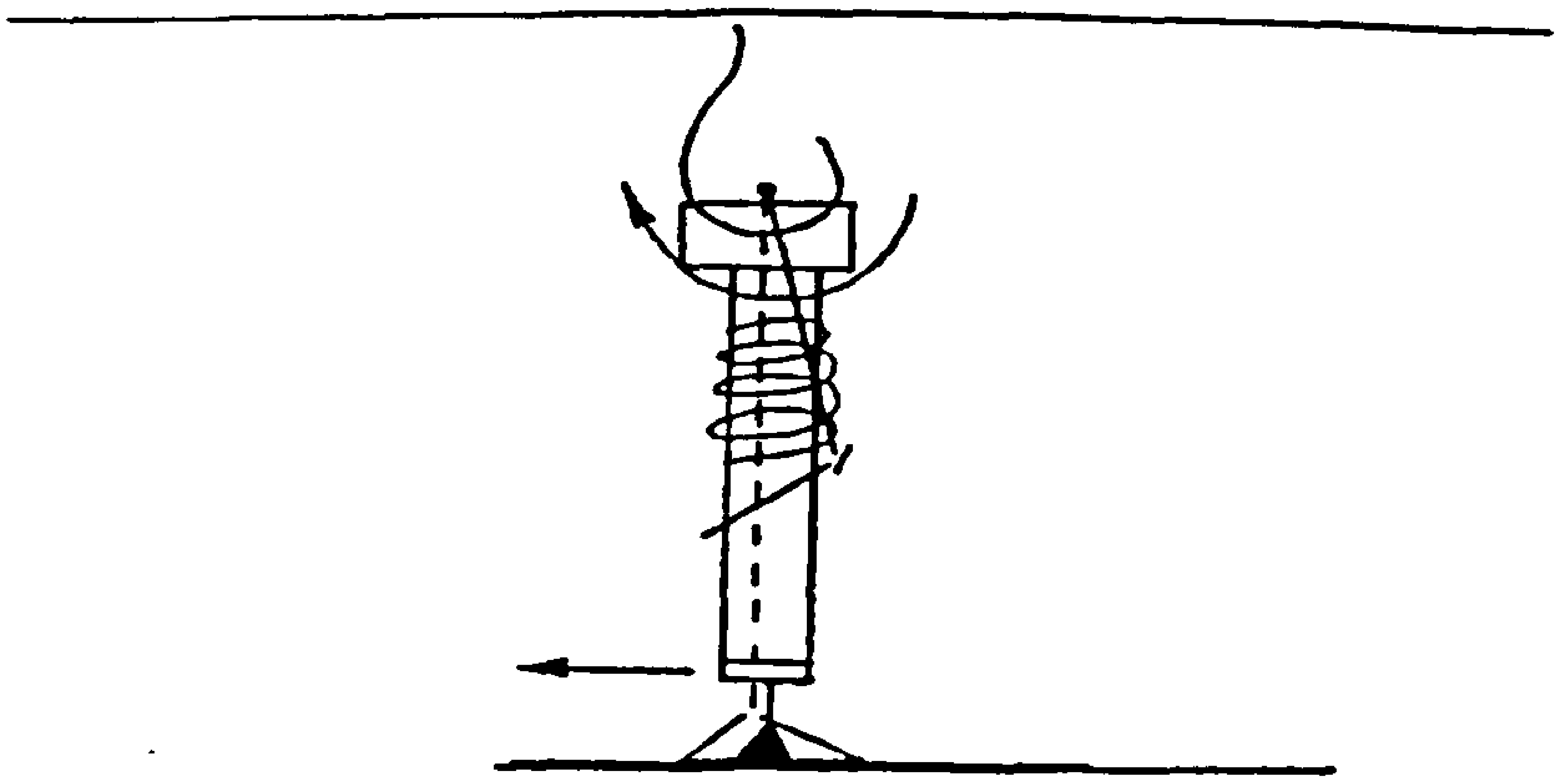
It is necessary to pay attention to the lack of full knee extension of the sound lower limb. It is the muscular insufficiency that is the cause. It is decreased by an appropriate exercise and by verbal correction of the gait pattern.

An other difficulty is the propensity of patients to pull symmetrically on parallel bars using the ischial bearing prosthesis which is rigid at the knee level, as a lever to pass his body over the vertical line at mid stance phase. The patient must put his hands flat or use rigid skates as shown in figure II.86.

Some amputees have a good cardiac - respiratory adaptability, no deficiency due to osteoarthritis and enough mental energy. They have the possibility to use a tread - mill. The ground unwinds under them so that the patients are forced to increase their posterior stance phase as shown in figure II.18.

11.II.7.1.1.2 transtibial level with a gypsum provisional prosthesis

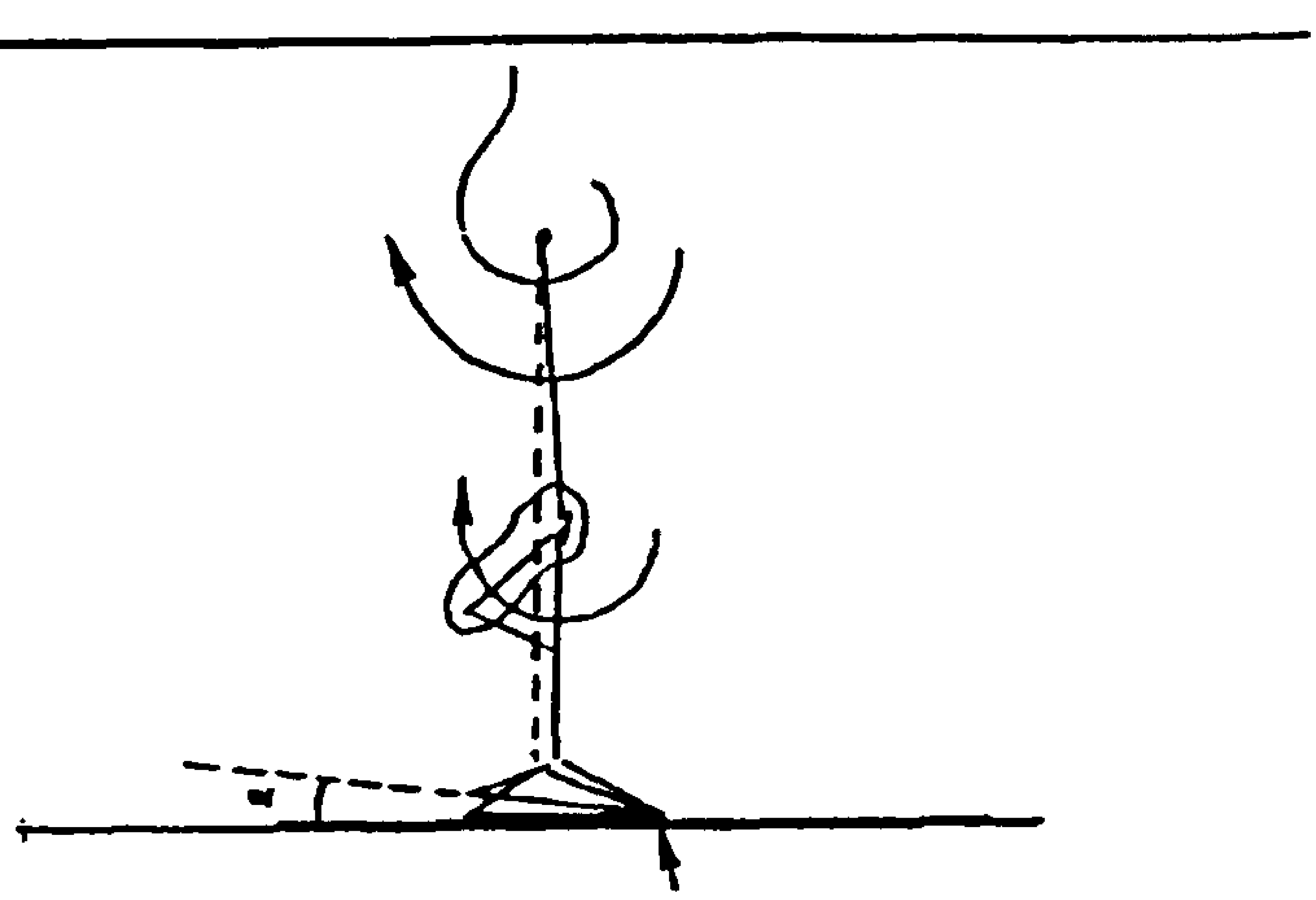
At each step of the prosthetic fitting, the patient is often disappointed. He always hopes, more or less consciously, that the « beautiful old days » before the amputation will come back again. The cosmesis of the prosthesis is often discussed. The patient has to understand that the function is always more important than the appearance.



Patient vu de profil
Appareil de décharge ischiatique

Port et utilisation quotidienne la plus longue possible
Pas postérieur ample

Figure II.84a: Fore - aft view
The patient is using an off - load ischial bearing prosthesis at the beginning of his rehabilitation : enough daily use and late stance phase as large and long as possible



Même patient quelques semaines plus tard
Prothèse de jambe à secteur

Port et utilisation quotidienne la plus longue possible
Appui vertical important
Attaque talon-sol franche
Pas postérieur ample

Figure II.84b: The same patient few weeks later, he is fitted with a sector prosthesis: sufficient daily use, unequivocal heel-on, late stance phase as large as possible

Equally, the problem of the weight of the prosthesis is evoked. Patients still have often, at this stage, insufficient strength. They think that the gypsum socket with its hydraulic device is far more heavy than the definitive socket made of acrylic resin. It is far from being the rule, the difference is minimal (see chapter II.3.2 about the description of prostheses). Even though the weight of both is less than that of the portion removed.

Nevertheless, it is true that the patient will not feel the same sensation of weight between the two prostheses, there are two main reasons for that:

1. the patient's general condition, his stump and his muscular strength have improved

2. the adaptation of the new soft socket, the loading and shock areas of the socket will be different

The physiotherapist has to explain thoroughly to the patient that the sensation of the weight of an object (whatever its bulk is) depends on the muscular strength (with an equal stump length) and on the quality of the interface between the residual limb and the soft socket (Pinzur *et al.* 1996). When the muscular strength increases, the actual feel of the prosthesis will be less and less heavy. The influence of lower - extremity muscle force on gait characteristics with transtibial amputations secondary to vascular disease was recognised by Powers *et al.* (1996).

At this stage, the main points are:

- becoming accustomed to the loads transmitted through the involved areas: patellar tendon, tibial plateau and popliteal recess. If necessary, the pain, always more or less present on these areas, favours the integration of loads in some automatic gait pattern of the patient as noticed by Sanders *et al.* (1993).
- patient in equilibrium on two scales situated under each foot
- sense of the vertical in front of a mirror with vertical reference lines
- to serve the patient's apprenticeship to the lateral gait if required and according to his possibilities, trained the patient to move laterally along the bar to optimise the loading. If necessary, the amputee can walk with a prosthesis provisionally over - loaded with a bag of sand fixed on the shank tube; the training of stump muscles and those of the knee and the hip is thereby increased. The effect of alterations in prosthetic shank mass on the ambulation of transfemoral amputees was quoted by Czerniecki *et al.* (1994)
- single support load bearing on the prosthesis during daily life is difficult (Pinzur *et al.* 1991). A perfectly distributed load on the two lower limbs is always avoided for multiple reasons such as pain, stump too short, misalignment of the prosthesis, previous and future gait patterns. The effect of some prosthetic feet on the gait and loading of the sound limb was emphasised by Snyder *et al.* (1995).

Since this load training is in the standing up static position, it is opposite to principle of the intermittent dynamic work (IDHW, see above section 3.3.1.5) but it is nevertheless unavoidable. Therefore, it must be done each day even a bit. The current pain that the patient has in the beginning of his rehabilitation induces a bad gait pattern with a tendency to become fixed. It is therefore necessary to be very vigilant from the beginning and not to hesitate to repeat assiduously the same advice to the patient.

- training of the quadriceps femoris of the amputated side: sometimes, the excessive stiffness of the prosthetic foot (see section II.3.3.4 for the description of the artificial foot used) requires from the patient an excessive consequential range of flexion of the knee at early stance phase. The prosthetist can correct that by making the posterior shock - absorber bumper of the monoaxial foot more flexible and / or by increasing the plantar flexion alignment at the artificial ankle level. The limit of these two possibilities, together, is rapidly found. The rehabilitation solution is to reinforce the strength of the quadriceps

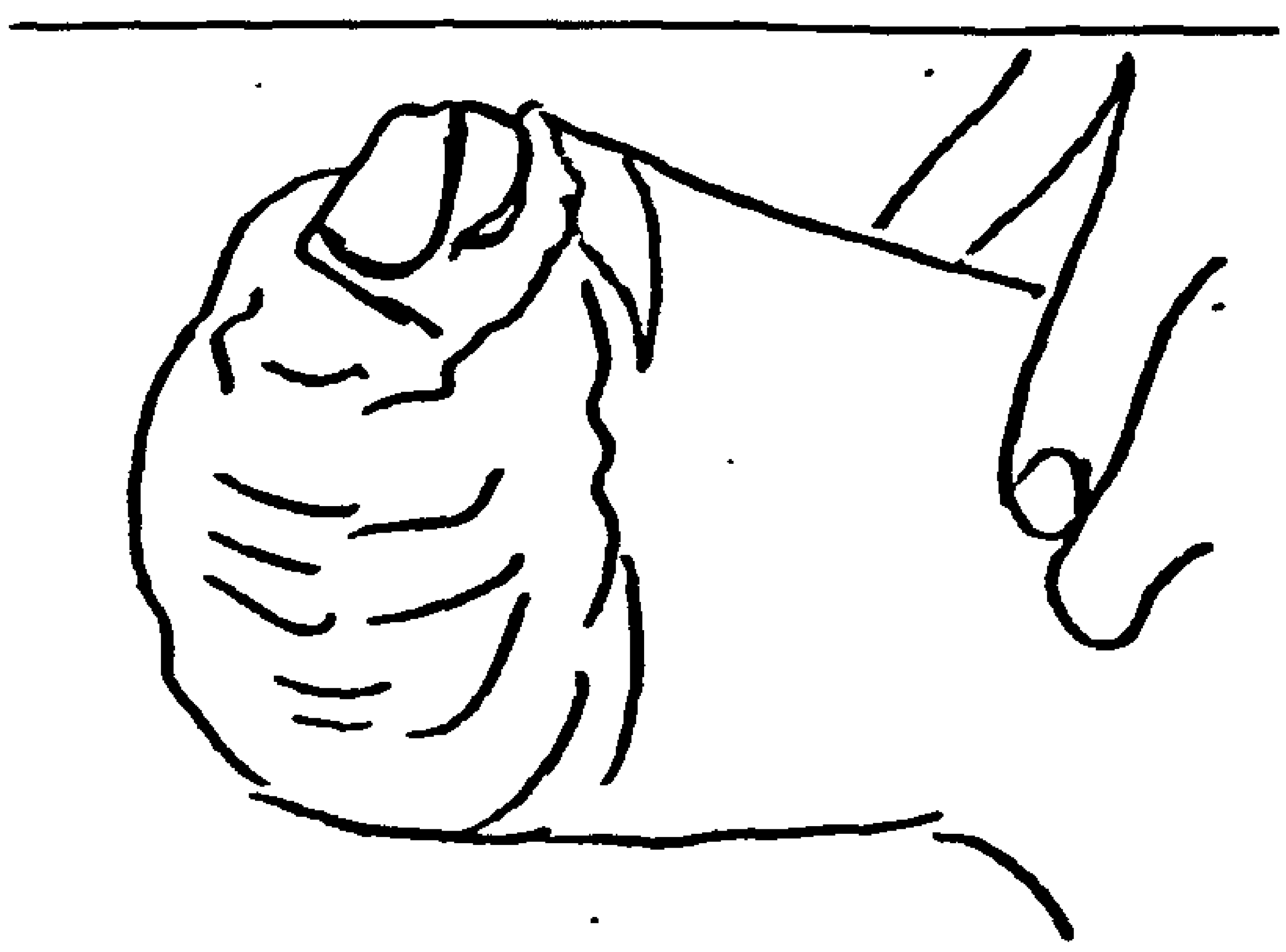


Figure II.85: A wounded stump of a transtibial amputee with an exposed tibia bone femoris and to automate the tensing of the knee extensors at the moment where the artificial foot is supported on the ground. The strength of the thigh muscles in below - knee amputees and its way of recovery were analysed by Isakov *et al.* (1996).

In other words, it is paramount to insist on the characteristic of the heel strike: the foot is not placed on the ground in a flat position, which would require early flexion of the knee. This is the remainder of the training of the quadriceps femoris.

- the existence of a good late stance phase with a full extension of the knee joint is controlled. The length of this late stance phase is checked so that the contralateral foot is in front of the prosthetic foot. Initially, all these corrections can be made with the assistance of the patient's view, but without any misusing of it, in case the bad habit to looking all the time at the ground becomes fixed.

It is necessary to have the patient in parallel bars for the minimum time because he would be secured too much. When the slightest equilibrium is obtained, one must pass to the next stage (see section II.6.1.2). The different patterns of recovery of equilibrium was thoroughly studied by Felez & Courtade (1996).

11.II.7.1.1.3 transfemoral level

As well as the problems common to all PVD amputees, the characteristics of the re-education at this level are dominated by the problem of the stability of the hip since the prosthesis has a big lever arm. A good position of the centre line of the prosthesis relative to the loading line and the centre of gravity of the patient is therefore mandatory. The learning of this placement and guidance of the prosthesis is often of long duration.

This training is difficult because of:

- the bad transmission of sensation between the ground and the patient himself through the conventional socket made of gypsum;

- the small discriminatory command of the muscles of the hip joint that, like all muscles of limb - root, are badly individualised in the brain with a poor nervous discrimination. All these problems were noticed by Eakin *et al.* (1992).

Transfemoral amputees require more hours of gait training to develop confidence than do transtibial amputees. Thus, the development of muscular strength, without the prosthesis in early rehabilitation, is of particular importance.

The main defect of patients is to place the prosthesis too far forwards from the line of gravity. The prosthesis, with its locked knee, pushes them backwards all the more so that their hip extensor muscles are not strong enough. To avoid this tendency to a posterior drop, the patient pulls on the parallel bars. One suspects that with such a balance, the next step outside parallel bars is impossible.

The patient must lay the heel of the prosthetic foot at the level of the anterior tip of the contralateral foot and use his hip extensor muscle in a concentric contraction. The effectiveness of these muscles, both in strength and endurance, is therefore essential. Concerning the contralateral foot, it must be placed in front of the prosthetic foot at the beginning of the following stride. All of these problems in gait rehabilitation of PVD amputees were outlined by Kotzki *et al.* (1994).

11.II.7.1.2 Using one stick and one bar

11.II.7.1.2.1 transtibial level

During this phase, the patient can still use an ischial bearing prosthesis or a distal prosthesis made of gypsum. It was seen above that the change from the first prosthesis to the

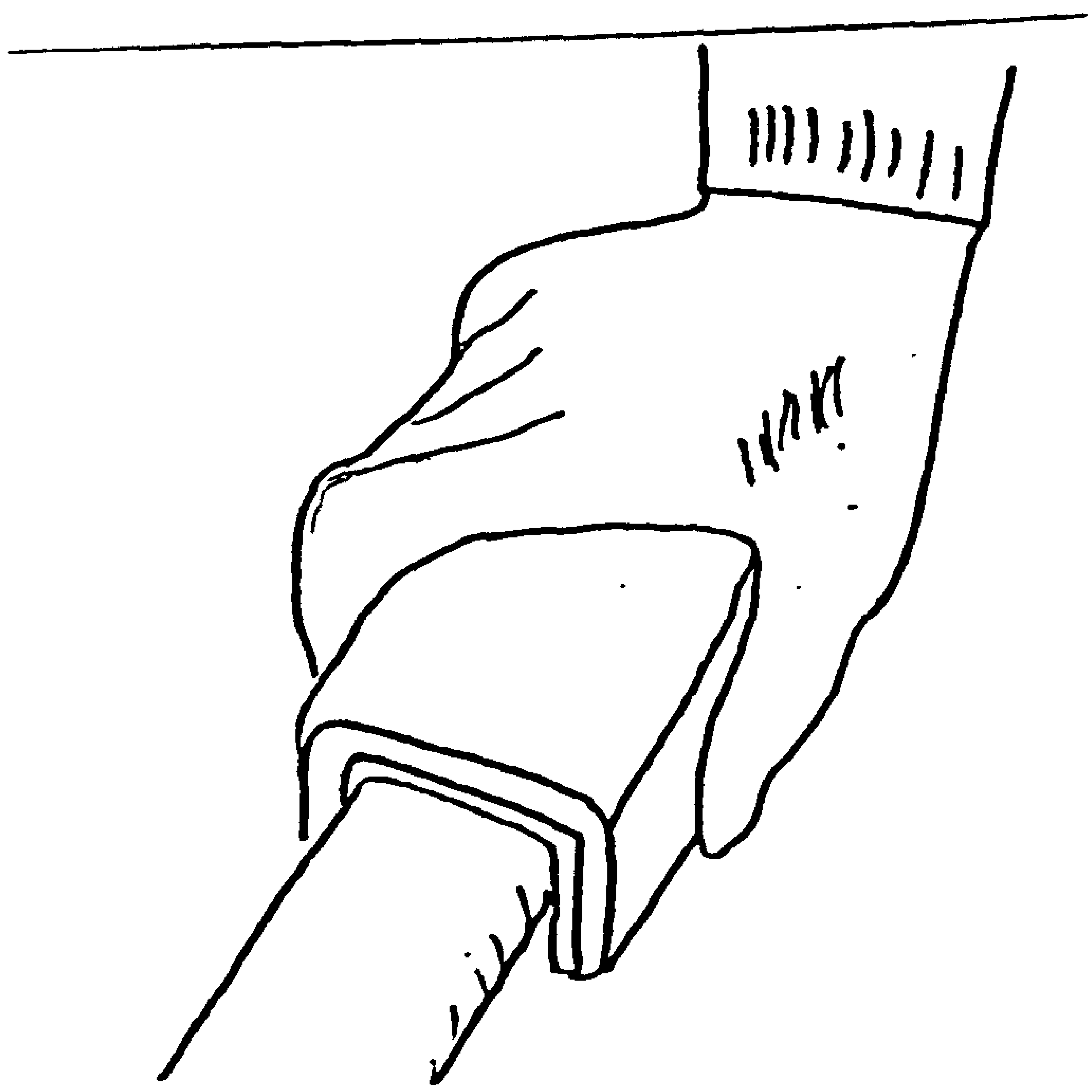


Figure II.86: The patient is using a rigid skate on the parallel bars avoiding pulling on it distal one is conditioned by the level of the wound healing and the condition of the stump rather than by the progression of the re-education.

The use of one stick - one bar is important to learn how to use a stick which is a inter-load lever. This way of using these walking assistive devices is completely described by Deathe *et al.* (1993). The most unskilful patients misuse the forearm counter - load and in this case the device loses all its benefit. This new phase signals equally an improvement in the use of the prosthesis by an increase of the transmitted load from the stump to the socket and from the ground to the stump through the socket.

To move from sitting to standing up position, the patient needs to use the armrest of his wheelchair to push on with the heel of his hand, while holding the handle of the stick. With the other hand, it holds the bar and it is unavoidable that the patient pulls it towards him. From this stage and to avoid this bad habit, although the wheelchair is placed beside the parallel bar, one can begin to train the patient to lift himself by using the two armrests as shown in figures II.88 to II.90.

The about - turn is made facing the bar to avoid any falls. According to which side the prosthesis, the parallel bar and the stick are, the patient feels one way easier than the other. When the bar, offering the maximum of stability, is on the opposite side of the prosthesis, walking is easier.

This stage might have a short duration and when the patient these trials easily, it is time to go to the next stage: two sticks, walking together with the physiotherapist.

11.II.7.1.2.2 transfemoral level

All the remarks made for transtibial amputees are relevant. The training begun in parallel bars is followed up. It is usually a good time to begin to learn how to move from sitting position to standing up with an above - knee prosthesis supplied with a locked knee (Didier *et al.* 1982).

When the patient lifts himself from the wheelchair, he stands up by pushing on one of the armrests while holding the rail. He holds his sticks in the end of the fingers. The knee is unlocked. When he has finished the stand up movement, he throws the prosthesis slightly forwards and puts the prosthetic foot as far forwards as possible. The patient has now to contract his hip extensor muscles to put the prosthetic knee in full extension to lock the knee axis. A characteristic noise is heard and signals to the amputee that his knee is locked and that it can start to walk. Because of the pattern in which the patient stood up, the artificial foot is forward relative to the contralateral foot. The first step is therefore always begun by the prosthetic foot. The initiation of gait was thoroughly studied by Nissan (1991) and Rossi *et al.* (1995).

To sit, the amputee must be placed with his back to the wheelchair and he has to feel the edge of the seat at the level of the popliteal recess of his non amputated leg. With the opposite hand on the rail, the patient unlocks the artificial knee, then catches the armrest of the wheelchair; he can finally securely sit down.

These sequences of movement are difficult to learn, to co-ordinate and to automate. Many above - knee amputees will never be able to do it. In this case, the prosthetic knee is locked and unlocked when sitting. The aesthetic level of the gait and the comfort of the use of the prosthesis decrease. It is particularly true when it is the moment to sit down: the lever arm has a tendency to separate the socket from the residual limb. Some times, the prosthesis, in full extension with its foot off loading, increases the stress on the knee lock so much, that unlocking is almost impossible.

11.II.7.1.3 Using two sticks

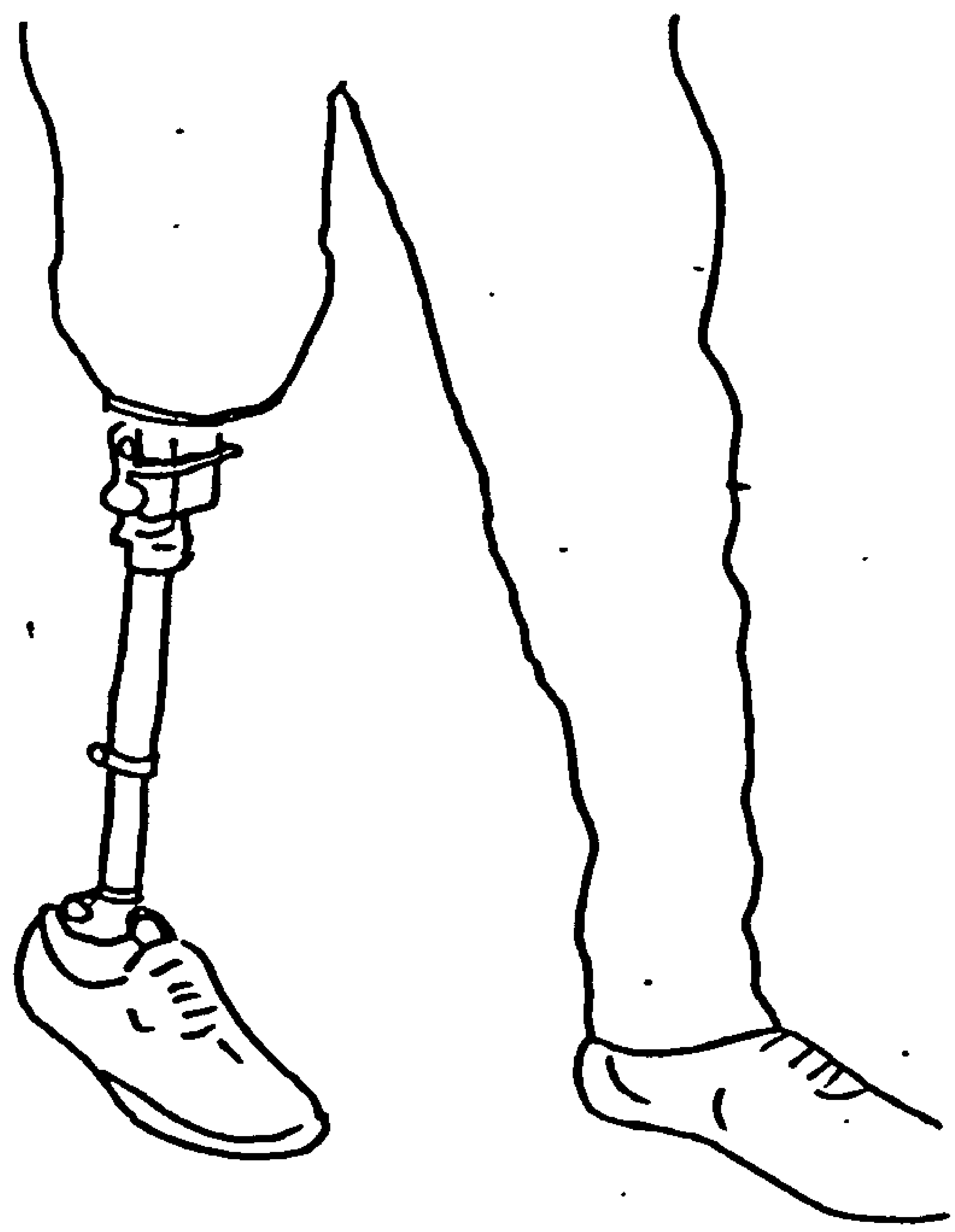


Figure II.87: The patient is training his hip extensors and fore-aft balance. The shank tube above the artificial ankle is only 25 mm as diameter; it is therefore not to be likely to use the removable Villiers Pylon Transducer, described in chapter 5.

11.II.7.1.3.1 common problems for all patients

This stage has to begin as quickly as possible. It is started when the physiotherapist estimates that his patient has increased sufficiently his muscle strength and his self-control not to be in a position of collapse. There are no accurate rules to determine this stage, it is essentially the physiotherapist's skill and knowledge. Both the patient and medical doctor have to give their advice.

In the beginning, to help the patient and to give him confidence, he must be controlled by the physiotherapist. To avoid emphasising his amputated natural asymmetry, the patient has to be held in the middle of his back, between the two scapulae. It is well known that any amputee must re - build his own bodily schema as noticed by Kotzki *et al.* (1996). For above - knee amputees, the shoulder - belt is handy. For below - knee amputees, the shirt, in the middle of the two scapulae, is used (Le Roux, 1986).

Later, the patient is simply accompanied by the physiotherapist who exerts an attentive look-out to avoid any risk of falls. This risk of falls must be the obsession of the therapist. The consequence of these falls on any patient could be dramatic in the loss of confidence in himself and in the physiotherapist (Raupp *et al.* 1991).

The physiotherapist corrects his patient to improve his safety gait pattern (Baker & Hewison, 1990; Lemaire *et al.* 1993). He must not force the patient to improve too much towards the aesthetic and/or the performance. This will increase gradually by training and:

- an economy in energy cost by decreasing all parasitic gestures;
- a lower level of pain that decreases the reflex contractures of defence;
- a decrease of fear;
- a more effective cardiac - breathing adaptation at any effort;
- a better extraction from blood red cells and local use of oxygen by muscles.

In early training, the gait pattern used is usually the Unilateral Pendular Strolling (UPS) described in chapter 3.7.2. Three events can be described:

1. The patient puts the two sticks ahead of him. During this shifting, he is loading his body weight on his two lower limbs. The vertical force on the stump can be minimised by increasing the load on the residual limb. At the end of this movement, the sticks are relatively forwards, the subject is loaded onto the sticks and the two lower limbs: four point loading; the safety is maximal;

2. The prosthesis moves forward to the level of the sticks. During this prosthetic swing phase, the safety must be always assured, so that the patient bears on his two sticks and on the residual limb: three point loading; the safety is still good;

3. The patient carries his sound limb forwards the prosthesis - sticks line. During this residual limb stance phase, the patient is loading on his two sticks and his prosthesis. The role of the contralateral limb in below - knee amputee gait was reported by Hurley *et al.* (1990). The vertical forces and pain should be minimised by a strong loading on the two walking assistive devices but the equilibrium is more precarious.

It is at this stage that the first test, recording the gait behaviour of the patient using a provisional prosthesis and two sticks by means of the equipment described in chapter 7, is usually conducted (except for transfemoral amputees for reasons given in section II.4.1.1.). A thorough discussion about these gait events will take place in chapter 8.

The timing of these three events shows that the duration while the prosthesis is in swing phase (event n°2) is the longest (Datta *et al.* 1996). The patient decreases the period of the load on the prosthesis systematically to avoid any pain and discomfort. Equalisation of the two swing phases is achieved little by little as pain and apprehension decrease.

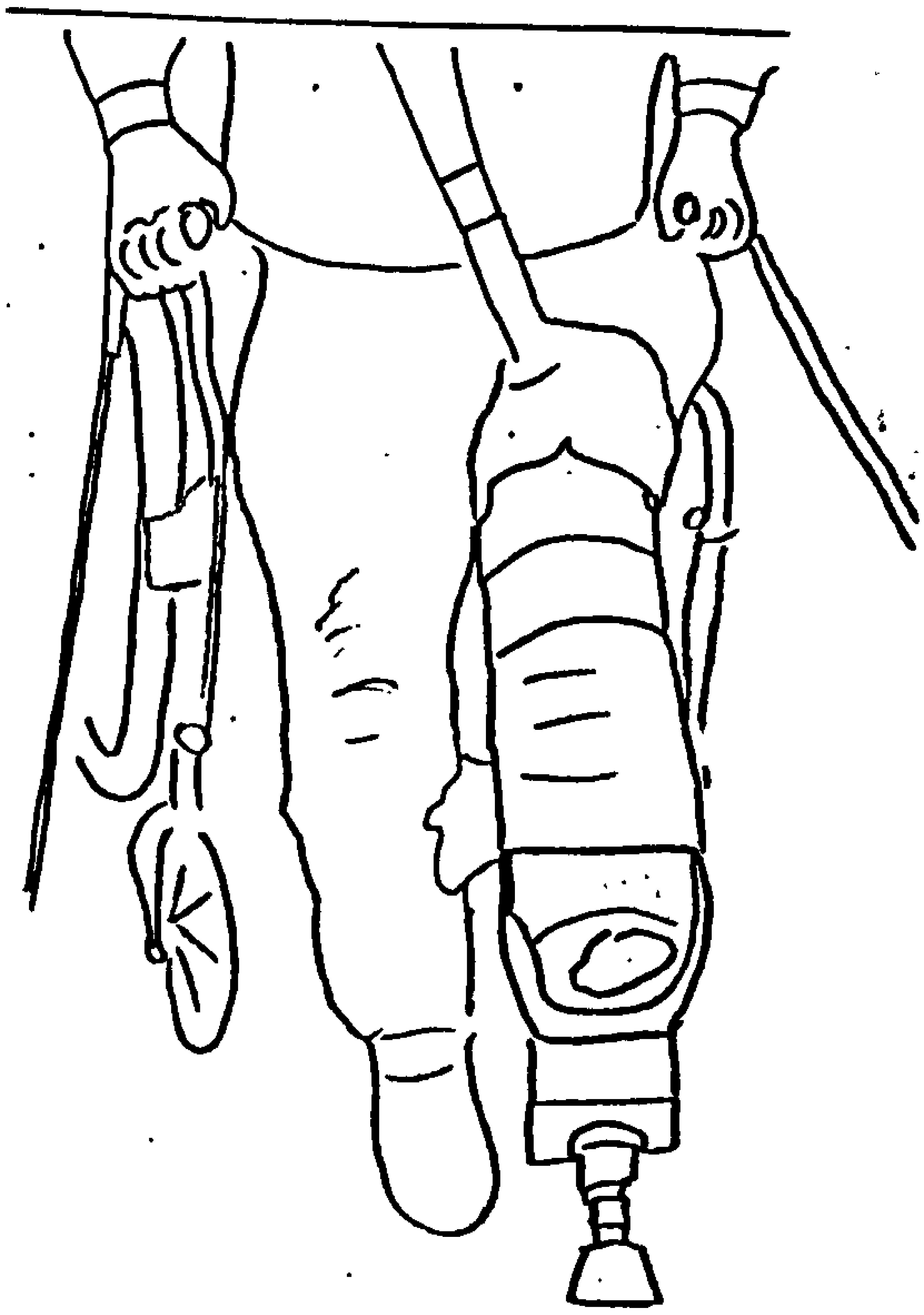


Figure II.88: This transtibial patient wears an ischial bearing prosthesis and to stand up, he must use the armrests of his wheelchair

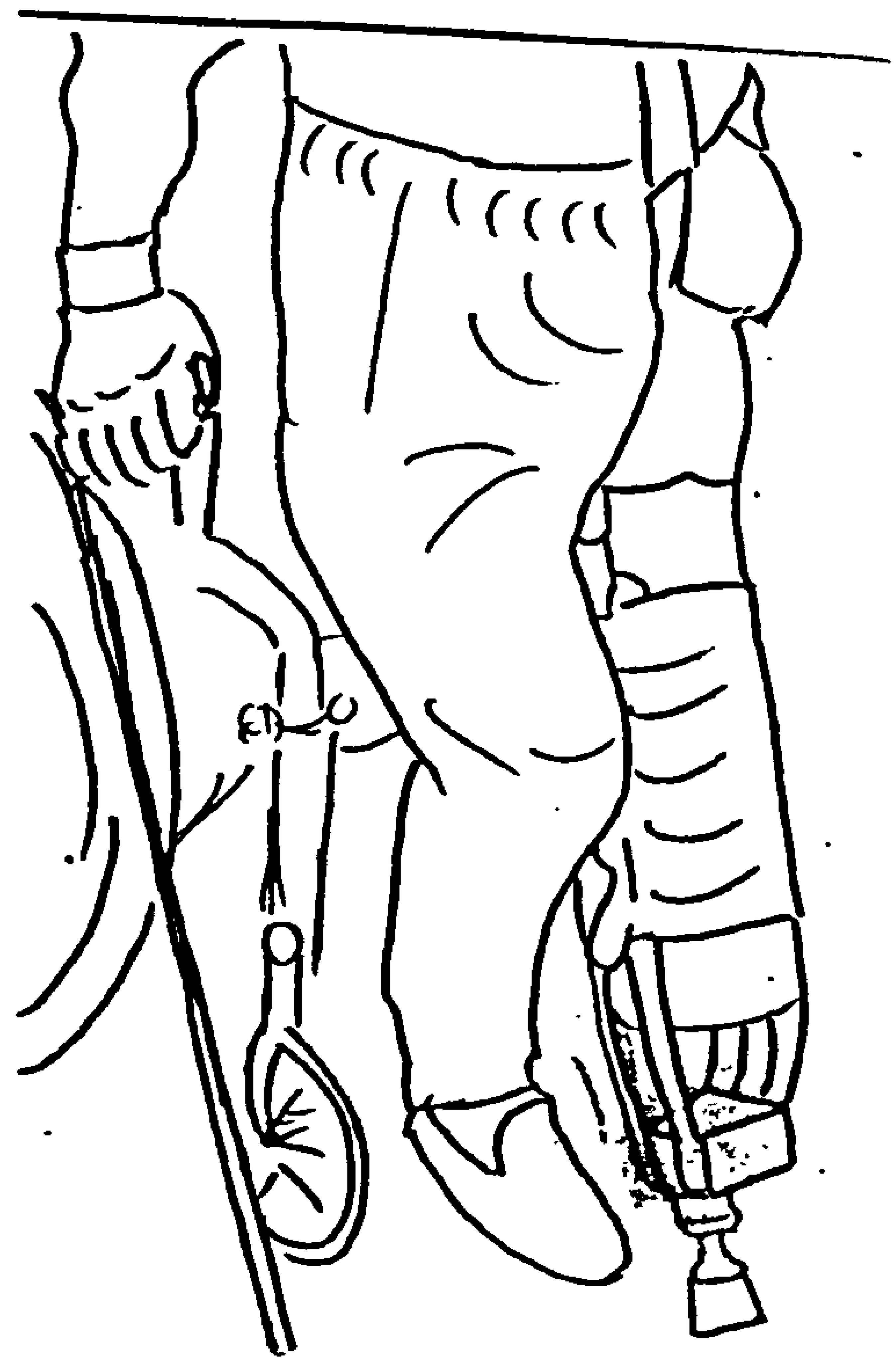


Figure II.89: The patient is pushing on the armrests

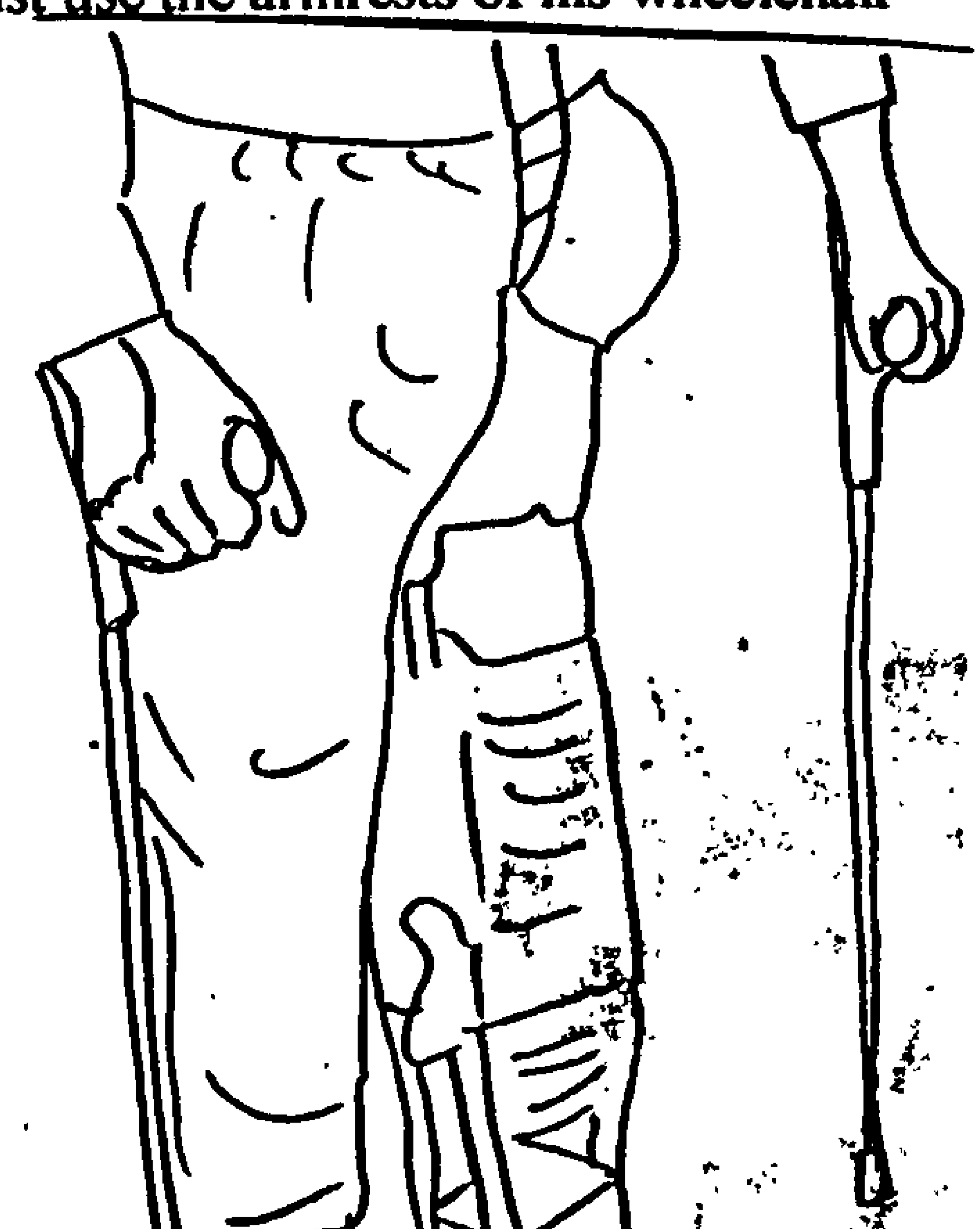


Figure II.90: The patient is standing and he has found his equilibrium. The prosthesis is ahead, the initiation of gait will start by the sound limb.

This training is longer if the stump is short, painful, with a fragile skin and / or if the patient is more elderly, here also the time factor is essential. This apprenticeship is not difficult nor very technical in the re-education field but it is paramount.

An easy walking pattern with two sticks is one of the criteria used by the rehabilitation staff for moving the patient towards a definitive prosthesis.

It is at this stage that the second test, recording the gait of the patient using a definitive acrylic resin socket and two canes by means of the equipment described in chapter 7, is commonly recorded.

The two other criteria are: the stabilisation of the volume of the stump and the degree of progress of wound healing.

11.II.7.1.3.2 transtibial level

The physiotherapist has to be attentive to two problems:

1. the patient must pass through the vertical line, between early and midstance phase of the residual limb, with his knee joint, on the amputated side, close to the maximum extension. The pain, due to loading, often makes this extension range of motion difficult to obtain. A wrong gait pattern can be established more or less rapidly;

2. the knee, on the opposite side, has to bend during the swing phase of the sound limb.

The patient forgets this often for two major reasons:

- the flexion of the knee, on the amputated side, entails a relaxation of muscles of the stump, which entails a decrease of the interface pressure between the stump and the soft - socket. The result is that the prosthesis slips downward a little and the patient is afraid to lose his prosthesis. This is one of the gait failures described by Paquin *et al.* (1996).

- if the patient has many gait trials, some times over several months, with an ischial bearing prosthesis, he develops the habit to unbend his knee while he walks.

Although, the walking pattern of transtibial amputees has a relatively low energy cost as shown by several researchers such as Didier & Casillas (1986), Gailey *et al.* (1994), Dulieu *et al.* (1994), Torburn *et al.* (1995) and Casillas *et al* (1994 and 1995). The effort that the subject has to provide for walking is compatible with the pathology. The characteristics, of the gait pattern obtained by some patients, are often excellent and this frequently allows the expectation that in later stages the subject's autonomy and outcome assessment will be satisfactory.

According to the personal feelings of the physiotherapist and the wishes and possibilities of the patient, the improvement achieves a stage in which the patient uses a stick and a cane. The stick is usually used on the opposite side from the prosthesis. For some other patients, the passing to the next level is direct: two canes.

11.II.7.1.4 Using two canes

The use of the two sticks is not an end in itself; it is necessary to think of giving the patient a free hand, otherwise there is a large handicap is to a comfortable daily life especially if the subject is living alone, as described by Kay (1991).

This target may be envisaged if some favourable conditions are achieved, which are frequently:

- a thin and small patient decreasing the height of the centre of gravity;
- a stump long enough to have a small flexion contracture;

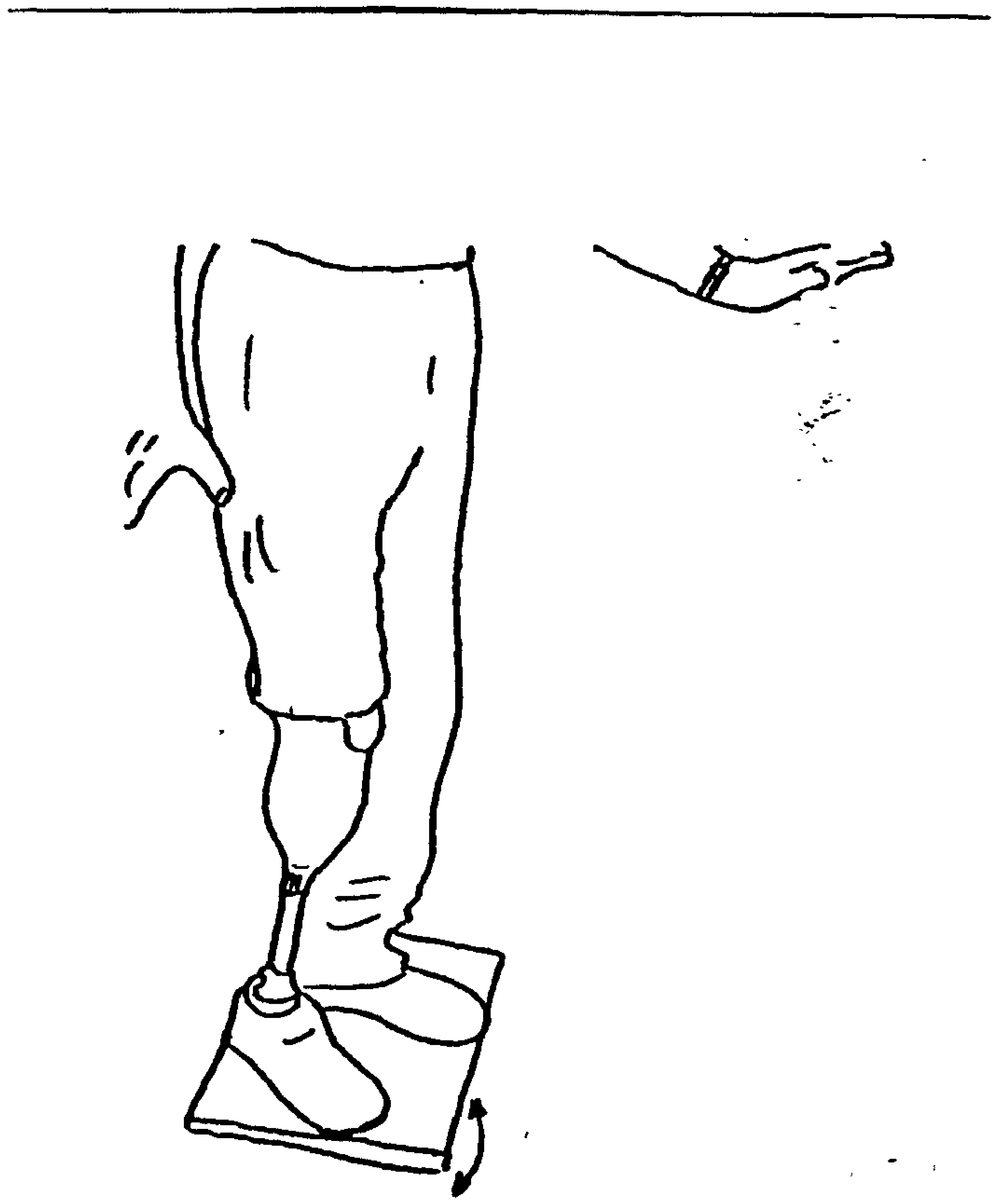


Figure II.91: Training of sagittal balance on an unstable surface

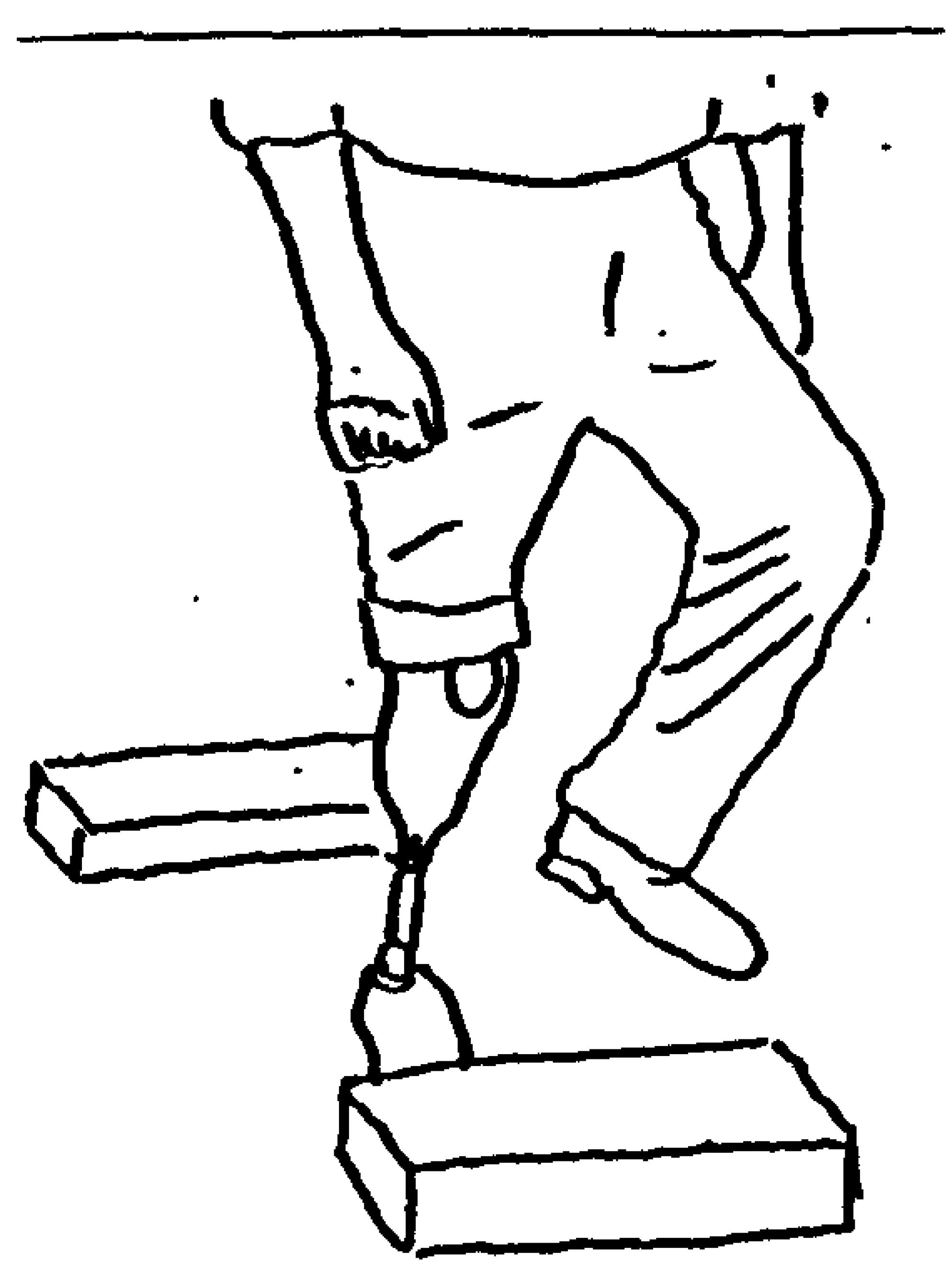


Figure II.92: A patient must learn to stride over some obstacles

- few pains;
- sufficient sense of equilibrium;
- normal brain capacity;

When these conditions are taken together, it is easy to obtain a gait pattern with two canes, then only one. This remaining walking device may even be abandoned at home, on a perfectly flat floor, as reported by Collin *et al.* (1992). All intermediate levels are of course possible as shown by Ham *et al.* (1994).

It is at this ultimate stage that the third test, recording the gait of the patient using his definitive prosthesis and just before his discharge from the Rehabilitation Centre, by means of the equipment described in chapter 7, is commonly undertaken.

11.II.7.1.5 Other technical assistance

The use of a walker or other articulated device must be envisaged only in the last resort:

- failure of walking with two sticks;
- major risk of falls when the patient is walking alone;
- stagnation in parallel bars walking with impossibility to go to the following level
- psychological problems with lack of vigilance
- bad neuro motor control

In all cases, the use of the walker has to be envisaged as a possible target towards the use of two sticks. The walker occupies both hands, making the use of any staircase impossible and the clumsiness of the device limits displacements at home if doors are width enough. A full and complete description of gait training of dysvascular amputees has been given by Charpentier *et al.* (1992) and Dechamps & Pillu (1994).

11.II.7.2 THE FINAL REHABILITATION OF PVD AMPUTEES

11.II.7.2.1 Endurance

It is not really a heavy effort training, illusory for this class of patients having this pathology but rather an education to the essential performance for daily life. Once the use of the prosthesis is perfectly acquired on any flat ground., an adapted improvement according to the requirement and possibility of the patient such as his age and his general condition must be expected. All these possibilities have been mentioned by Pillu *et al.* (1995).

For example (this list is not exhaustive):

- to sit down and get up from any seats, particularly from a chair without any armrests
- to learn to lift the body from the ground, to walk laterally, to trample, to pivot, to retreat. Upright, motionless, the patient has to make some gestures of large range of motion of the upper limbs to generate an unbalance with the aim to recovery balance as shown in figure II.91. The standing balance in transtibial amputees is fully described by Hermodsson *et al.* (1994a), while constrained standing was wholly studied by Zhang *et al.* (1991), but not for amputees. At the beginning, the patient tries to improve the standing sway, investigated by Isakov *et al.* (1992). Later, it is always possible to train the patient to work in a kitchen for cooking, to use a bath - room, to undertake gardening; all of these activities are very important as shown by Crispils *et al.* (1984).

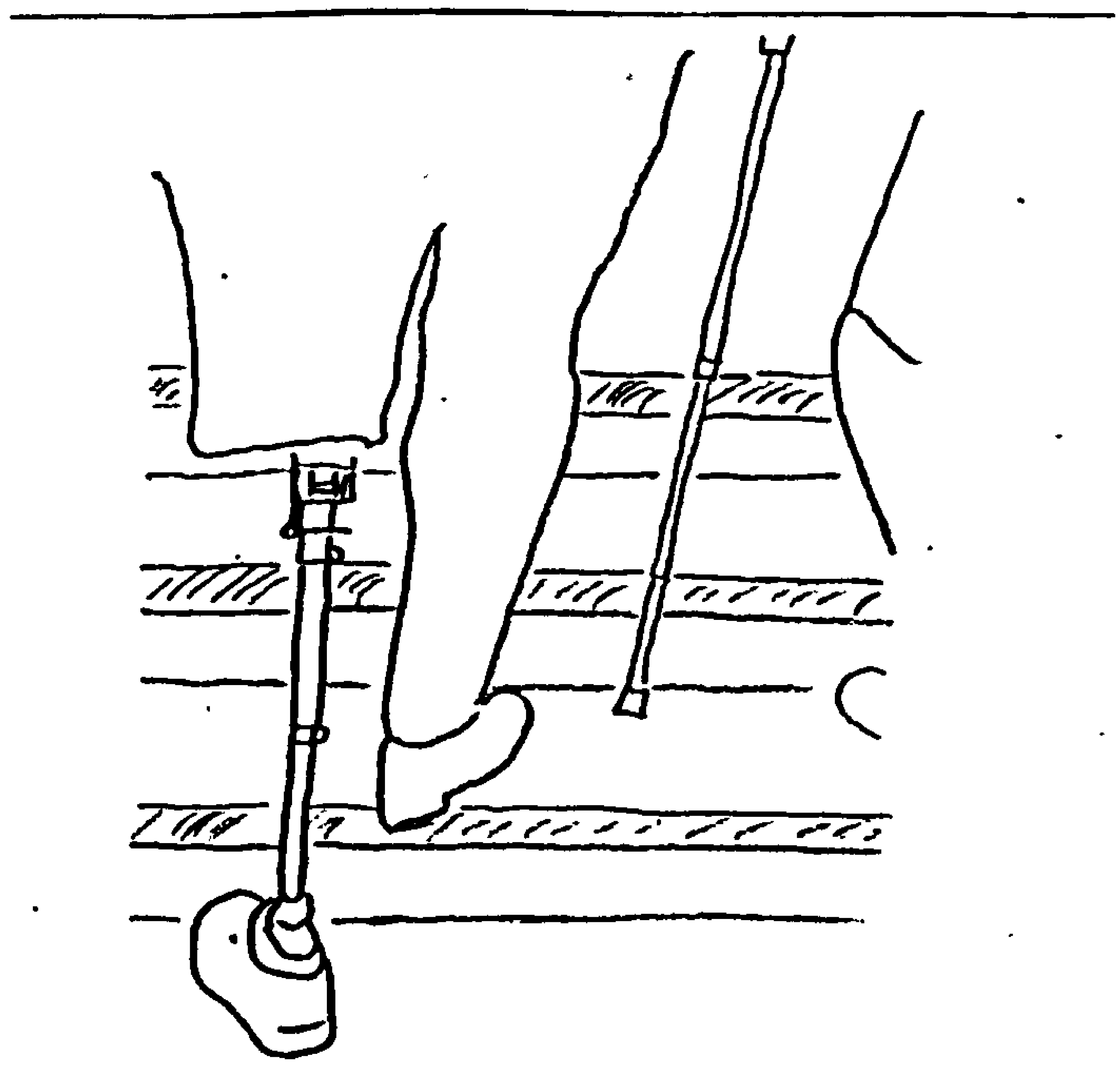


Figure II.93: Stair ascent with the sound limb ahead and the therapist behind

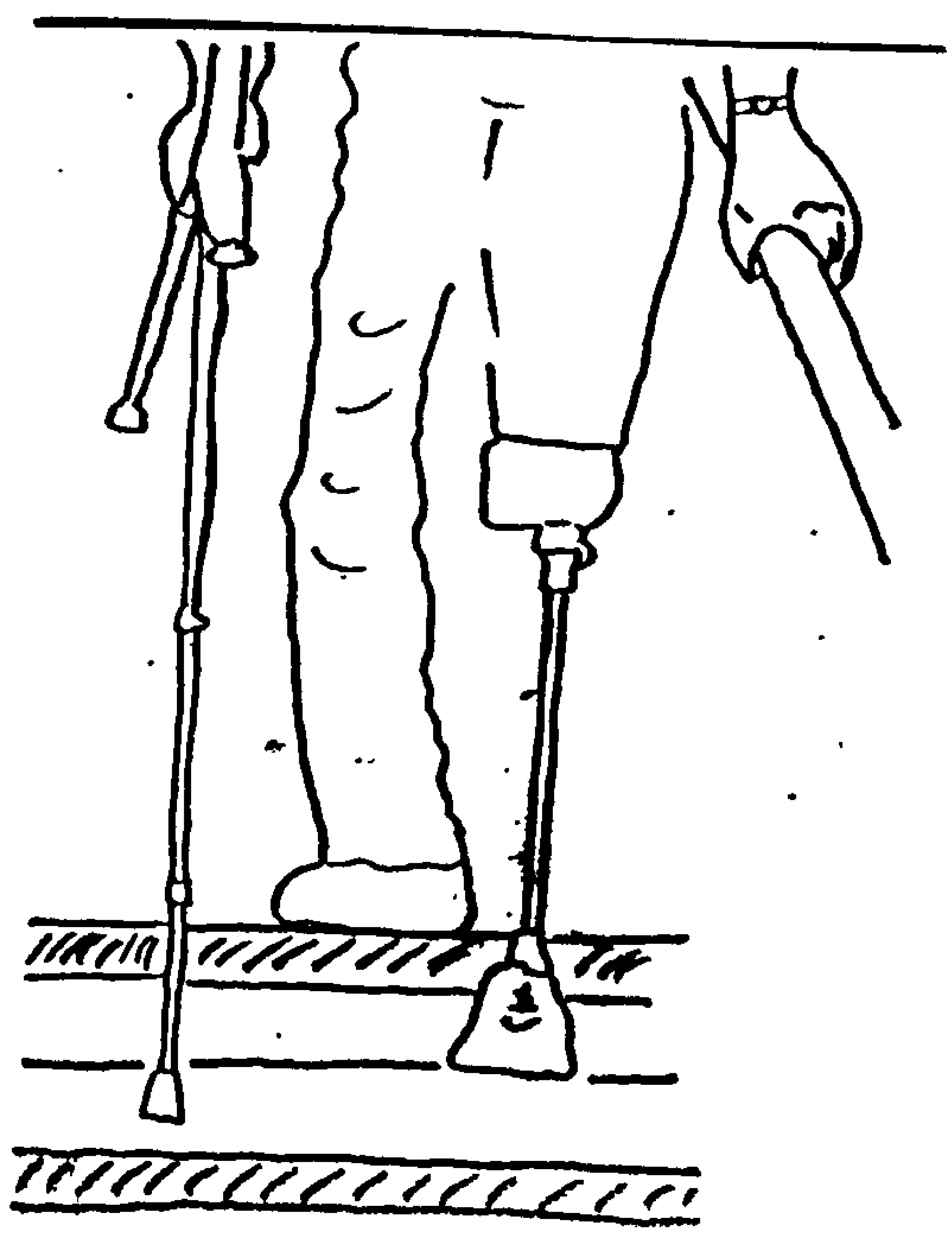


Figure II.94: Stair descent with the residual limb ahead. This transfemoral patient uses a banister and one stick. He carries his second stick in his right hand.

- to find out how to get up from the ground after any fall. This exercise is more or less easy according to the age and the fitness of the patient: upper limbs must be strong enough and the contralateral lower limb must have muscular and joint integrity. It is necessary that the patient stands up kneeling then in half kneeling then he holds on one of his walking assistive device and has to hoist himself using the device and his forward sound lower limb.

- how to avoid any obstacles. This exercise serves as a test before learning to negotiate staircases and the use of pavements as shown in figure II.92.

All these exercises have the common goal of increasing the load bearing transmitted on the stump through the prosthesis. All these loads have to be integrated by the patient so that the pain which might be increased is accepted.

11.II.7.2.2 Staircase

Most often, the ascent and the descent of any staircases is made step by step with one stick and a banister. There are usually no particular problems. The patient must be trained to grasp the unused stick with the fingers, externally to the other cane. The descent, although it is more impressive, imposes fewer efforts. The ascent is made with the sound lower limb forwards to lift the patient over and the stick backwards to protect any possible forward falls. The physiotherapist is behind his patient as shown in figure II.93. The descent is done with the residual lower limb forwards while braking on the contralateral lower limb, the stick must be in front of the patient to protect him at the maximum. The physiotherapist is forward and beside the patient, to safeguard him while leaving the patient to familiarise himself with the void ahead of him as shown in figure II.94. A full description of the stair ambulation for transtibial amputees, wearing a specific artificial foot, was given by Powers *et al.* (1997).

Patients use the banister a lot and avoiding its use is often difficult. According to the capability of each patient and their home conditions, this improvement is nevertheless is paramount, and a pavement is only a stair step without any banister. All these exercises were taught as Gait and Activities Training in the post - graduate Medical School of the University of New - York (1968).

11.II.7.2.3 Tread - mill

The role of the tread - mill in the recovery of hip extension and knee bending has been mentioned. It is also used to increase the endurance of the patients. They are two adjustments: the speed and the slope. Thus, the patient can be a personal goal (figure II.95). The use of an instrumented treadmill allowed Dingwell *et al.* (1996) to study real-time gait symmetry evaluation and feedback in both normal and transtibial amputee subjects.

Diabetic patients should be closely observed if a supplementary unusual effort is requested of them since they can be put suddenly into hypoglycaemia (colourless, sweating).

11.II.7.2.4 Bicycle

The re-education bike is a tool not to be neglected. The therapist must never forget to be sure that there is no functional by-pass crossing both the knee and the hip. There could be too much bending by the knee and hip flexion on the bike. The height of saddle must be carefully set, a transtibial amputee cannot bend his knee beyond an average of 90 or 100° because of the popliteal recess counter - load. The saddle is therefore raised to the maximum. According to his goal, the patient pedals with his two lower limbs or only with the one of the prosthetic side. In the first case, it is the sound lower limb that makes the motion. The knee of the amputated side, moves passively so that the habit of rhythmic movement in the assemblage knee - stump - soft socket - prosthesis is trained. In the second case, which is more aggressive for the stump, the muscles of the residual knee move the prosthesis and

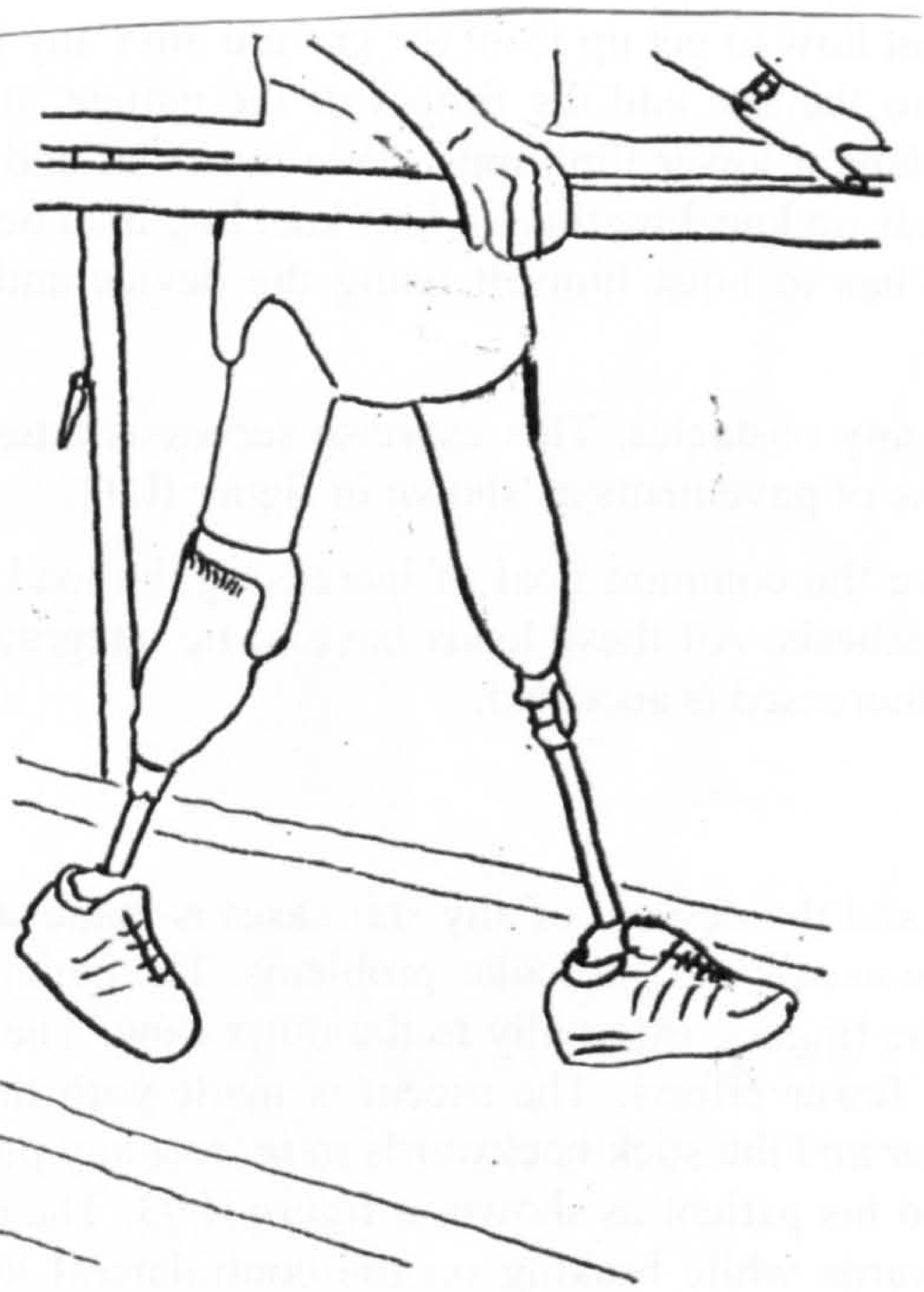


Figure II.95: A bilateral BK and AK amputee can use a treadmill

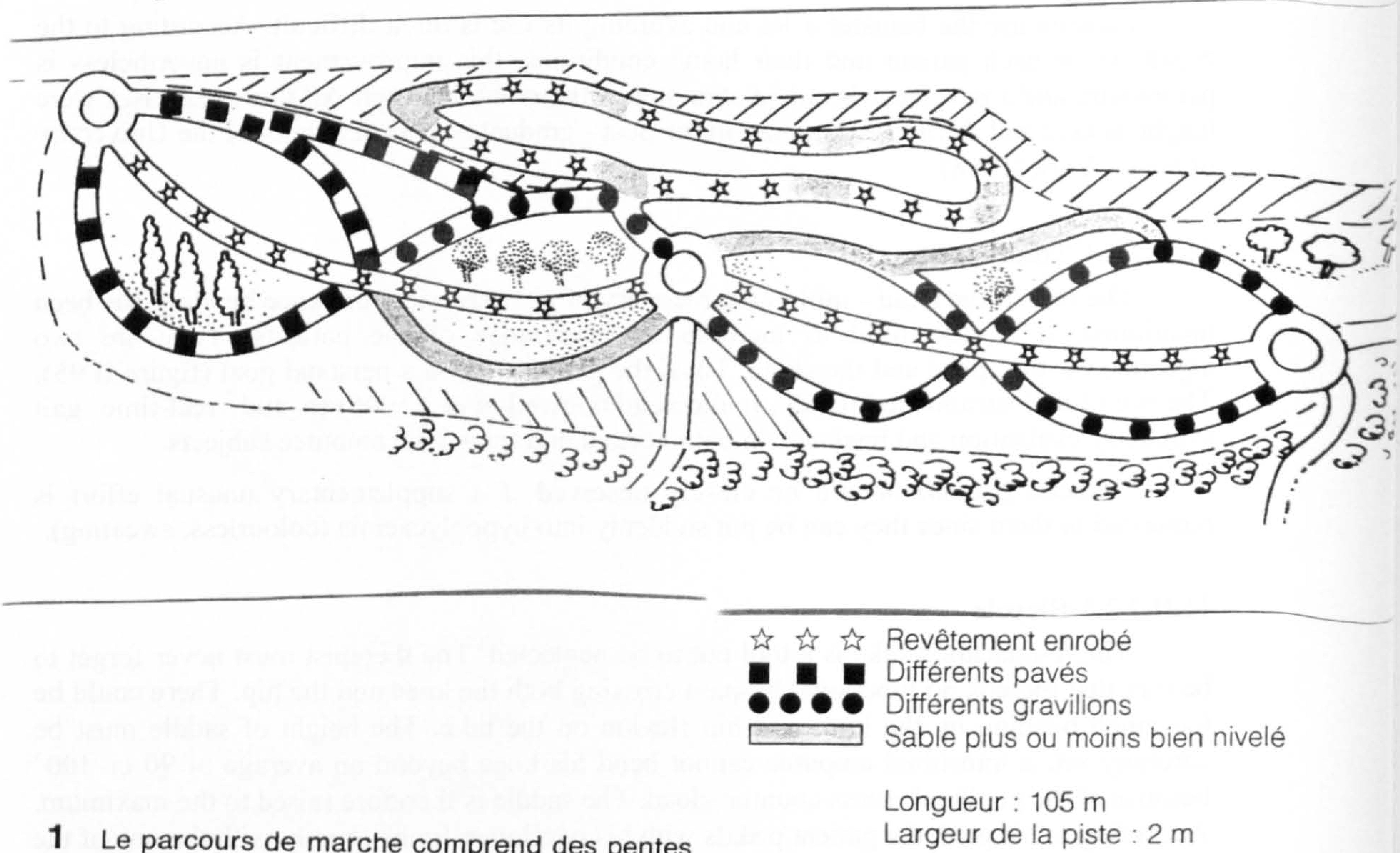


Figure II.96: Scale of the open-air gait training area in Villiers Saint Denis Rehabilitation Centre make the motion of pedalling. Frictions and stresses at the stump soft - socket interface are finally increased which could be efficient to improve the hardness of the residual limb skin. As for tread - mill, a watchful check should be observed, especially for diabetic patients.

11.II.7.2.5 Outside gait training

Outside gait training is mandatory. A special gait training unit in open - air, Pillu *et al.* (1995) indicates the possibilities: control of descent or ascent of slopes and different qualities of ground such as tarmac, sand, pebbles and stones as shown in figure II.96.

The rhythm of gait must be upset. Special attention is equally compulsory to adopt sufficient rest times, but most of the vascular elderly amputees are not able to have such a complete rehabilitation. The assessment of the gait training is not easy to undertake, this is why many physiotherapists or medical doctors have proposed their own solution starting from Day (1981), Khoury (1983), O'Toole *et al.* (1985), to Bardot *et al.* (1992). The results of the rehabilitation of such PVD elderly amputees was studied by many researchers, such as Joublin & Joublin (1986) in France, Pinzur *et al.* (1993) in America or Condie *et al.* (1996) in Scotland.

11.II.8 Conclusion

The usual process of gait evaluation tests made on one patient is as follows:

1. <u>for transtibial amputees:</u>

- 1st test: at the beginning of the gait training, when the patient starts to use two sticks outside the parallel bars with a provisional prosthesis with a socket made of gypsum
- 2nd test: when the patient initiates his gait training wearing his first definitive prosthesis with the socket made in acrylic resin
- 3rd test: when the patient is close to his discharge from the Centre, just before the cosmesis of his artificial limb is made

2. <u>for transfemoral amputees:</u>

- 1st test: when the patient is wearing his first definitive prosthesis with the socket made in acrylic resin and starts his gait training with it
- 2nd test: when the patient is close to his discharge from the Centre, just before the cosmesis of his artificial limb is made

In the above sections, it has been also possible to bring to the fore the three main problems it was necessary to face:

1. the shank tube of definitive transtibial prostheses is strongly and definitively attached to the socket; so that, as was said in chapter 2, a removable transducer was necessary.

2. all patients have a precarious gait pattern; so that all of them use at least one walking assistive device, such as sticks or canes. This is why the use of instrumented sticks was compulsory.

3. because of administrative and financial pressure, the hospitalisation period of all patients is increasingly short. Most of the patients have fragile health. This is why the common procedures for testing patients were not fully observed in all cases.

11.III DESCRIPTION OF THE FIRST DATA ACQUISITION SYSTEM AND RESULTS OF THE CALIBRATION OF THE FIRST REMOVABLE ANKLE TRANSDUCER (MODEL I):

11.III.1 The characteristics of the amplifiers

The following table III.1 and figures III.1, III.2 show the technical characteristics of the amplifier used for the calibration of the first ankle transducer described in chapter 5. There were eight identical amplifiers but only five of them were used:

Channel 1	External Axis Gauges
Channel 2	Internal Axis Gauges
Channel 3	Spindle Gauges
Channel 4	Front Gauges
Channel 5	Back Gauges

The bridge voltages could be ± 5 V. The followed choice was 3 V for all bridges.

The gain could be adjusted from 100 to 500. During the calibration tests undertaken with the first ankle transducer, all the bridges had a gain of 500.

The offset and balance of the bridges could be adjusted by soldering the appropriate resistors between red and green or red and white spikes: a resistor of 100 kΩ changed the offset of 3 V.

This set of amplifiers was also used as a part of the first data acquisition system (see chapter 5) when the shape of the definitive Villiers Pylon Transducer has been discussed (see chapter 4). These amplifiers were also used to perform the first part of the calibration of the definitive new Villiers Pylon Transducer (see chapter 6).

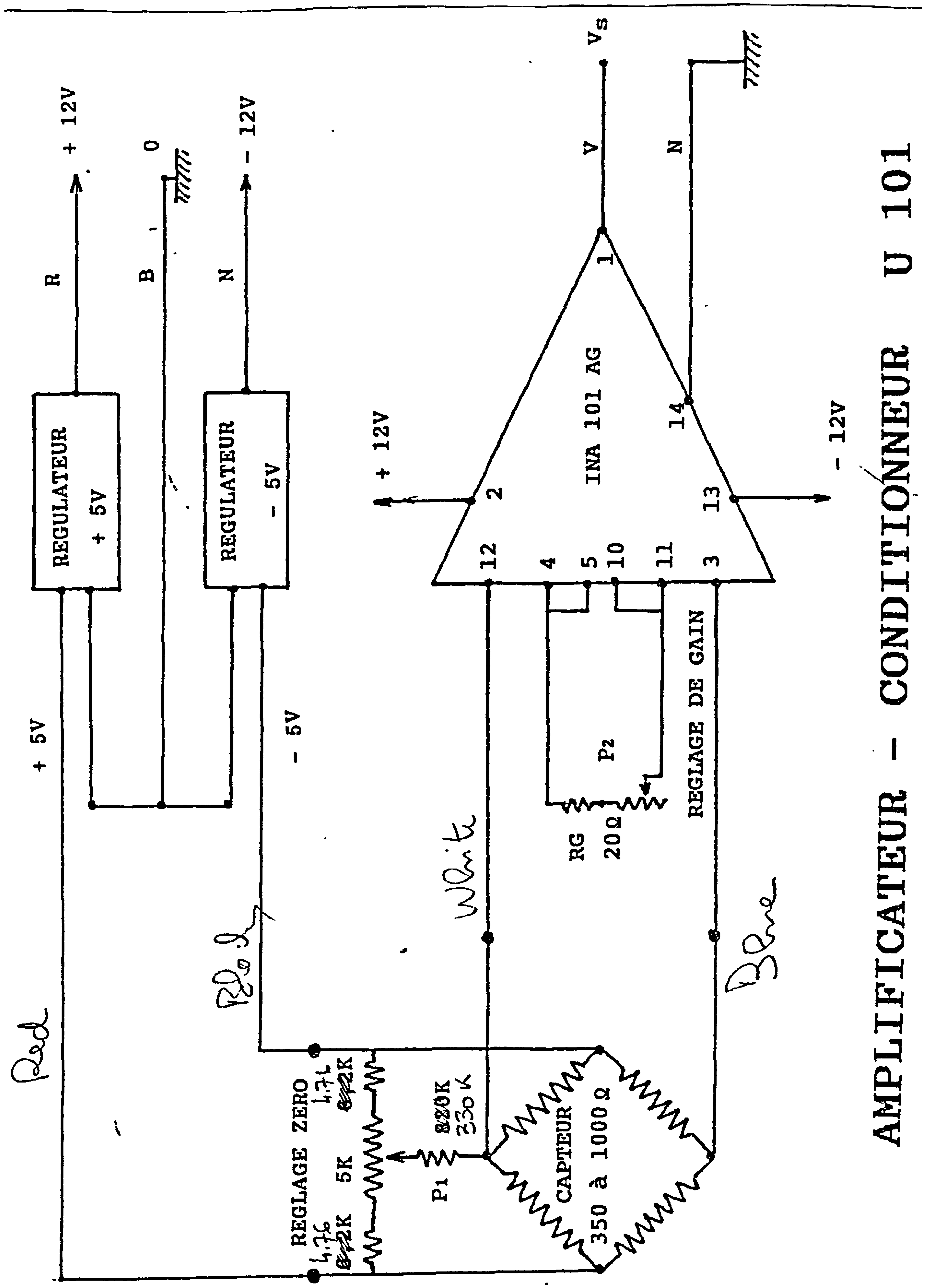
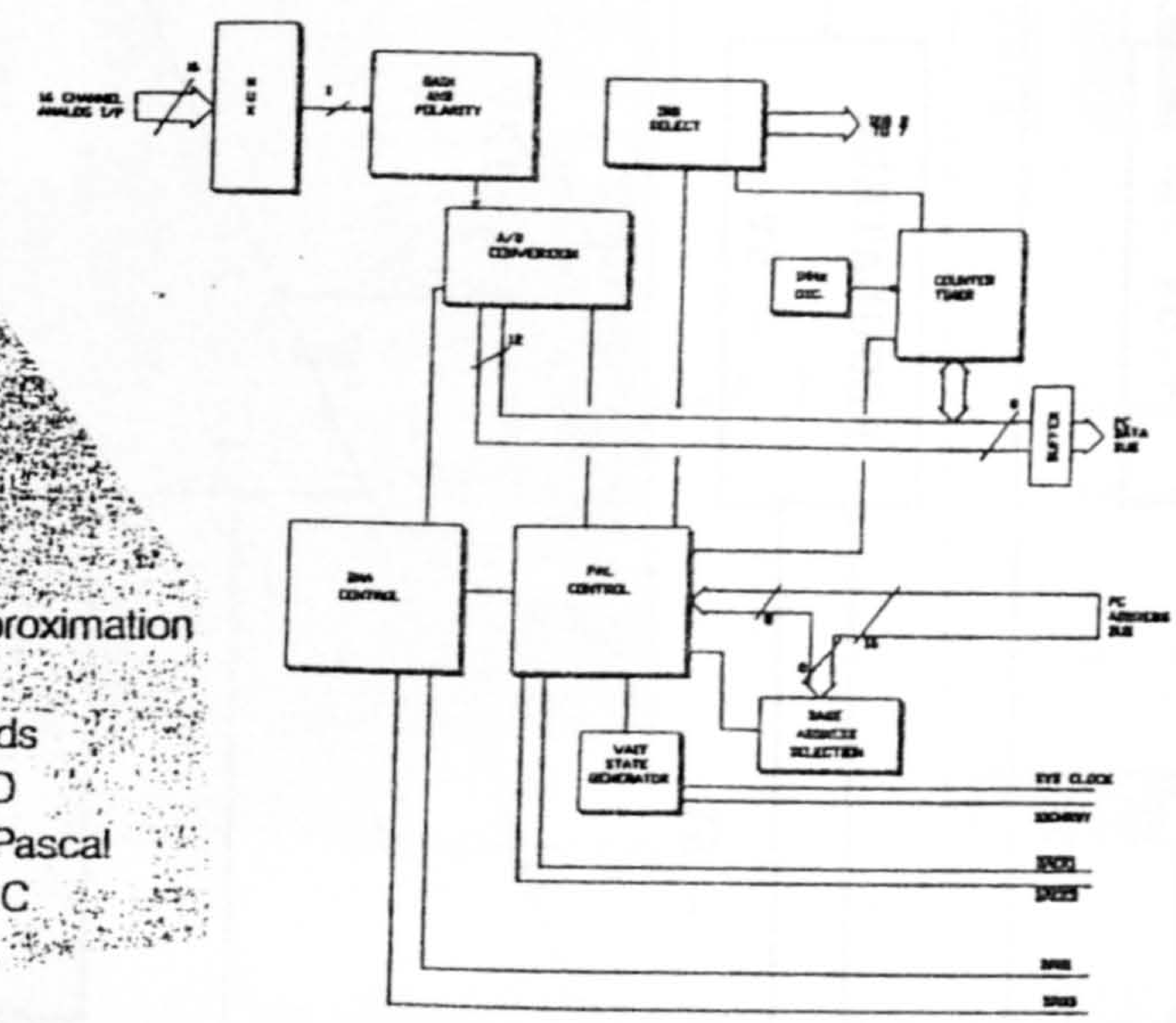


Figure III.2: The block diagram of the amplifier used in the first data acquisition system.

A/D DMA

PC 26AT BLOCK DIAGRAM



PC 26AT SPECIFICATION

ANALOG TO DIGITAL

Input channels	16
Input voltage range	0 to 3V 0 to 4V 0 to 10V ±1.5V, ±2V ±5V, ±10V
Input inpedance	100kΩ
Conversion type	Successive approximation
Resolution	12 bit
Conversion time	10 micro seconds
Sampling rates	Programmed I/O
(typical single channel	30 kHz – Turbo Pascal
for an 'AT' computer)	40kHz – Q BASIC
	90kHz – DMA

ON BOARD OSCILLATOR

Output frequency	1 MHz
Stability	± 50ppm

GENERAL

Size	98 x 203mm
Power requirements	± 12V 25mA +5V 400mA
Operating temperature	0°C to 50°C
Storage temperature	–20°C to 70°C
Humidity	5 to 90% RH

PC 26AT PIN CONNECTIONS

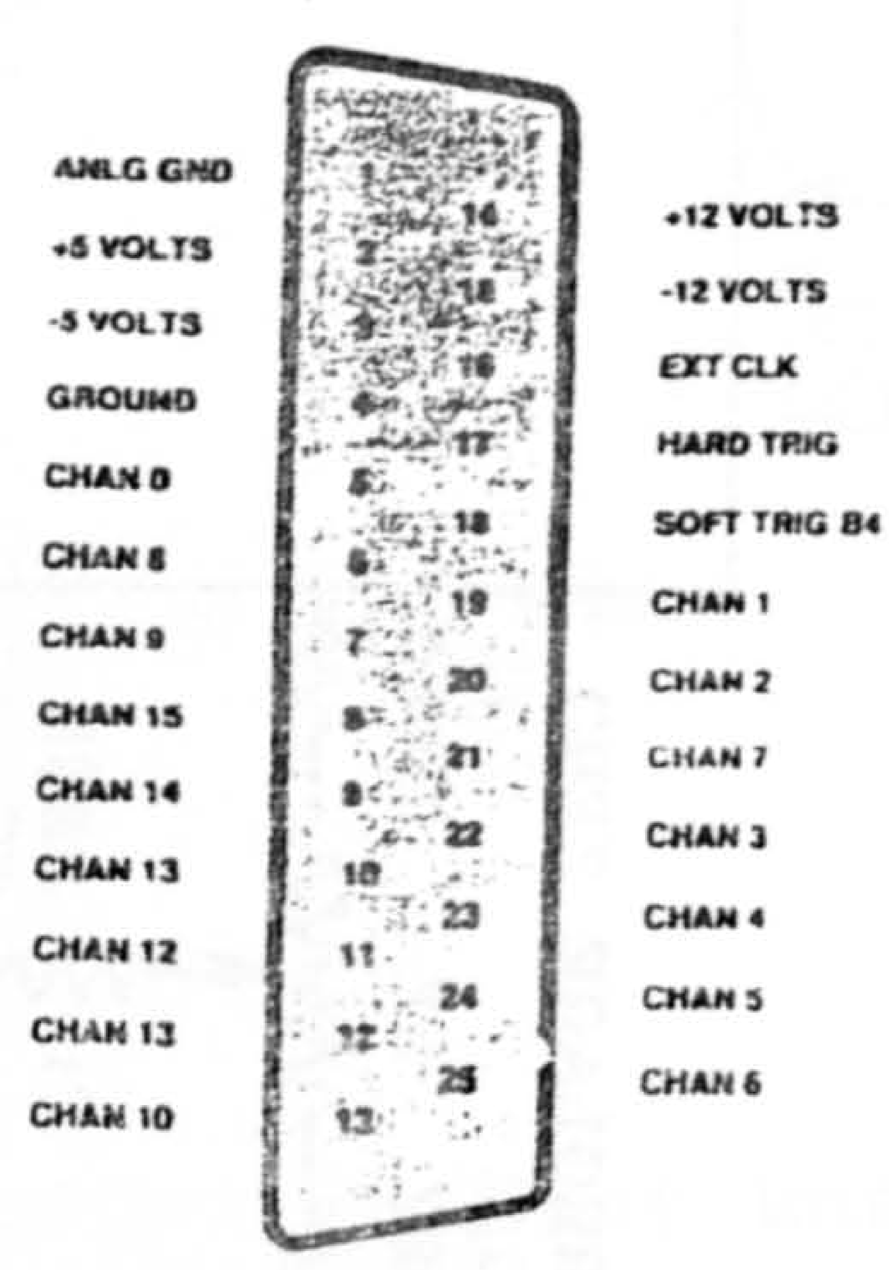


Figure III.3: The general description of the A/D board PC 26AT®

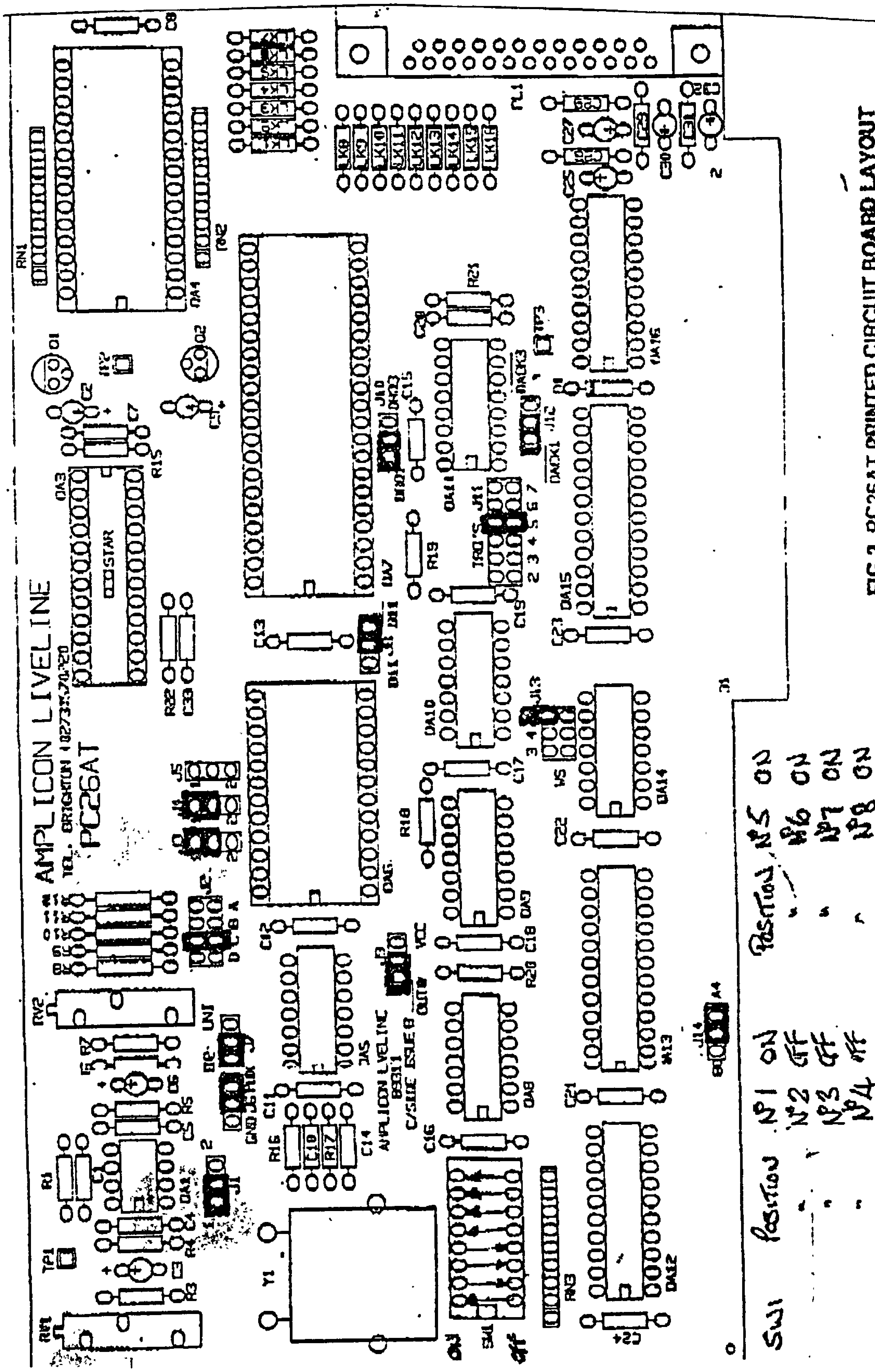
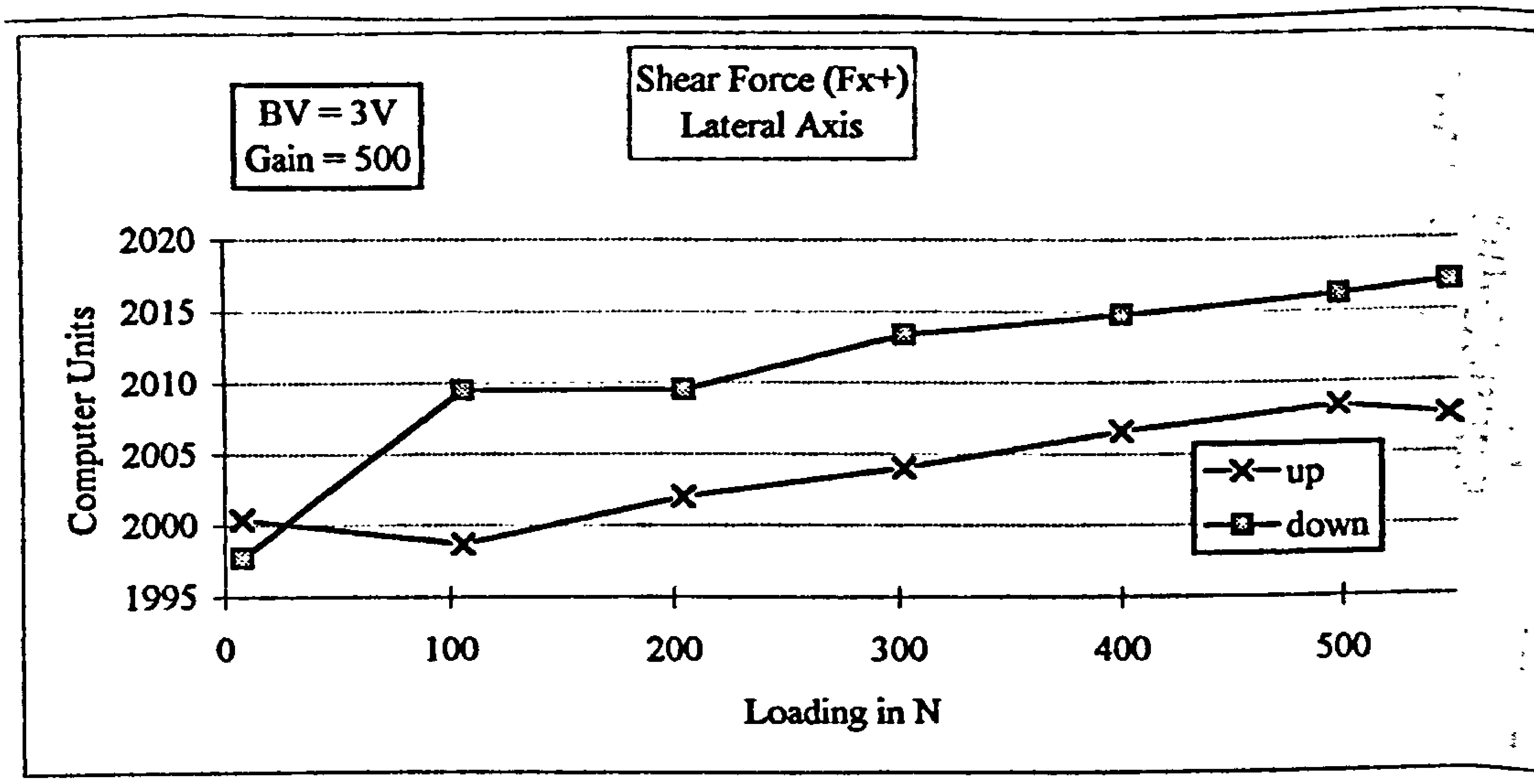
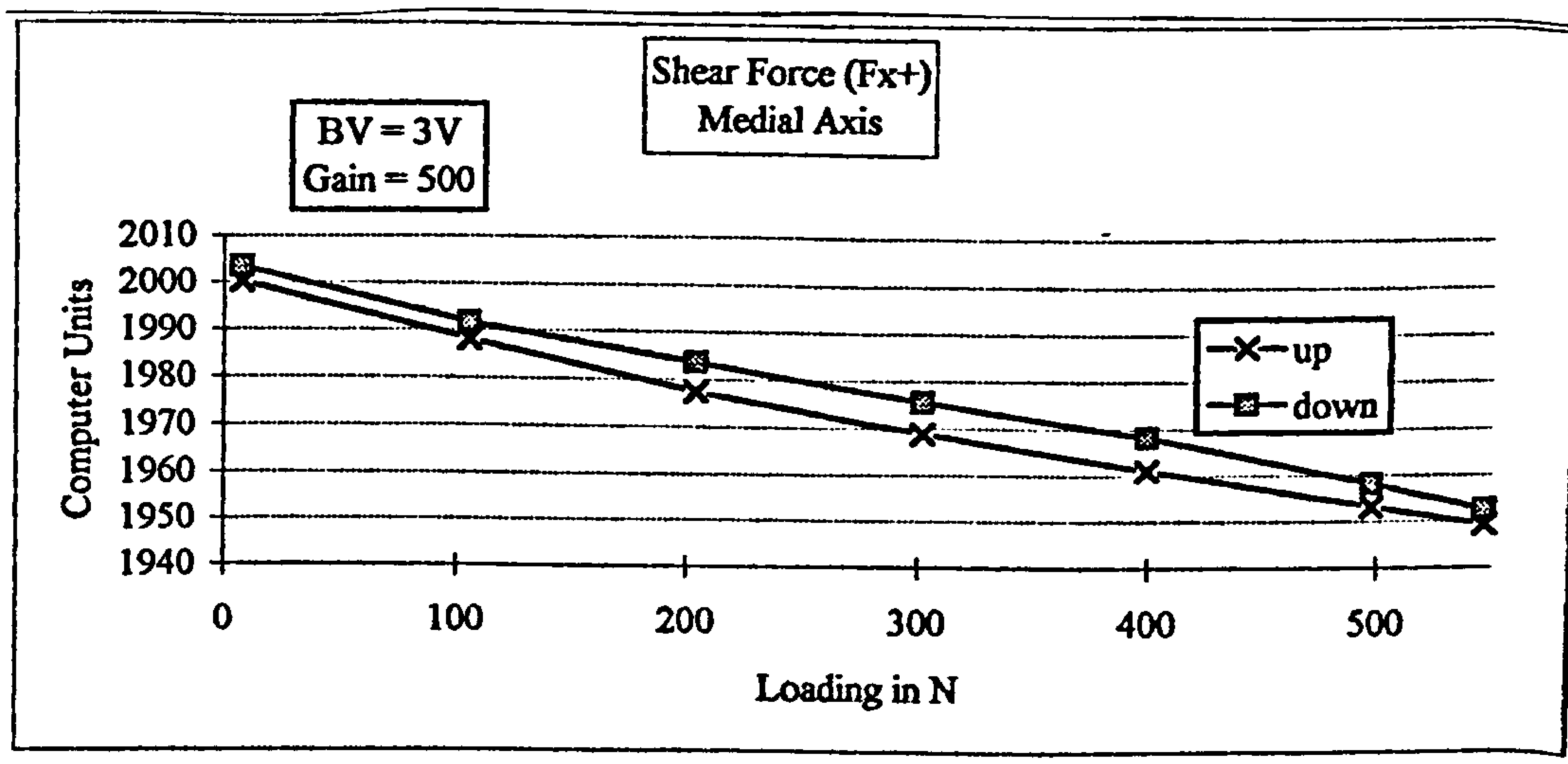


Figure III.4: The jumper selection of the A/D board used in the first data acquisition system.





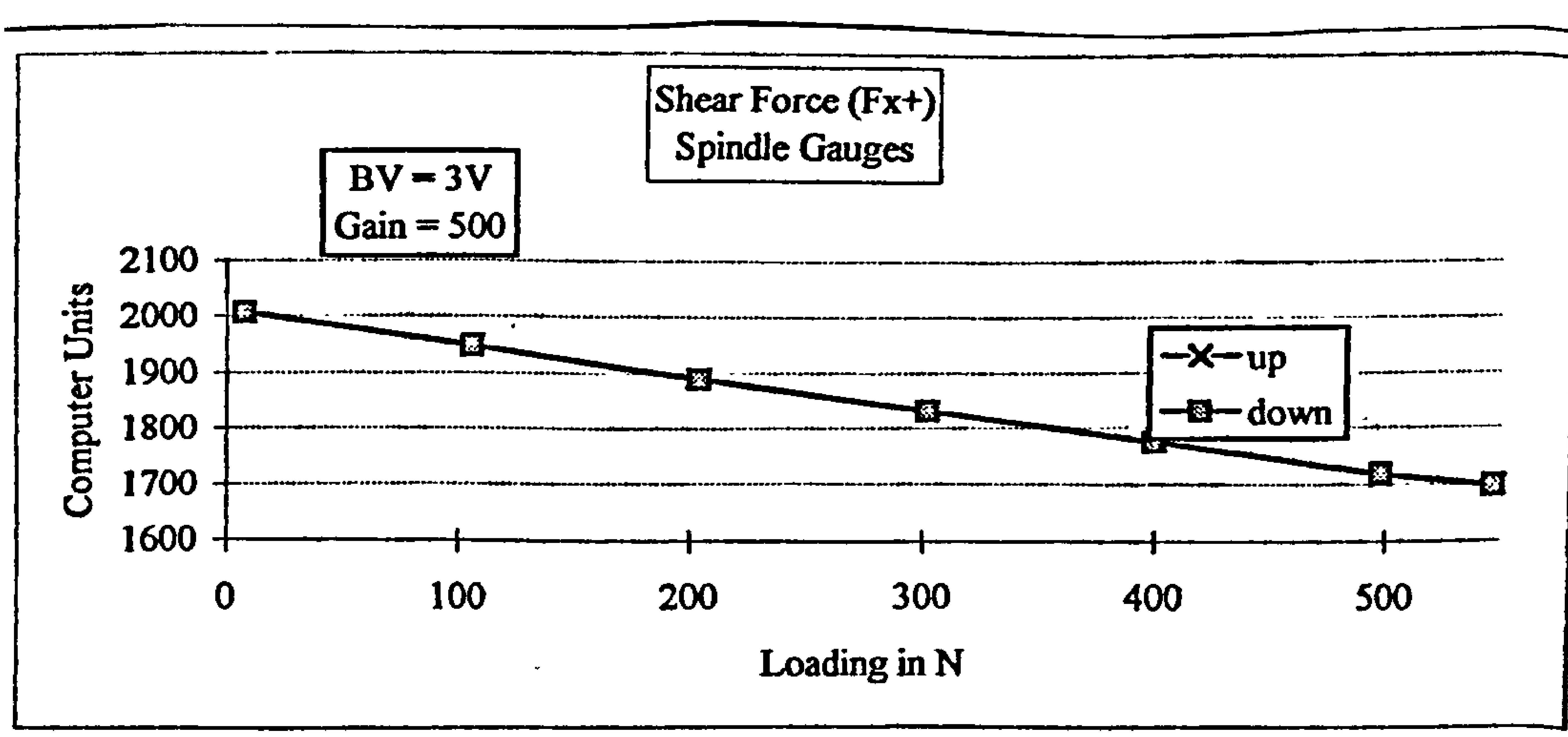


Figure III.5a: The traces from the data recorded in shear force Fx positive: top, lateral axis gauges; middle, medial axis gauges; bottom, spindle gauges.

11.III.3 The calibrated weights

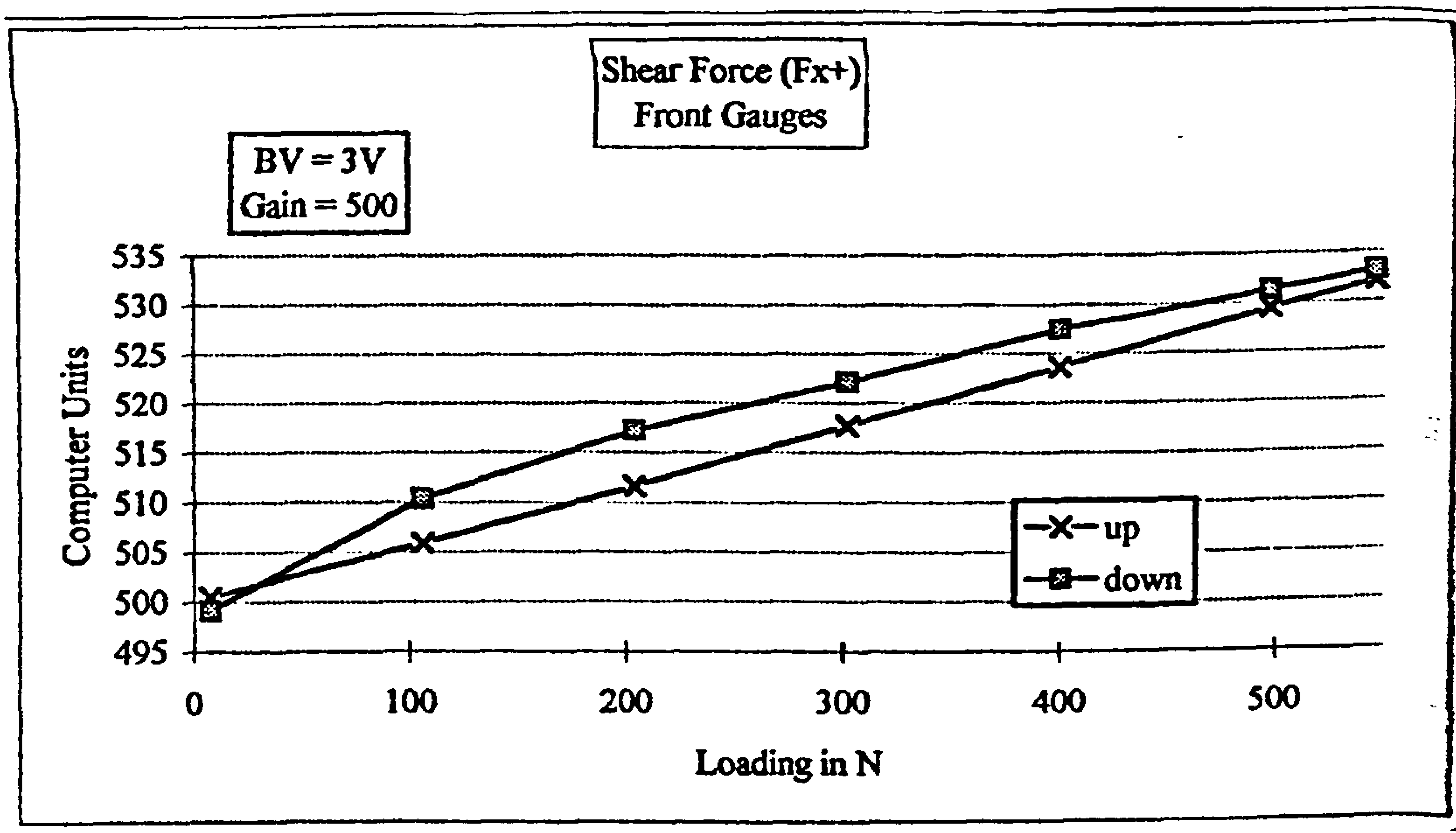
The certificate of calibration of all the weights used for the different calibration and validation performed in the presented work is shown in the following table III.2. The differences between the measured value and the used value are small enough to do not affect the recorded results and the conclusions expressed in the following chapters 4, 6 (calibration) and 7 (validation).

CERTIFICATE OF CALIBRATION	DATE OF ISSUE 22 FEBRUARY 1991
	SERIAL NUMBER 0596
ISSUED BY CALIBRATION AND TEST CENTRE	PAGE 2 OF 2 PAGES

IDENTIFICATION	MEASURED VALUE (g)
A1	449.837
A2	904.974
A3	2 023.807
A4	5 020.128
A5	5 011.532
A6	4 981.408
A7	4 995.299
A8	5 000.247
A9	10 036.50
A10	10 056.56
A11	10 046.97
A12	10 006.67
A13	10 087.92
A14	9 126.52
A15	9 097.60
A16	9 099.87
A17	9 087.51
A18	9 253.25

UNCERTAINTY OF MEASUREMENT 50 p.p.m.

Table III.2: The certificate of calibration of the weights used in the presented thesis.



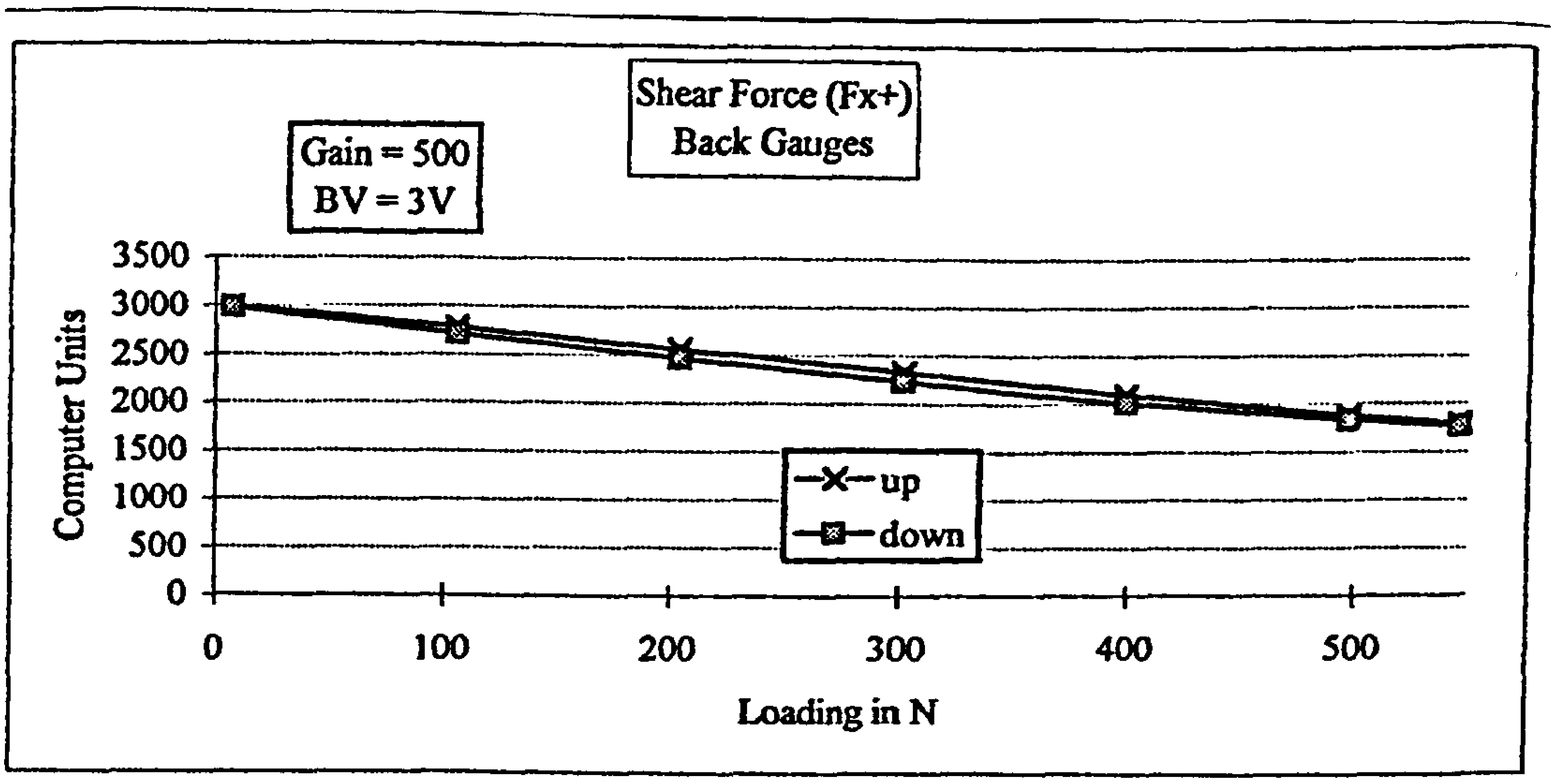


Figure III.5b: The traces from the data recorded in shear force Fx positive: top, front gauges; bottom, back gauges.

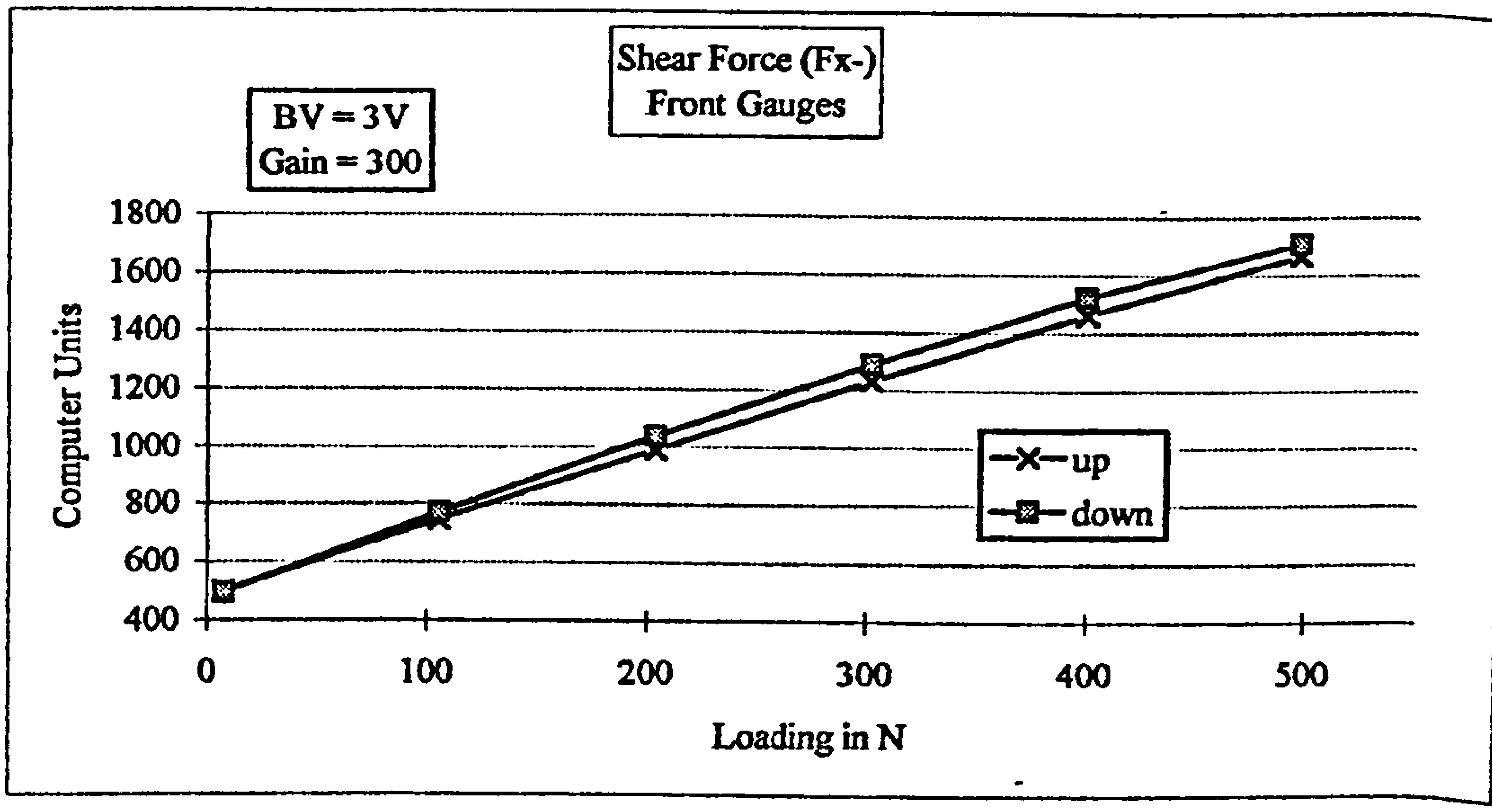
11.III.4 The results of the calibration of the ankle transducer

The full results of the calibration tests performed with the ankle transducer described in chapter 3 are presented in the following order: the A/P positive and negative shear forces, the axial load, the A/P positive and negative bending moments followed by the M/L positive and negative bending moments. For all the loading cases, five graphs are shown, one for each Wheatstone full bridge, namely:

Channel 1	External Axis Gauges
Channel 2	Internal Axis Gauges
Channel 3	Spindle Gauges
Channel 4	Front Gauges
Channel 5	Back Gauges

Globally, it is possible to note that the different channels, except the channel 3 which reflects the A/P shear force gauges, fitted on the spindle, express hysteresis and drifting. The traces were not on a straight line. The load and unload traces were not superimposed.

The shear force set up was a cantilever configuration. Thus, when a shear force was applied, a M/L bending moment was created such as: when Fx was positive, it was a plantarflexion (channel 5, back flange gauges in compression); when Fx was negative, a dorsiflexion was applied (channel 4, front flange gauges in compression).



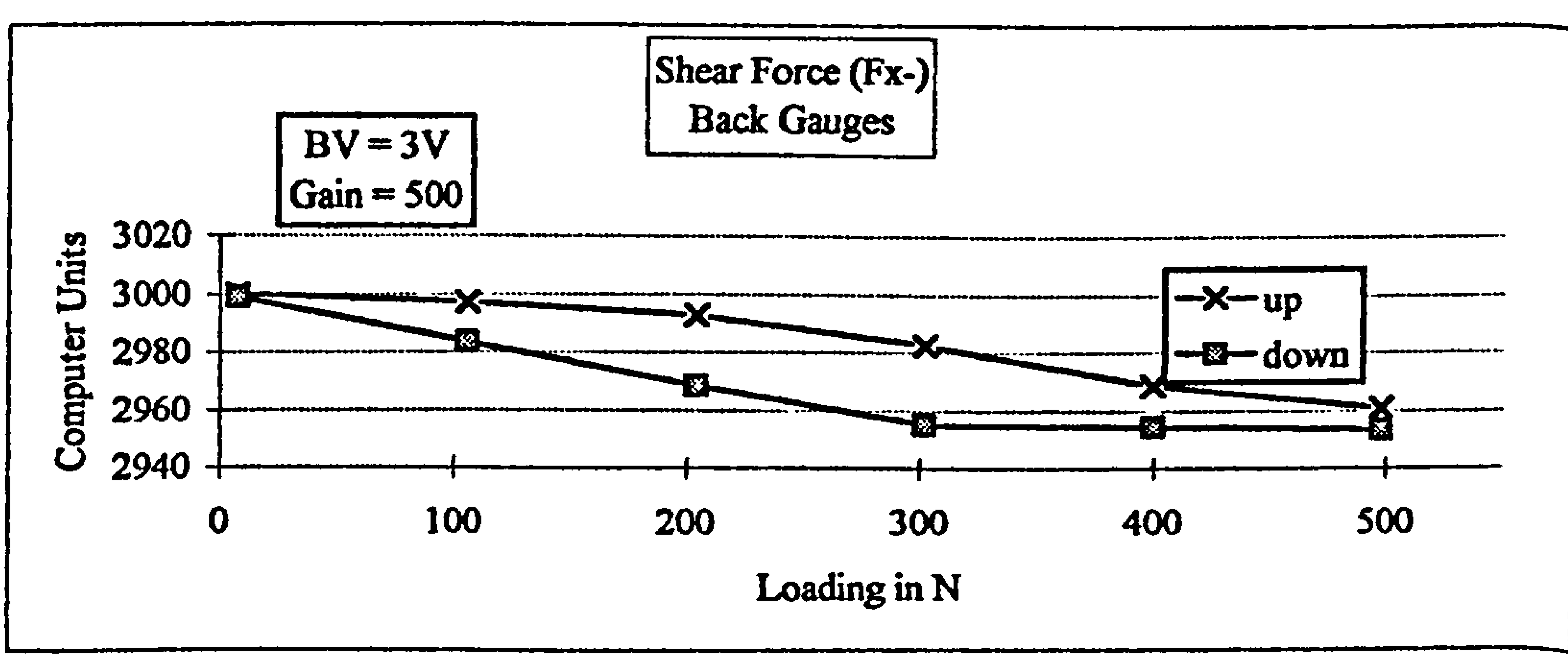
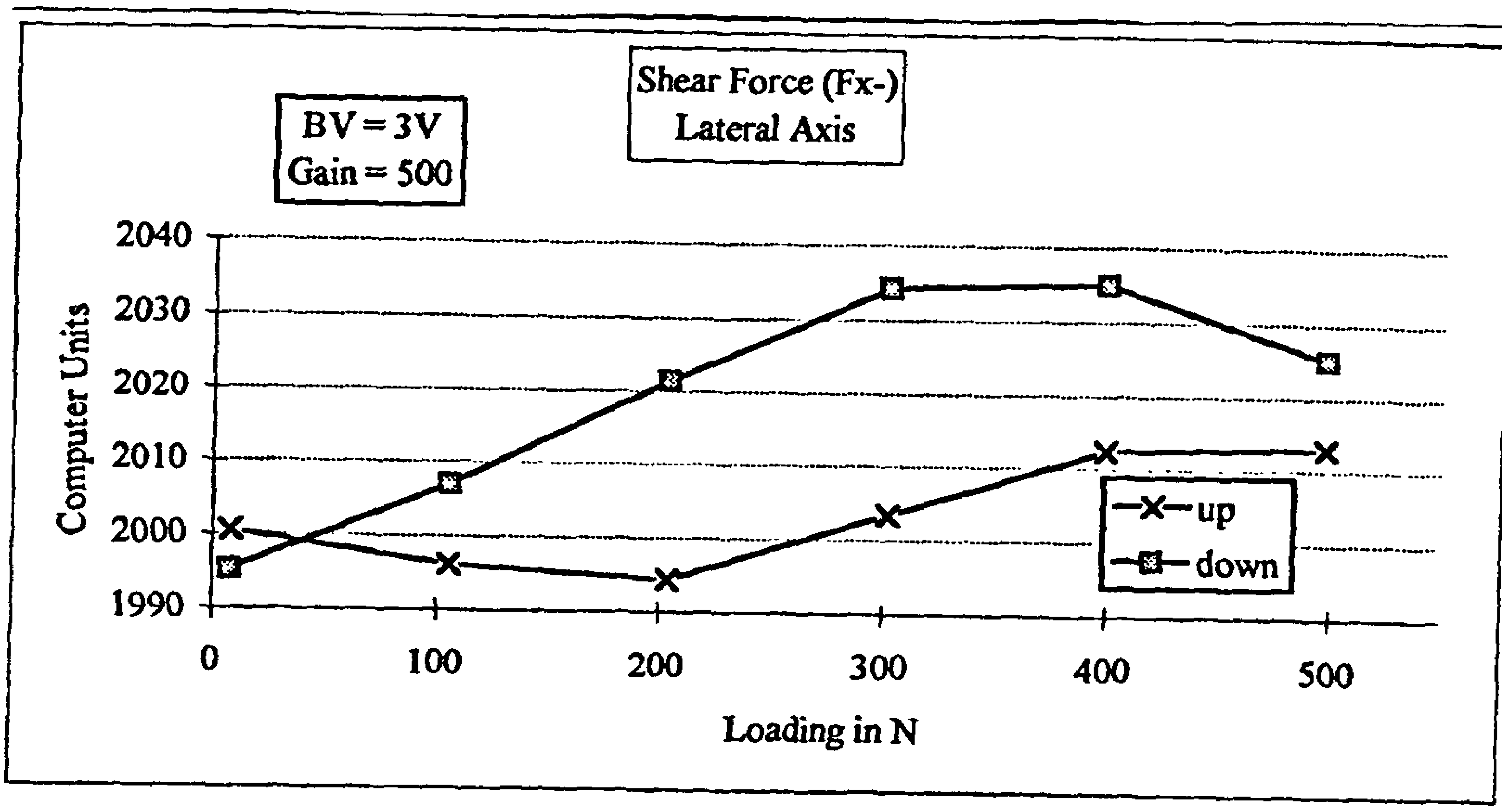
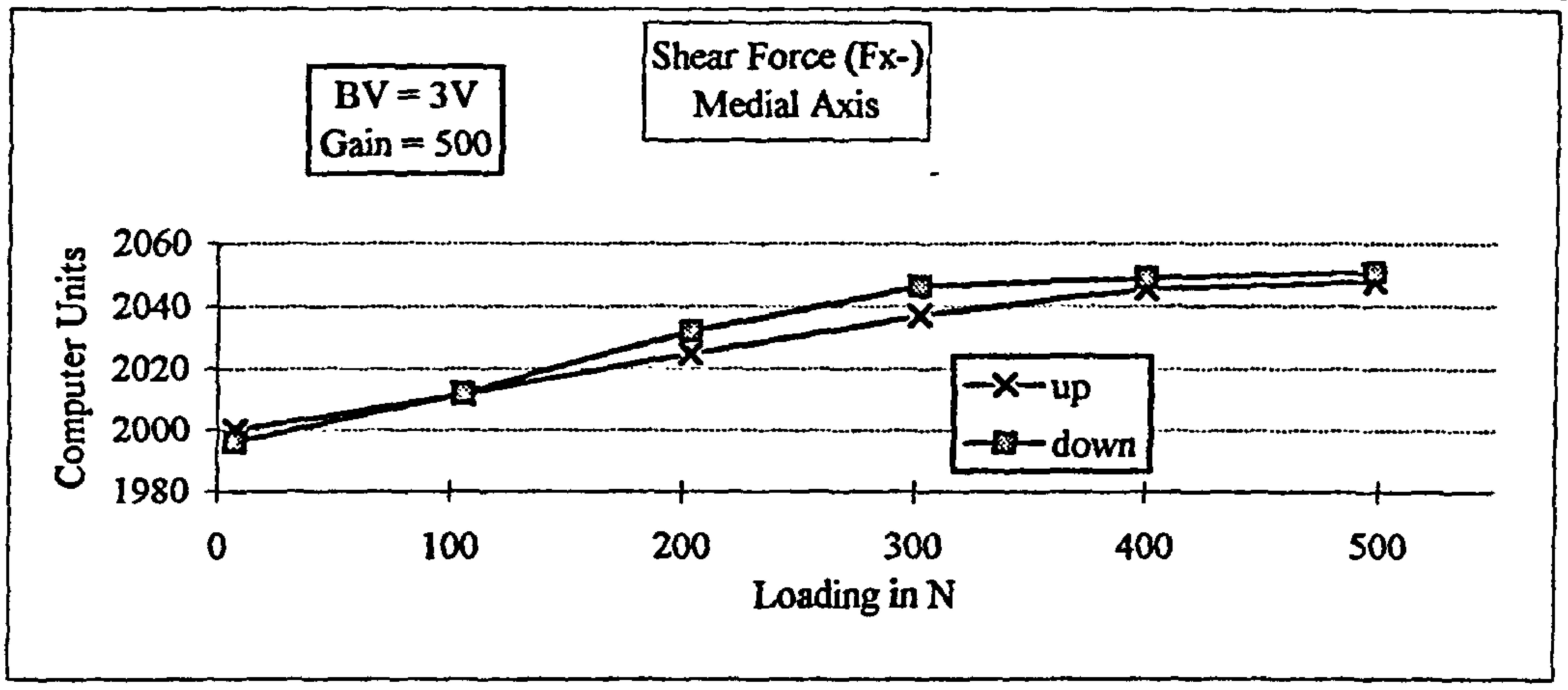


Figure III.6b: The traces from the data recorded in shear force Fx negative: top, front gauges; bottom, back gauges.





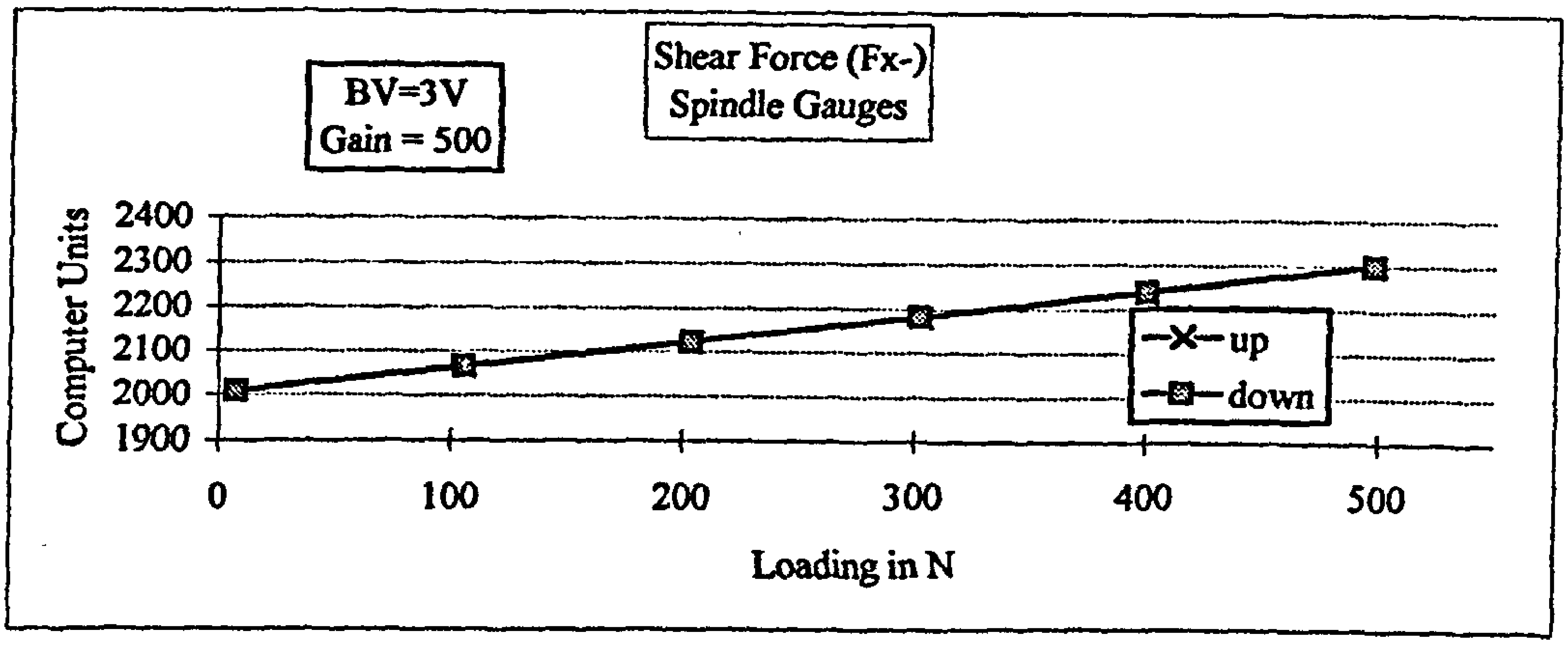
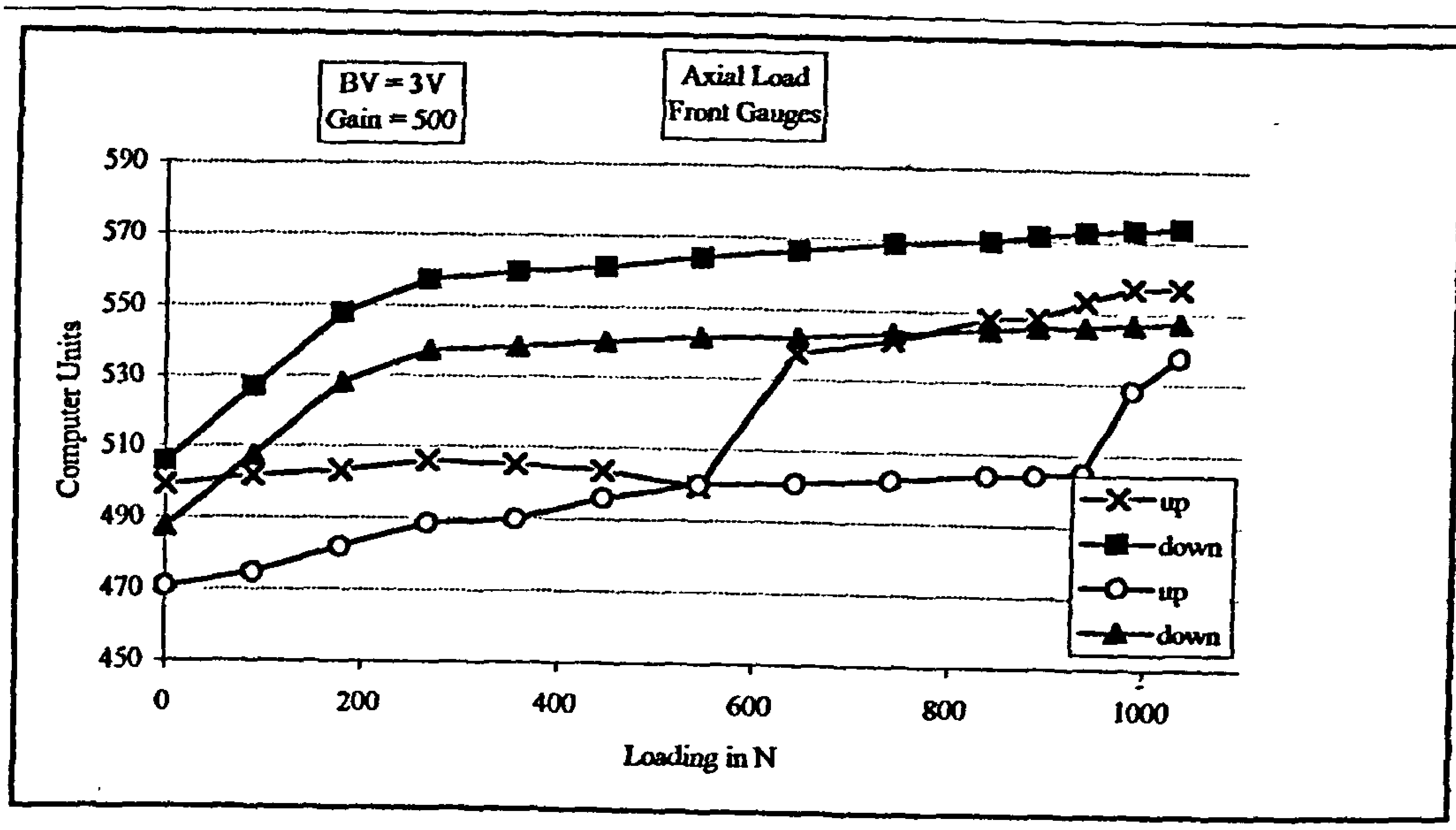


Figure III.6a: The traces from the data recorded in shear force Fx negative: top, lateral axis gauges; middle, medial axis gauges; bottom, spindle gauges.



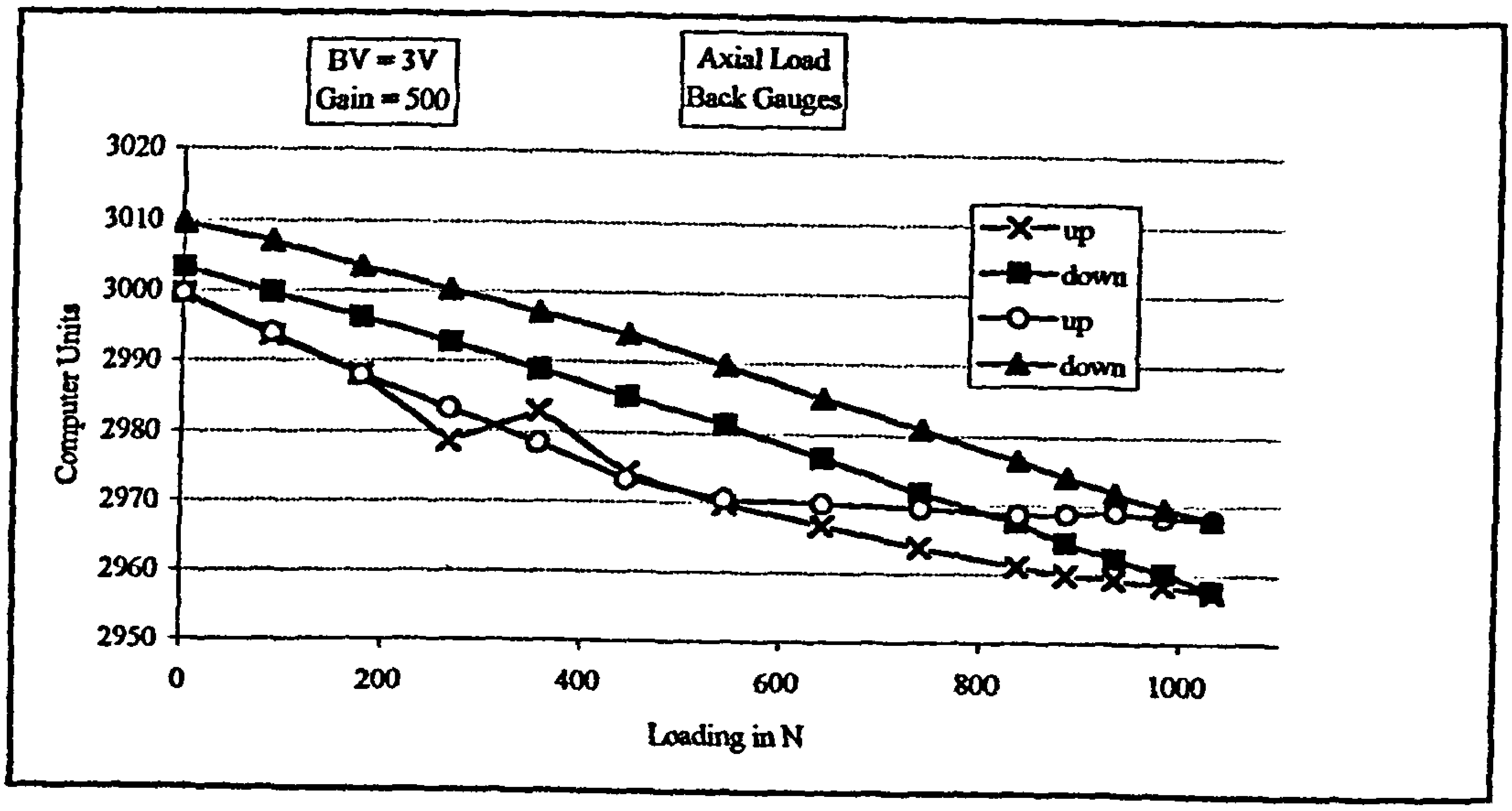


Figure III.7b: The traces from the data recorded in axial load: top, front gauges; bottom, back gauges.

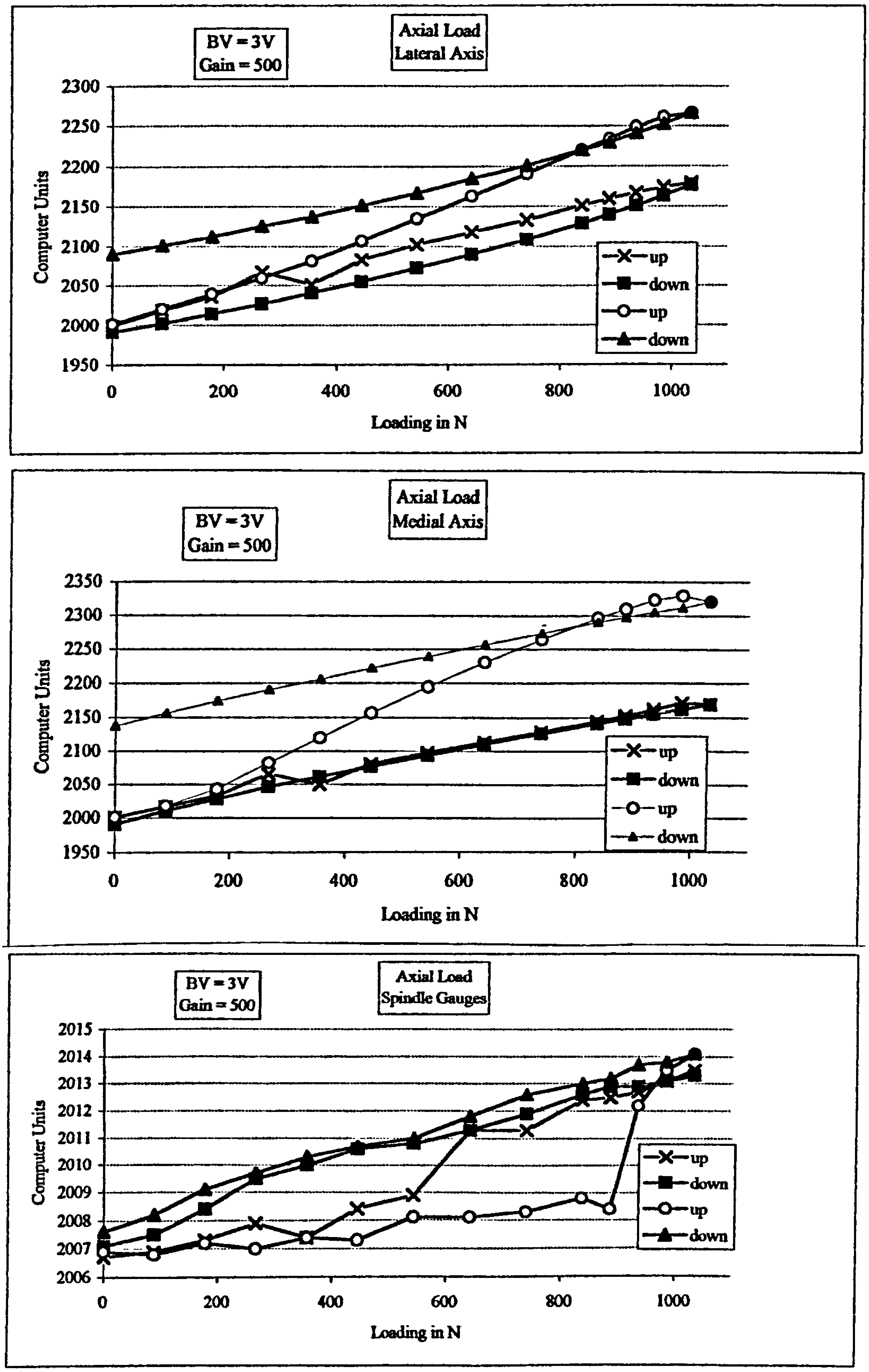
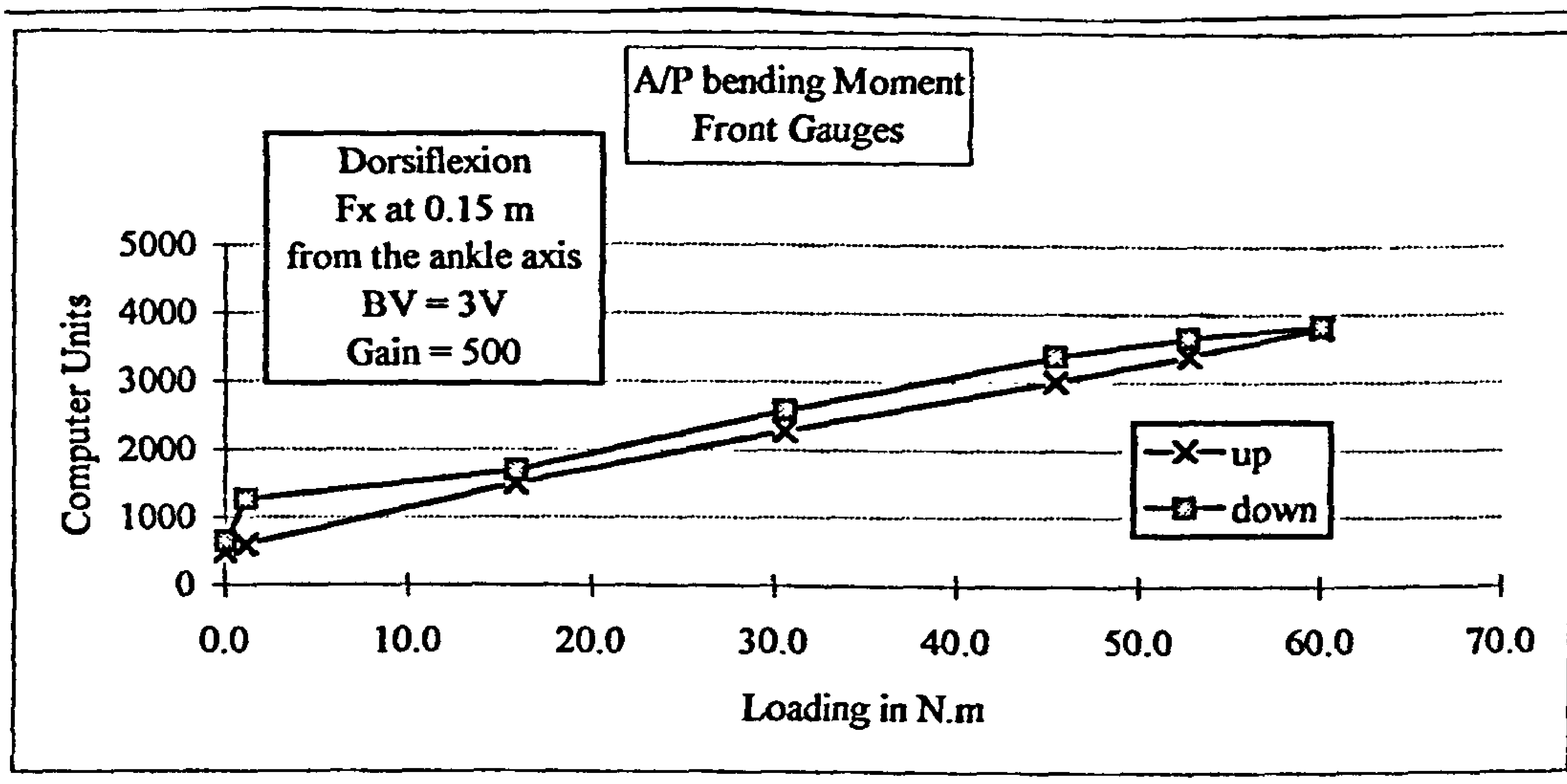


Figure III.7a: The traces from the data recorded in axial load: top, lateral axis gauges; middle, medial axis gauges; bottom, spindle gauges.



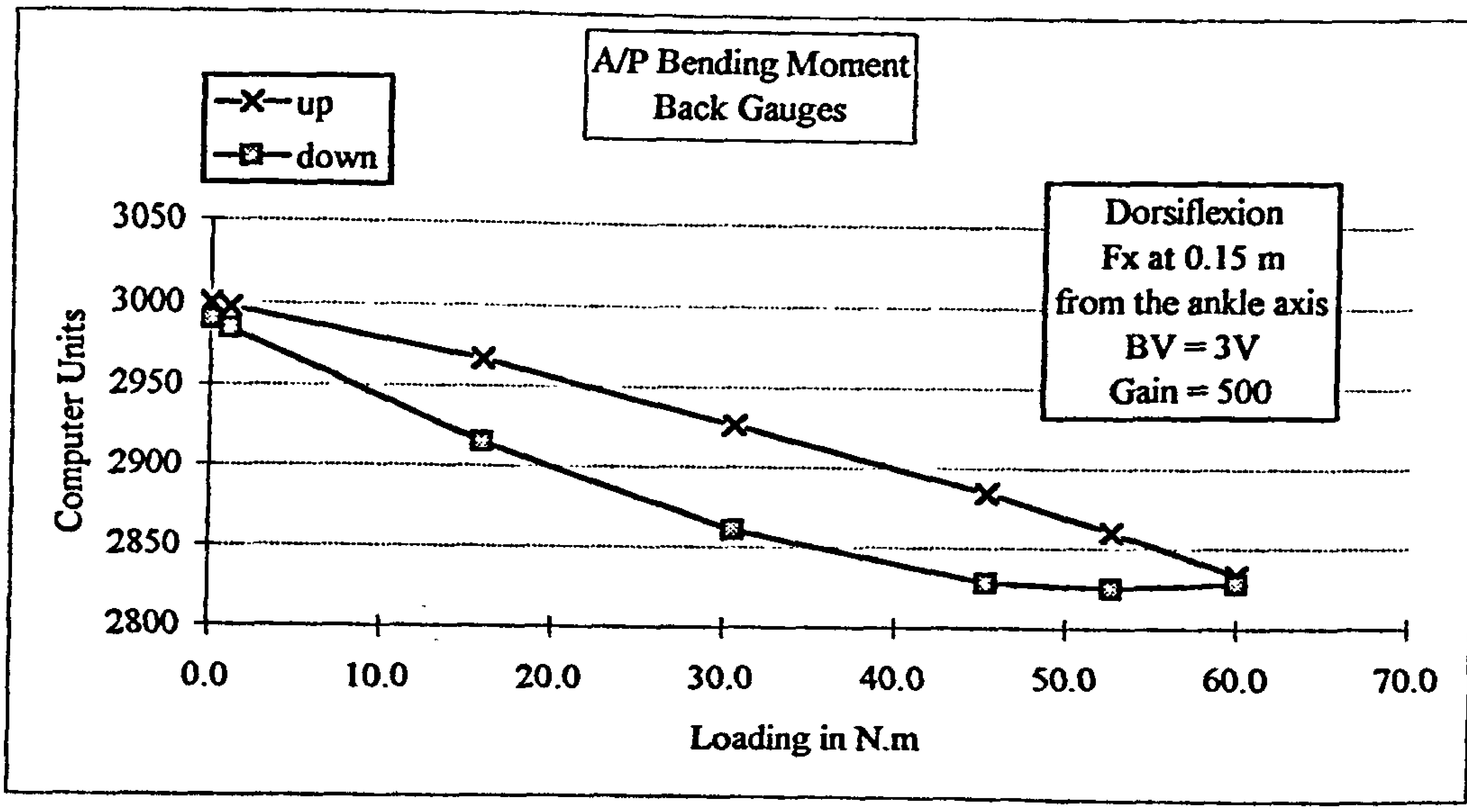


Figure III.8b: The traces from the data recorded in A/P bending moment positive (dorsiflexion): top, front gauges; bottom, back gauges.

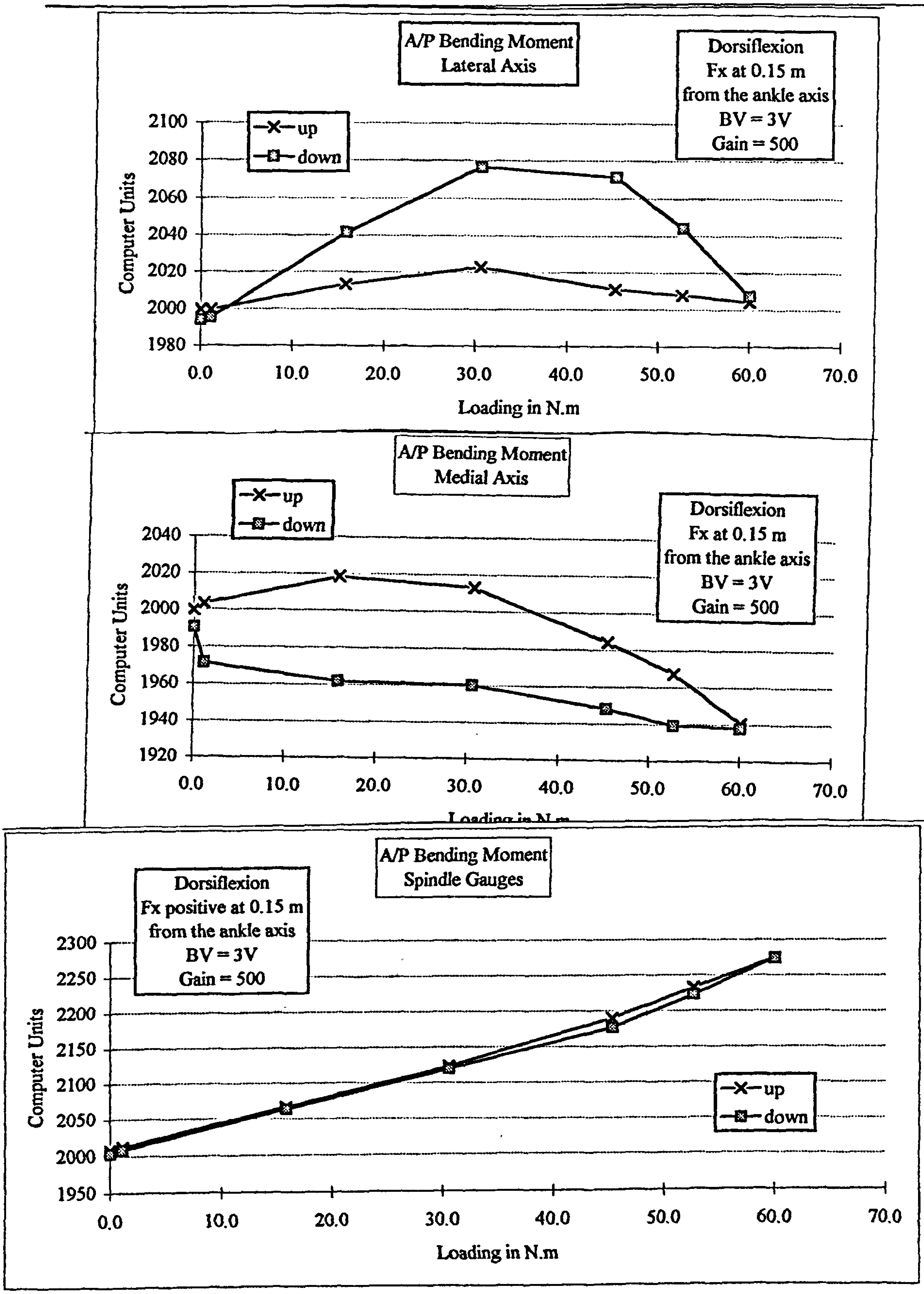
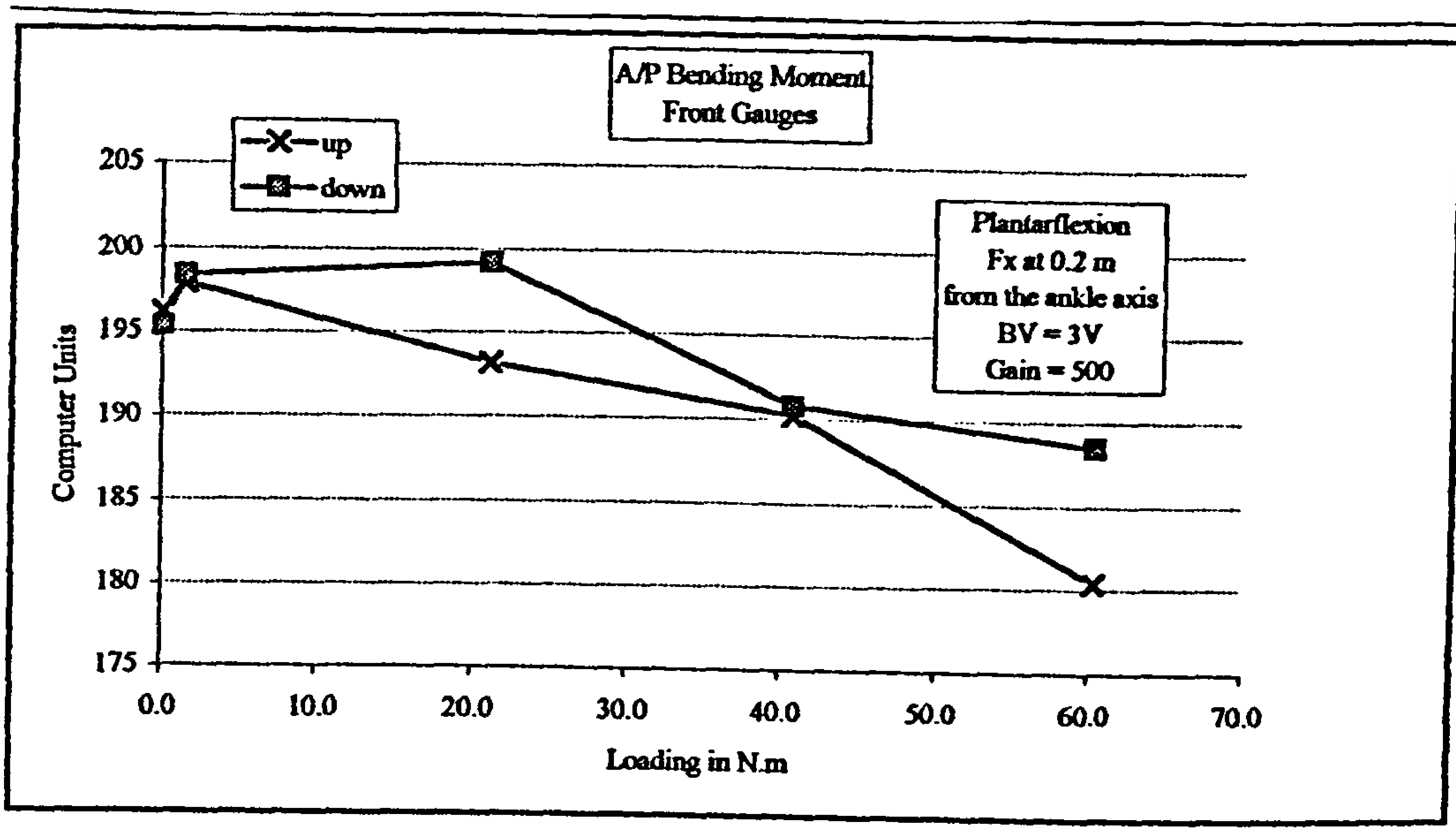


Figure III.8a: The traces from the data recorded in A/P bending moment positive (dorsiflexion): top, lateral axis gauges; middle, medial axis gauges; bottom, spindle gauges.



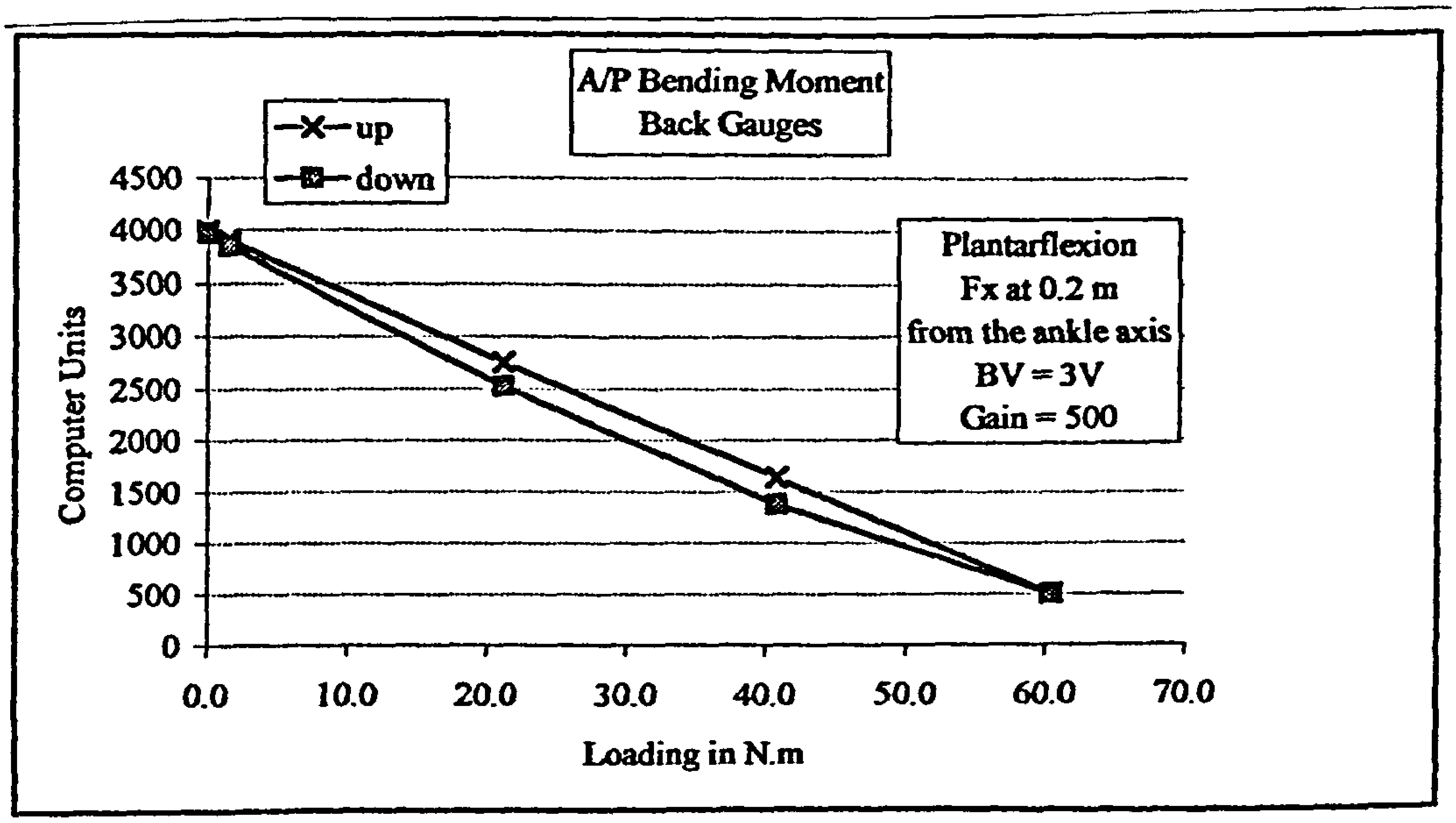
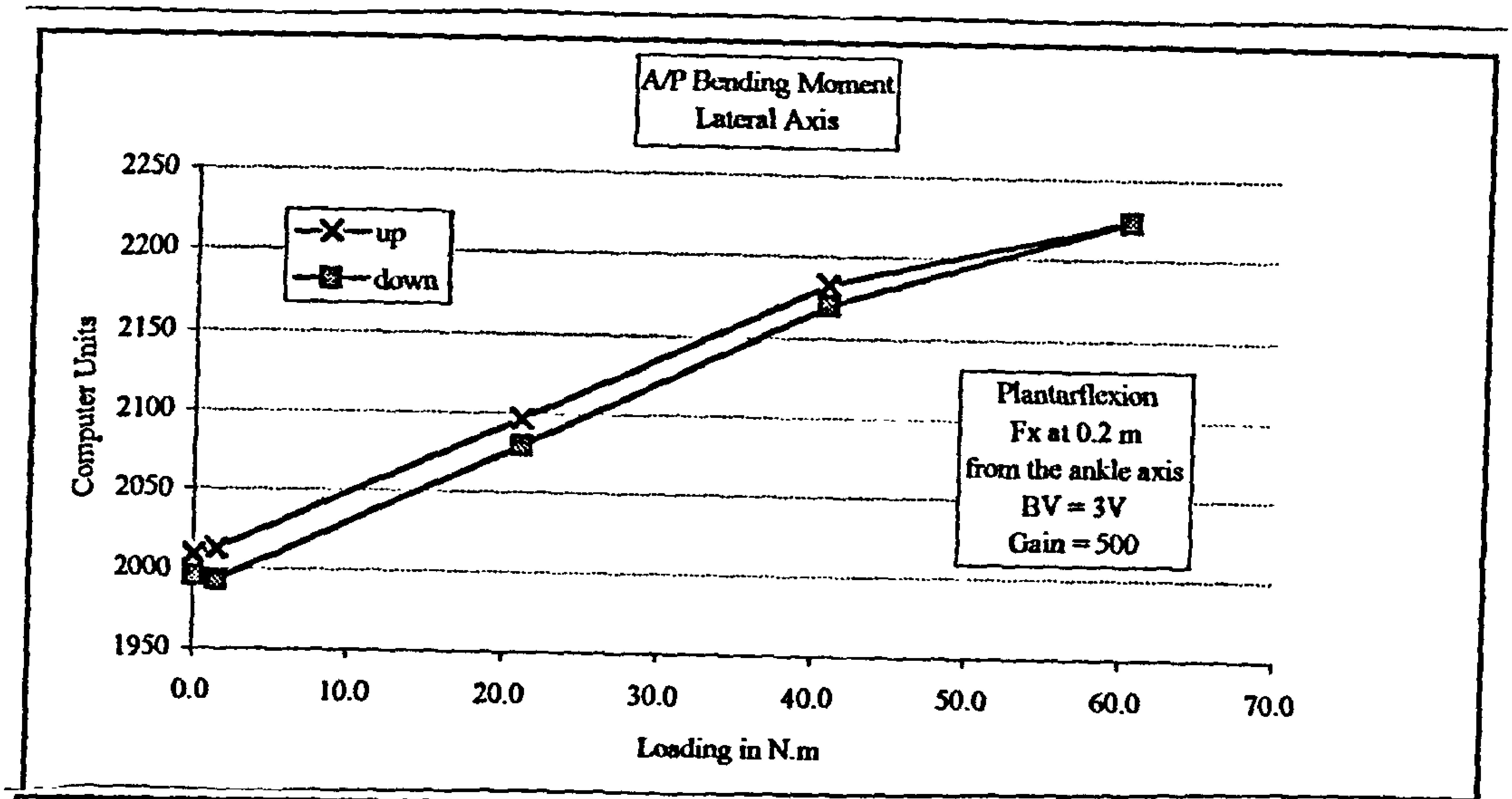
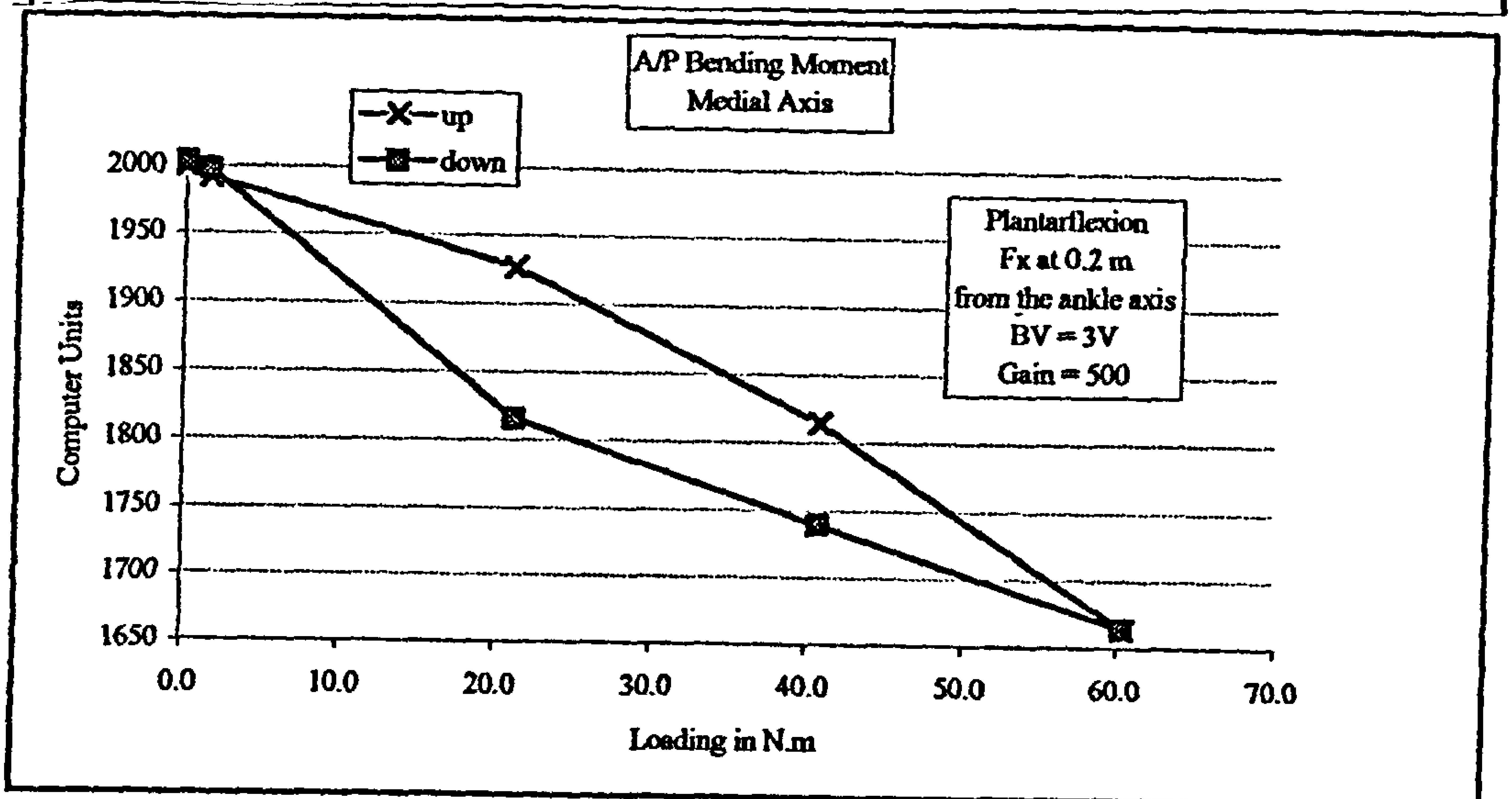


Figure III.9b: The traces from the data recorded in A/P bending moment negative (plantarflexion): top, front gauges; bottom, back gauges.





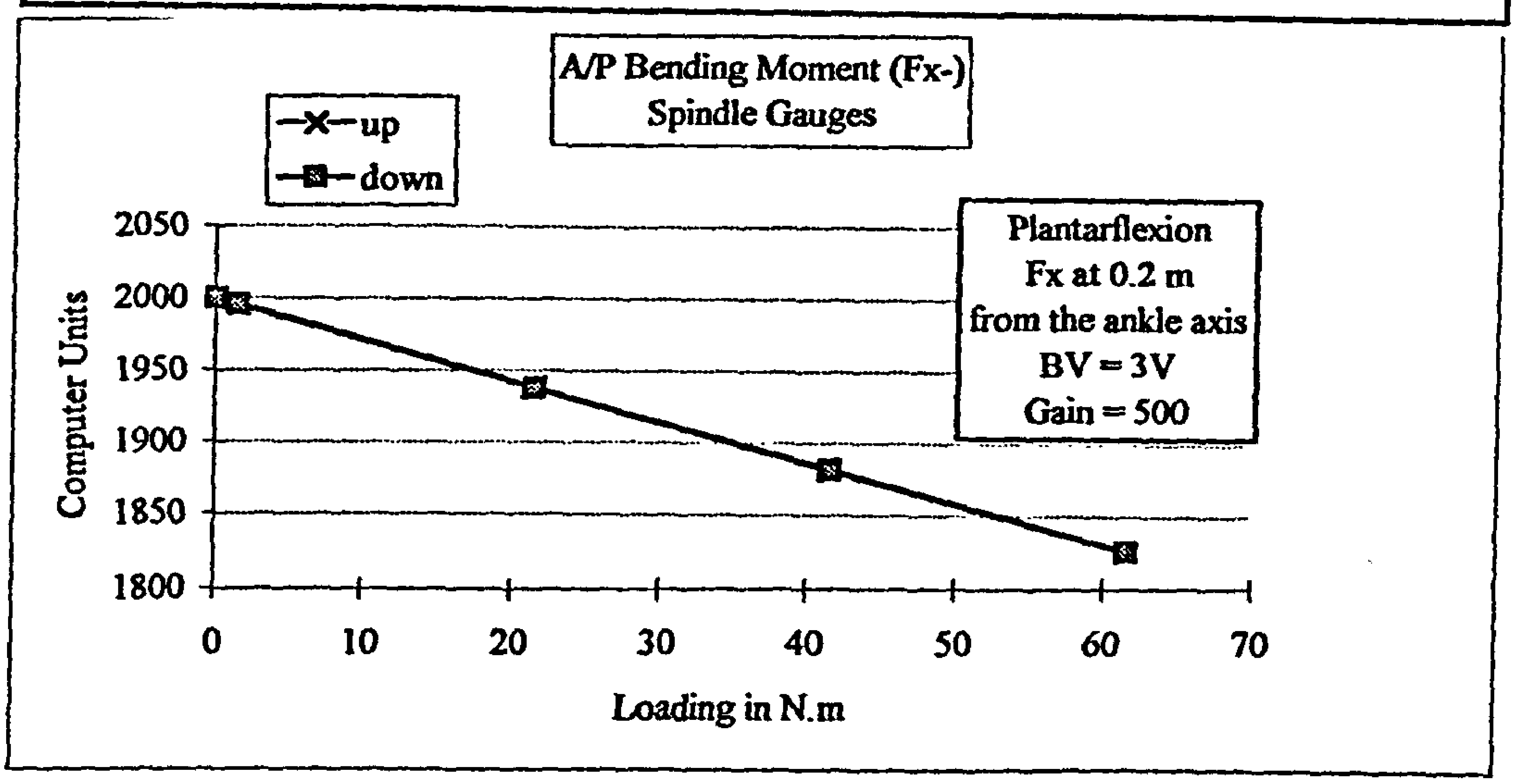
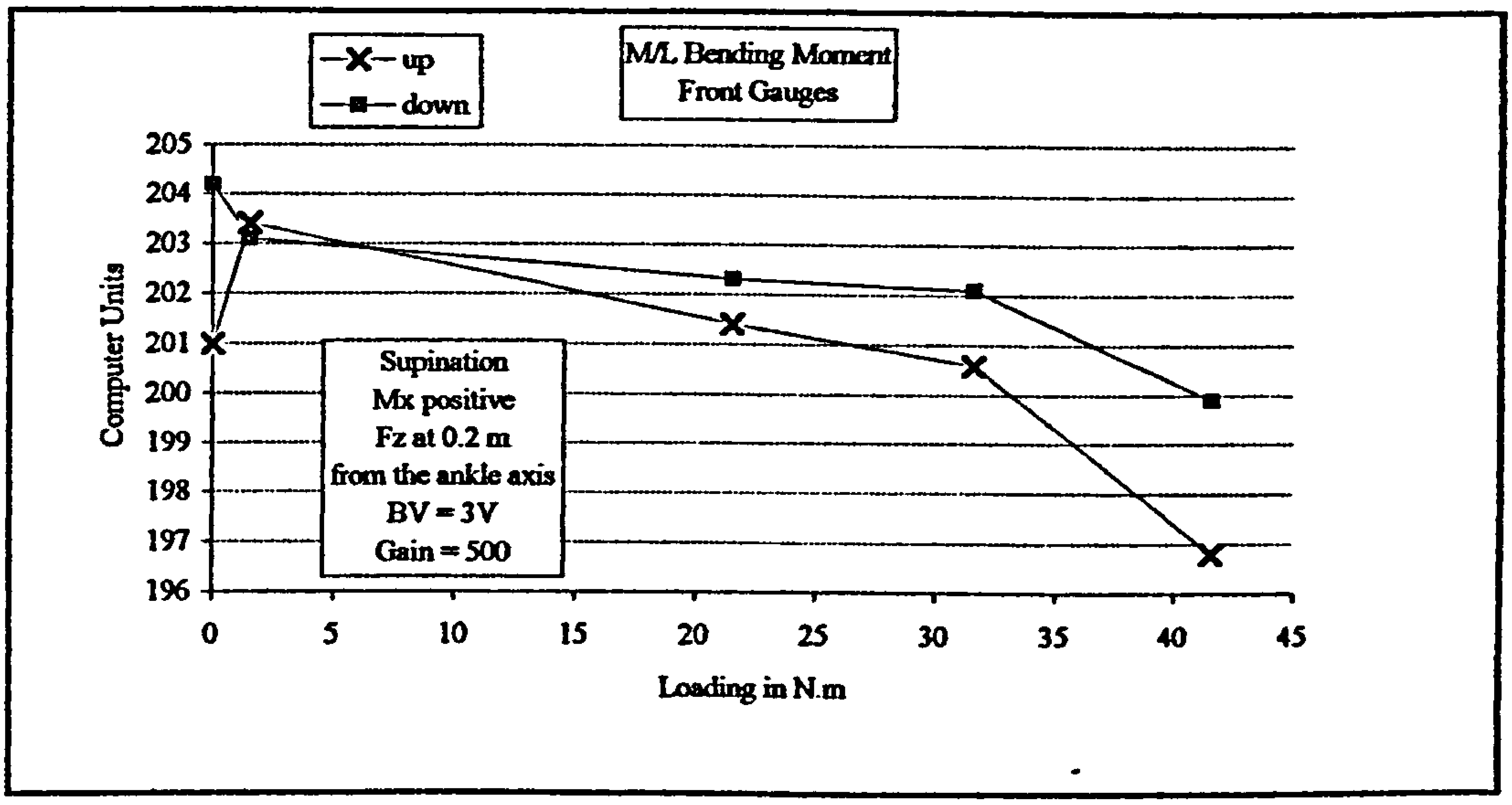


Figure III.9a: The traces from the data recorded in A/P bending moment negative (plantarflexion): top, lateral axis gauges; middle, medial axis gauges; bottom, spindle gauges.



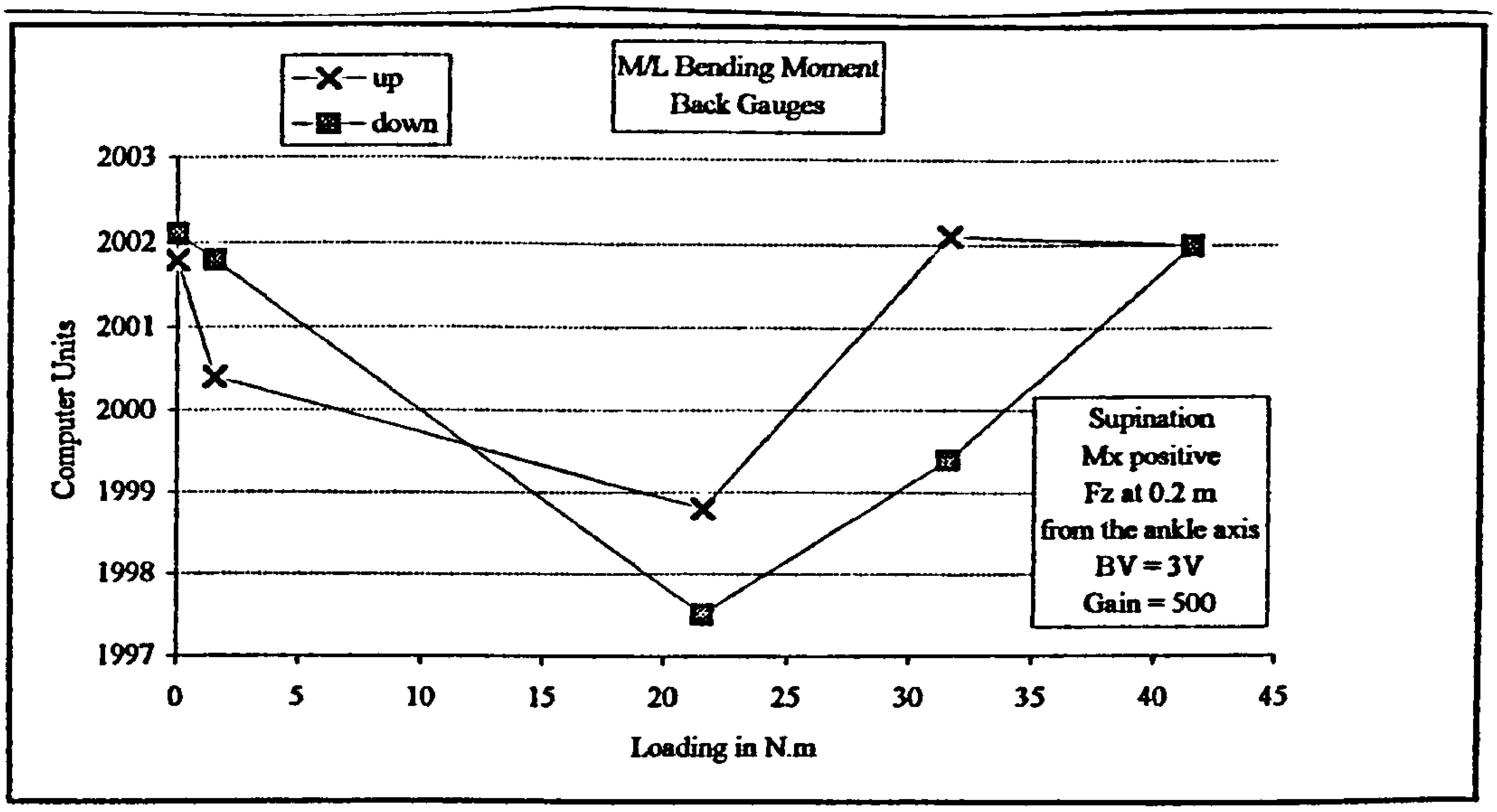
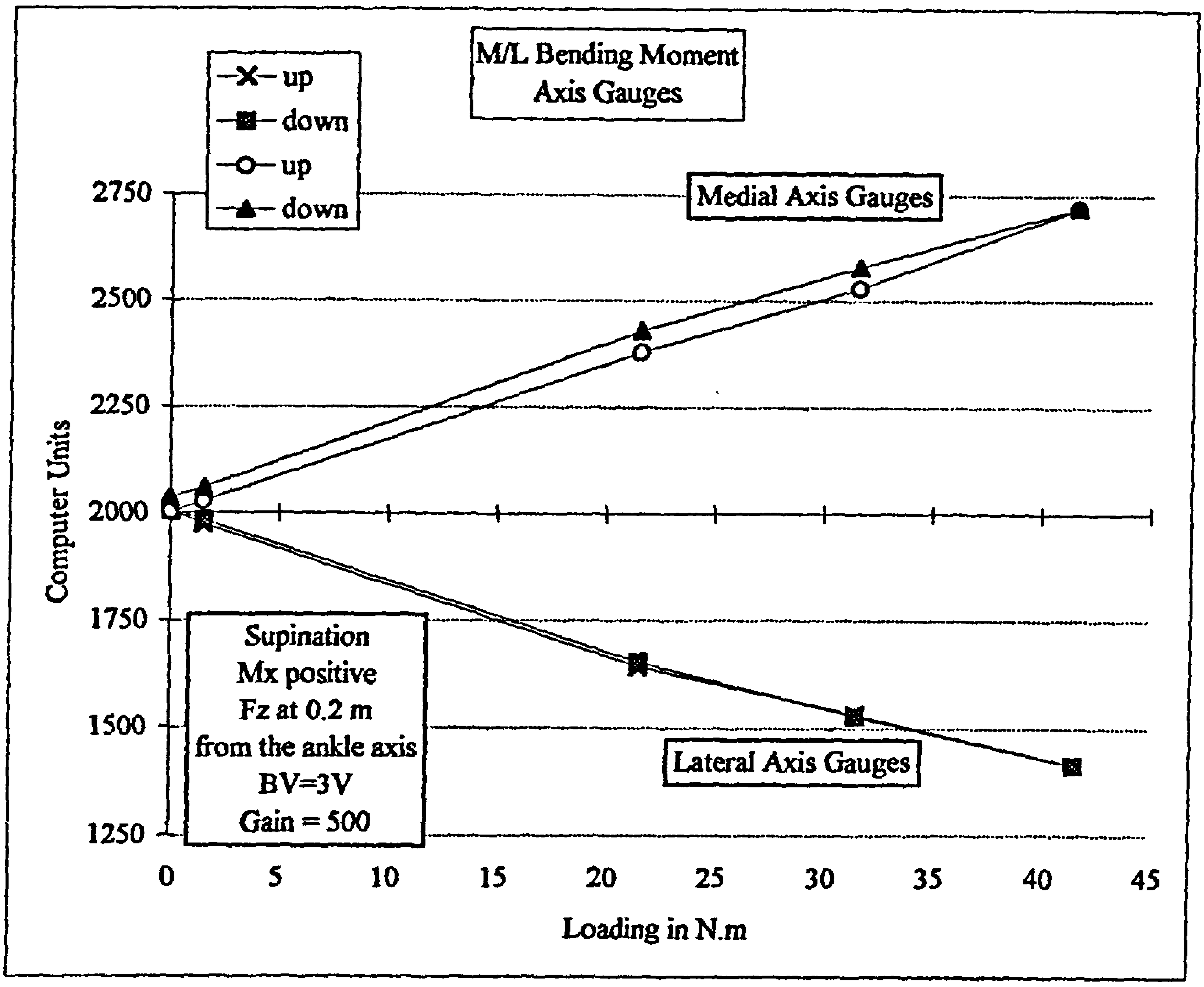


Figure III.10b: The traces from the data recorded in M/L bending moment positive (supination): top, front gauges; bottom, back gauges.



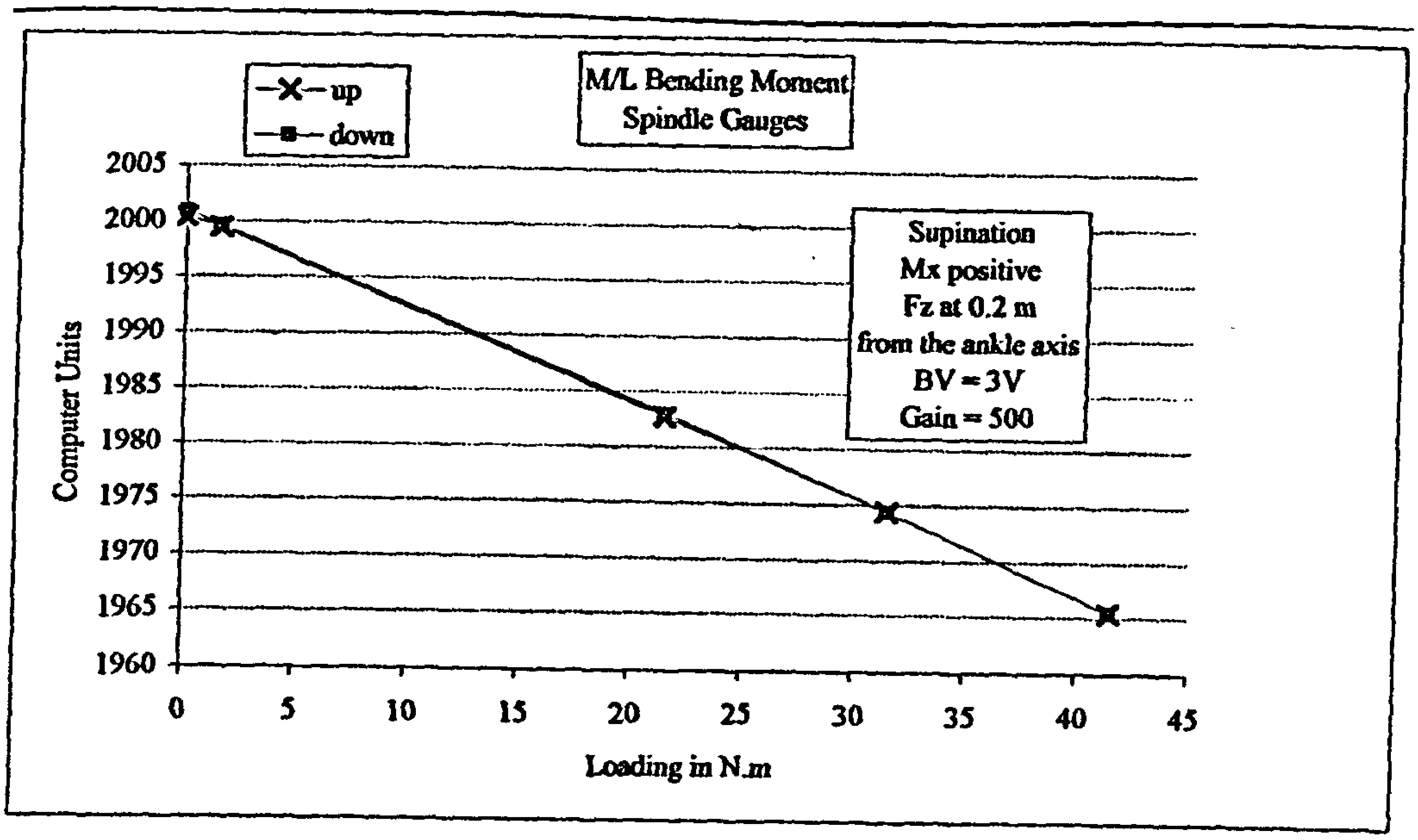
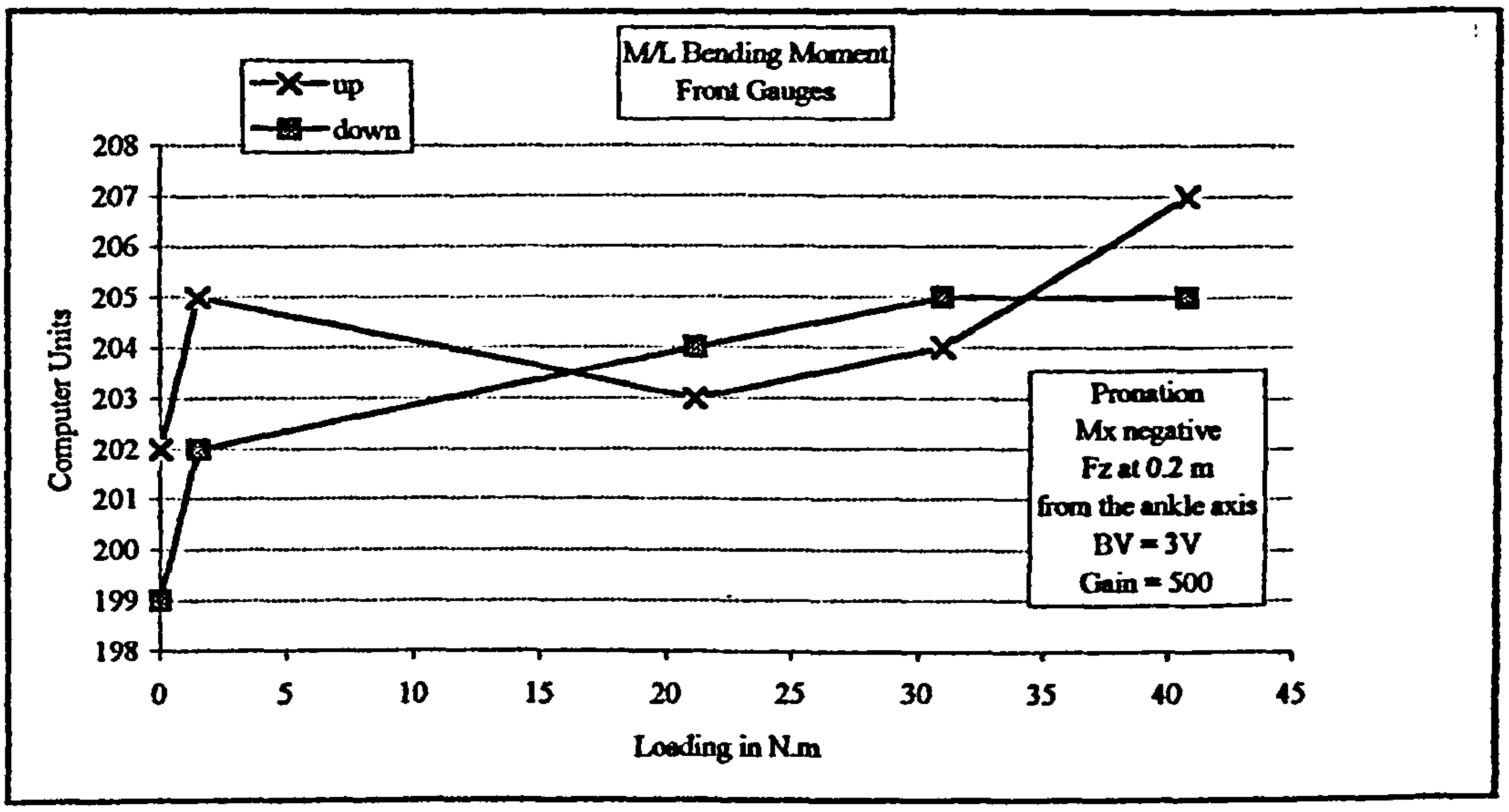


Figure III.10a: The traces from the data recorded in M/L bending moment positive (supination): top, lateral (tension) and medial (compression) axis gauges; bottom, spindle gauges.



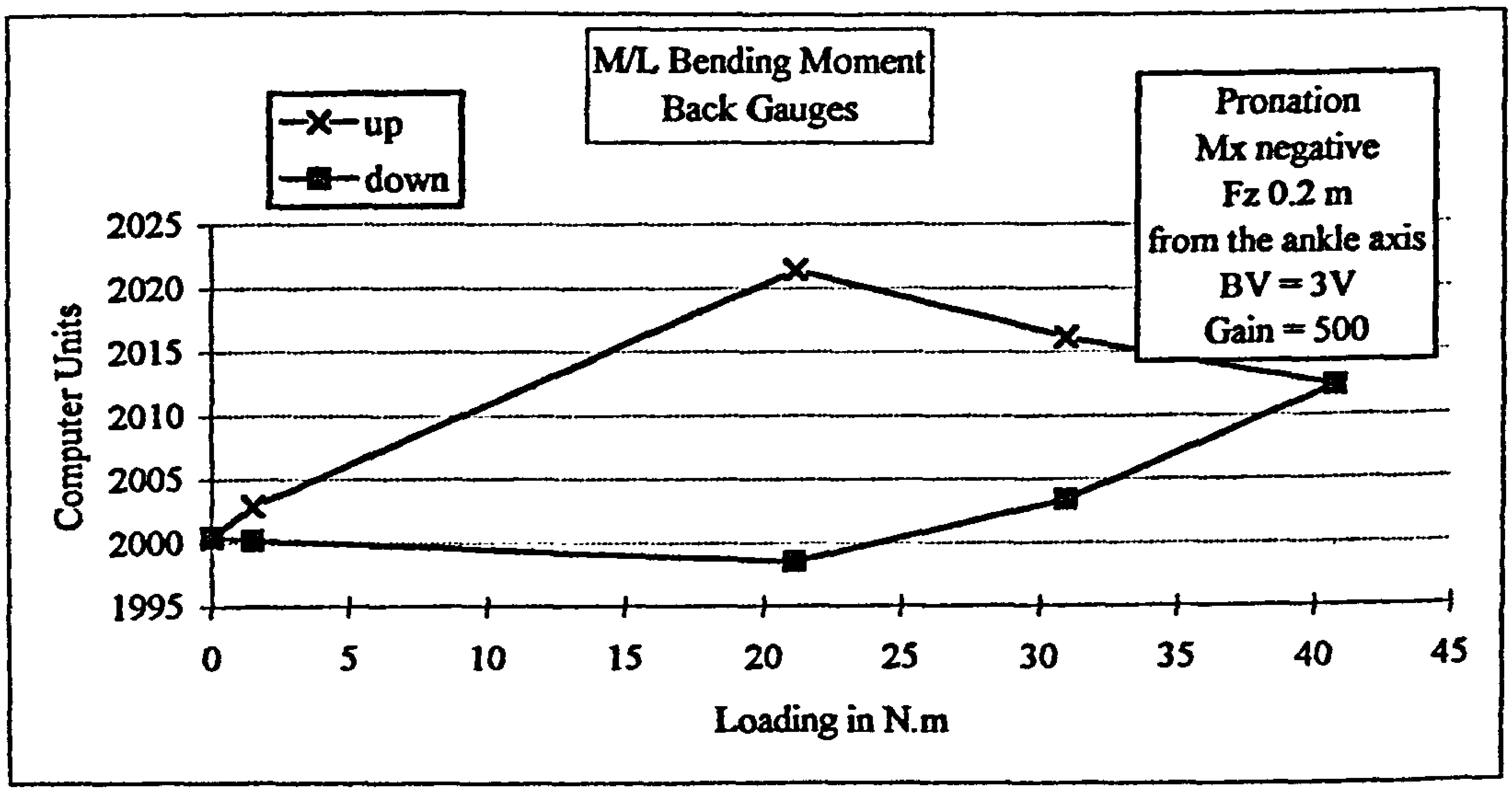
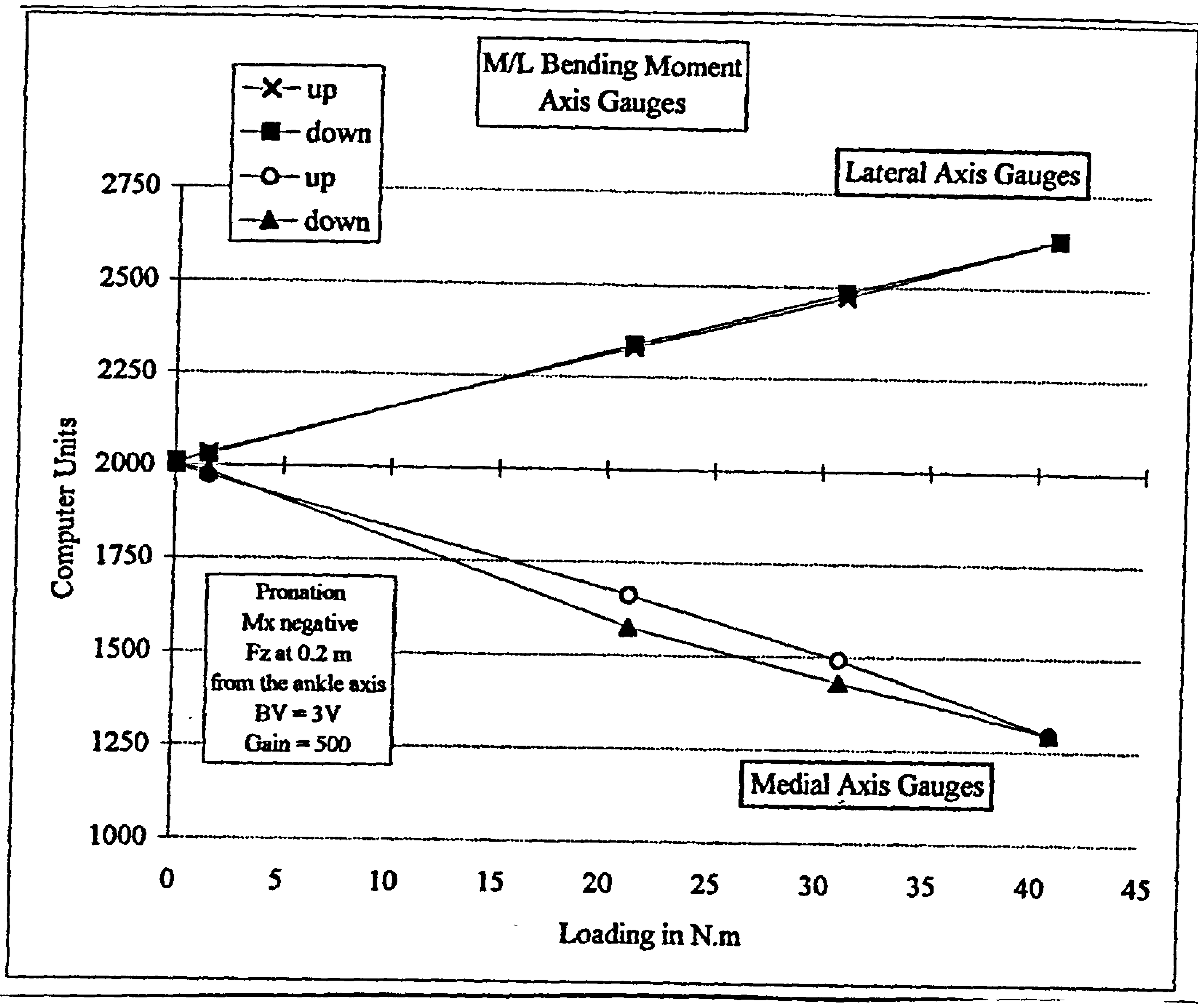


Figure III.11b: The traces from the data recorded in M/L bending moment negative (pronation): top, front gauges; bottom, back gauges.



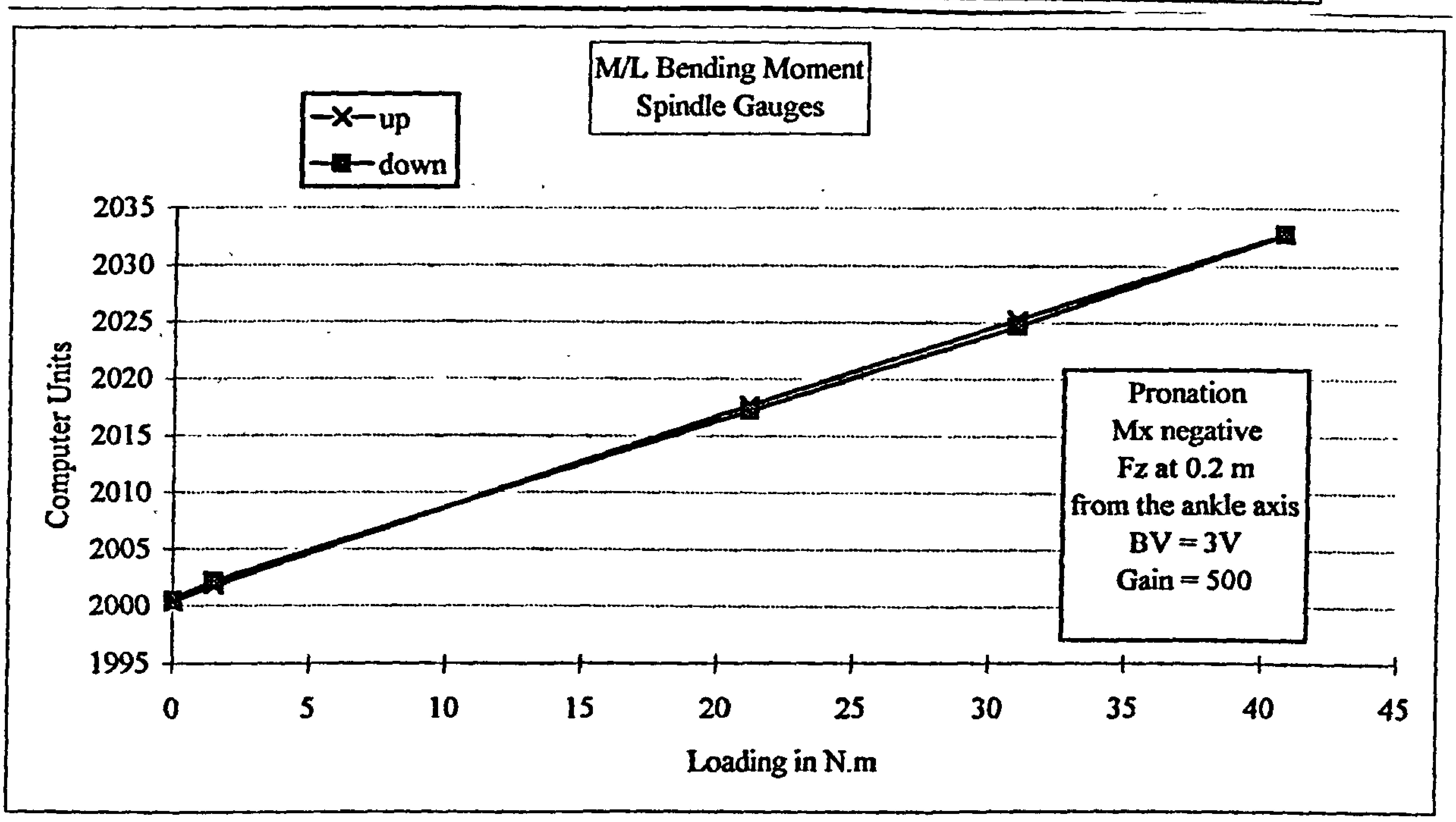


Figure III.11a: The traces from the data recorded in M/L bending moment negative (pronation): top, lateral (compression) and medial (tension) axis gauges; bottom, spindle gauges.

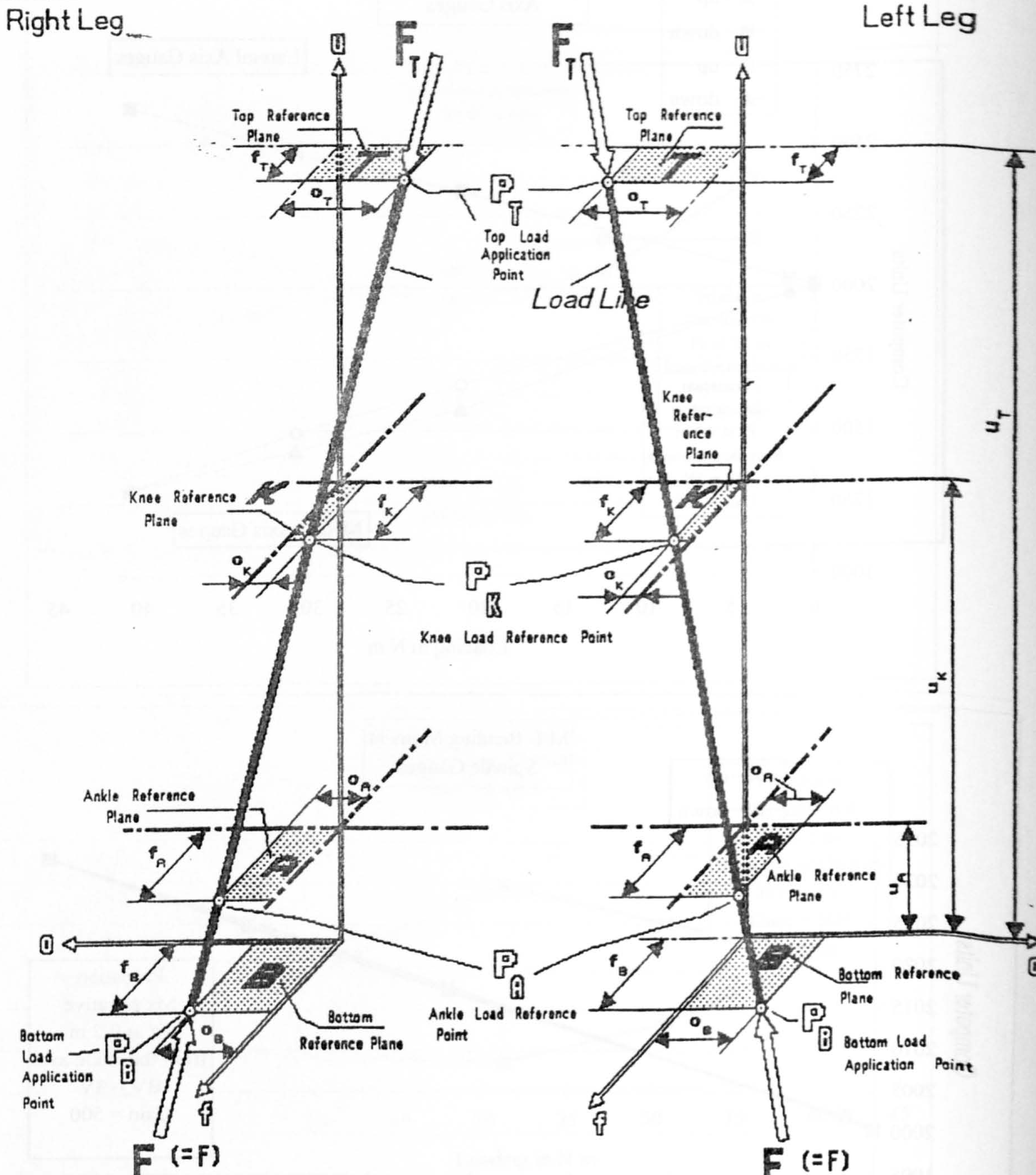


Figure III.12: Specific configuration for right and left leg showing co-ordinate systems with reference planes, lines, points and test force F.

11.III.5 The ISO recommendations for structural testing of lower limb prostheses

The following figures and tables are extracted from ISO 10328, Part 1 to Part 4. There were prepared by Technical Committee ISO/ TC 168 *Prosthetics and Orthotics.*

Figure III.12 shows the specific configuration of the right and left leg, seen face on. It shows the co-ordinate systems with reference planes, reference lines, reference points and test force F. The distance f_A (between the vertical line u and the load line at the ankle level) is important to evaluate the maximum A/P bending moment, relative to the requirements expressed in chapter 4.

Figure III.13 shows the measures for determining effective ankle joint centre line, effective ankle joint centre and combined bottom offset using centre line of foot.

Figure III.14 shows the application of a specific test configuration to a left-sided transferral prosthesis. The length f_A is shown more accurately than in figure III.12: it is the distance between 1) the common point shared with the effective ankle joint centre and the effective ankle joint centre line and 2) the ankle load reference point. This distance is given by ISO to have a value of 0.12 m.

Figure III.15 shows the total sample length and the test configuration for static failure test. The static proof test configuration and the test forces were shown in figure 4.23. The test loading condition I corresponds to late stance phase of the gait cycle (toe off) while the test loading condition stands for the early stance phase of the gaít cycle (heel strike). The test load level A100 is for an adult amputee in the middle range (A60 – A150).

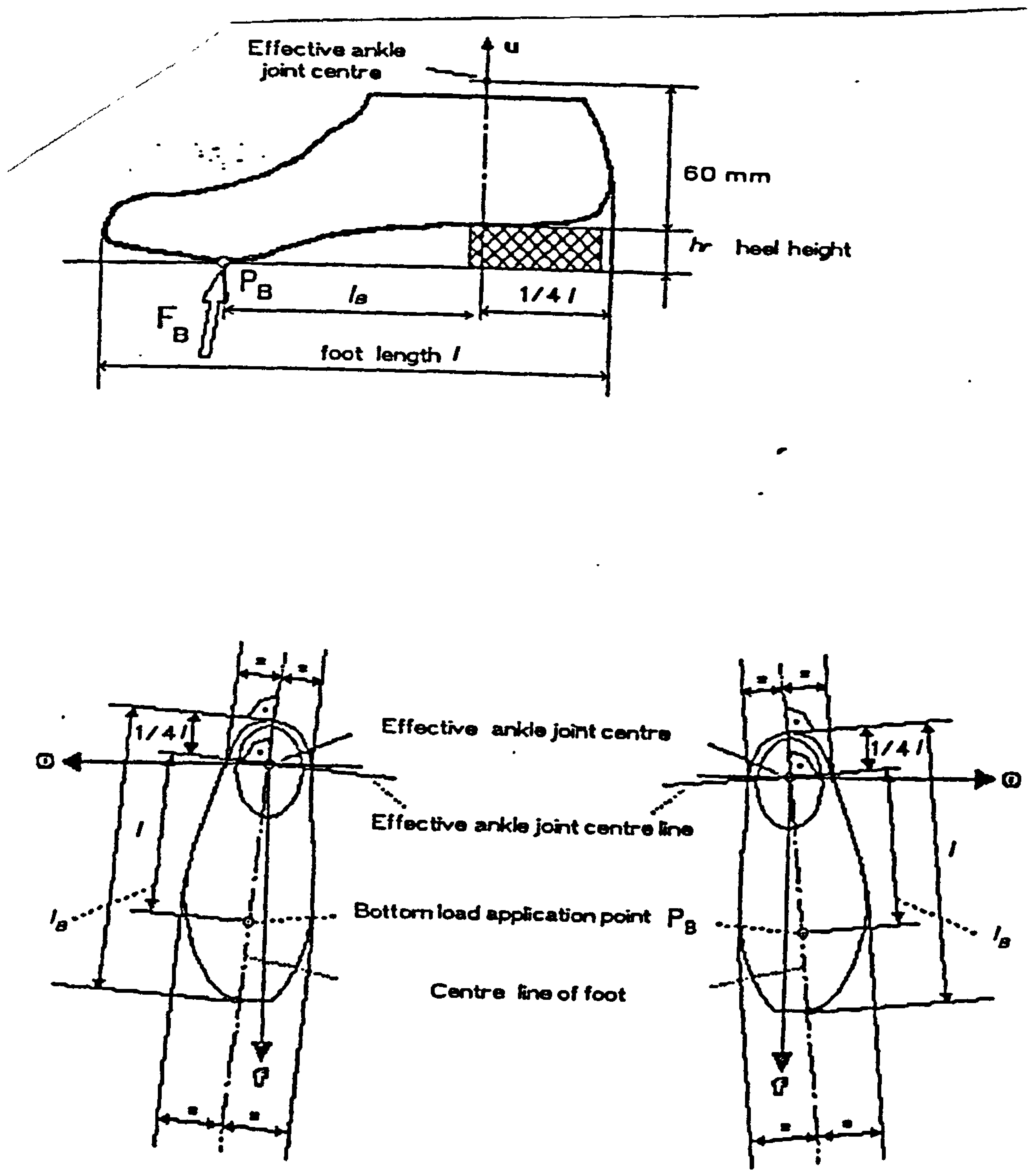


Figure III.13: Measures for determining effective ankle joint centre and centre line. The combined bottom offset, using the centre line of the foot, is also shown.

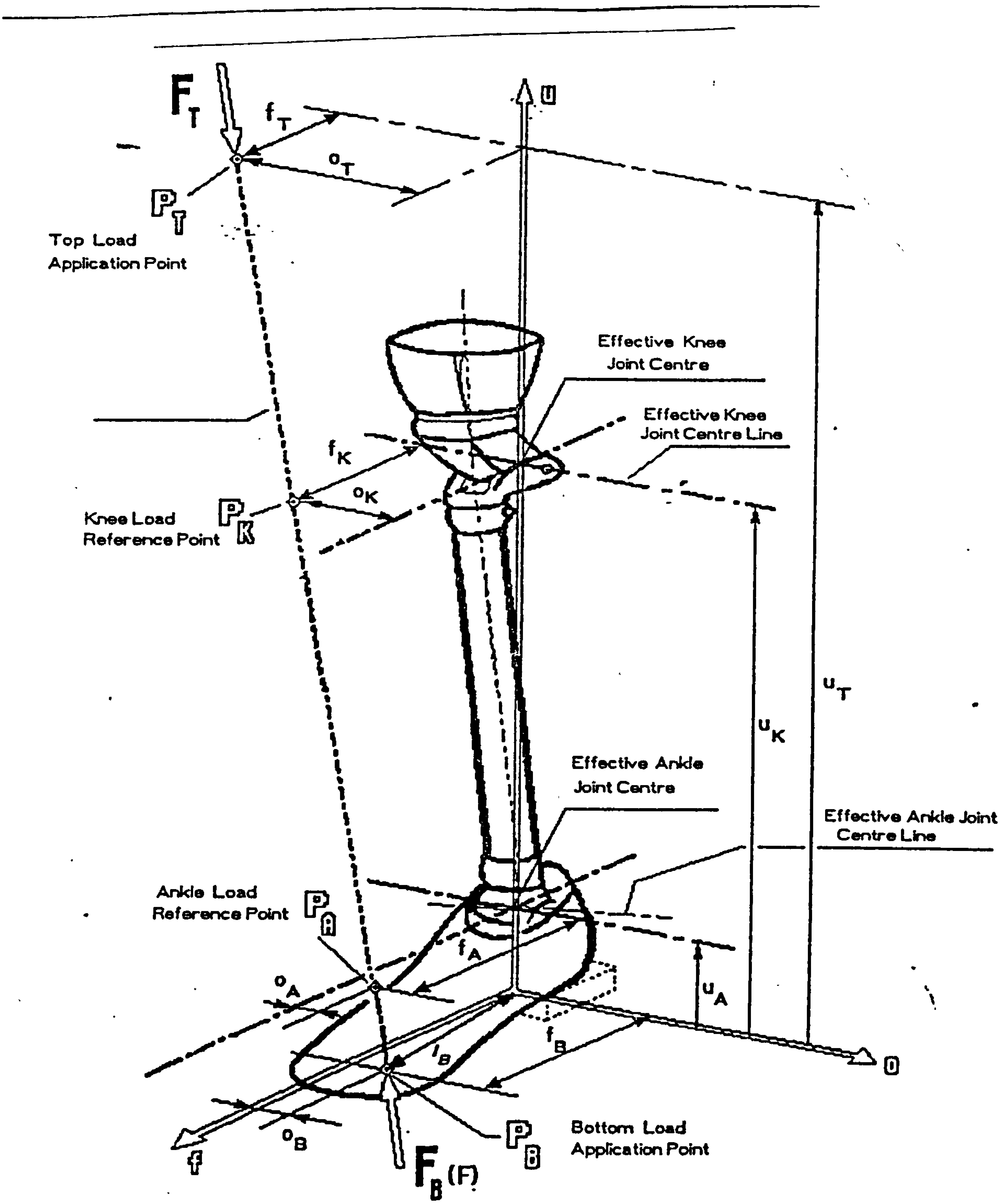


Figure III.14: The application of a specific test configuration: f_A is positive at the level of 0.12 m.

u-level	Combination of Dimensions (mm)		
	A	B	C
u_T u_K u_A u_B	$u_T - u_K = 150$ $u_K - u_A = 440 - h_r$ $u_A - u_B = 60 + h_r$	$u_T - u_K = 150$ $u_K - u_B = 500$	$u_T - u_A = 590 - h_r$ $u_A - u_B = 60 + h_r$
Total Length	650	650	650

h_r = recommended heel height in [mm]

Legend

complete structures	A
part structures	A, B, C
foot structures	(B), C
any other structure	A, B, C

Note: The legend only offers typical examples

	proof test force at attachement	static proof test force	static proof test force at failure	
Loading condition	F_{pa} [N]	F_{sp} [N]	F_{su} [N] *ductile*	*brittle*
I	5376	2560	3328	4480
II	4830	2300	2990	4025

4.2 Test configurations for test load loading conditions I and II

4.2.1 Static failure test

Offsets corresponding to clause 6.2.6 of ISO 10328-3

Table 2: Test loading condition I

Reference Plane	Offsets Direction	Value [mm]	Combined Value [mm]	Combined Angle [°]
Top*	f_T	132	182.6	-46.3
	o_T	-126.2		
Knee	f_K	52		
	o_K	-50		
Ankle	f_A	-32		
	o_A	30		
Bottom*	f_B	-48	66	-43.3
	o_B	45.2		

Test loading condition II

Reference Plane	Offsets Direction	Value [mm]	Combined Value [mm]	Combined Angle [°]
Top*	f_T	24.3	53.3	-27.1
	o_T	-47.4		
Knee	f_K	71		
	o_K	-35		
Ankle	f_A	120		
	o_A	-22		
Bottom*	f_B	129.3	130.8	-81.4
	o_B	-19.5		

*) only for guidance in aligning test samples

Figure III.15: The total sample length and the test configuration for static failure. The load level is for a middle range adult.

11.IV THE THEORETICAL STRAIN AND STRESS ANALYSIS MADE TO CHOOSE THE BEST TRANSDUCER'S SHAPE

11.IV.1 The ISO recommendations and the choice of the material

When it is used, a prosthetic component is subjected to several load actions, each of them varying individually with time. The test method specified by ISO consists of simplified static and cyclic strength tests in which compound loadings are produced by the application of a single test force (see appendix 11.III.5). The static tests relate the highest loads generated in any activity (ISO 10328-4, 1993). Consequently, these static loads were applied to test the new transducer.

This new device was built to be situated between the artificial foot and the shank tube. Therefore, it replaces the Proteor® artificial ankle[4]. Hence, the ISO recommendations for the ankle level must be taken in account. For static test condition, maximums are as follows:

Fy (Axial Load)	2560 N
Anterio-Posterior Ankle Moment (Dorsiflexion)	2560 * 0.12 = 307 N.m

Thus, the worst condition is the A/P bending moment in dorsiflexion and, because a cantilever configuration will be used, an A/P shear force Fx will be simultaneously applied (see the set-up in section 4.6.1.1).

11.IV.1.1 PRELIMINARY THEORETICAL STRAIN - STRESS ANALYSIS

The theoretical analysis has been made following the method explained by Roark (1954) and Benham & Crawford (1988).

The following assumptions about the transducer have been made: the pylon is considered to be machined to exactly its nominal dimensions without any discrepancies in the transverse plane. In other words, all cylindrical surfaces are co-axial about the device's axis, which is the Y axis.

Various geometrical properties of the cross-section of the transducer will be used in this study. These properties are the following:

1. gauged part of solid spindle (15 mm as diameter):

- area $A = \frac{\pi}{4} * D^2 = 176.7\ mm^2 = 1.77\ 10^{-4}\ m^2$

- second moment of area I (about X or Z axis)

$$I = \frac{\pi}{64} * D^4 = 2485\ mm^4 = 24.85 * 10^{-10} m^4$$

2. gauged part of hollow spindle:

- area $A = \pi * (R_o^2 - R_i^2) = 126.45\ mm^2 = 1.26 * 10^{-4}\ m^2$
- second moment of area I (about X or Z axis)

[4]Proteor - Handicap Technologie, 21, rue des Buttes 21000 Dijon, France

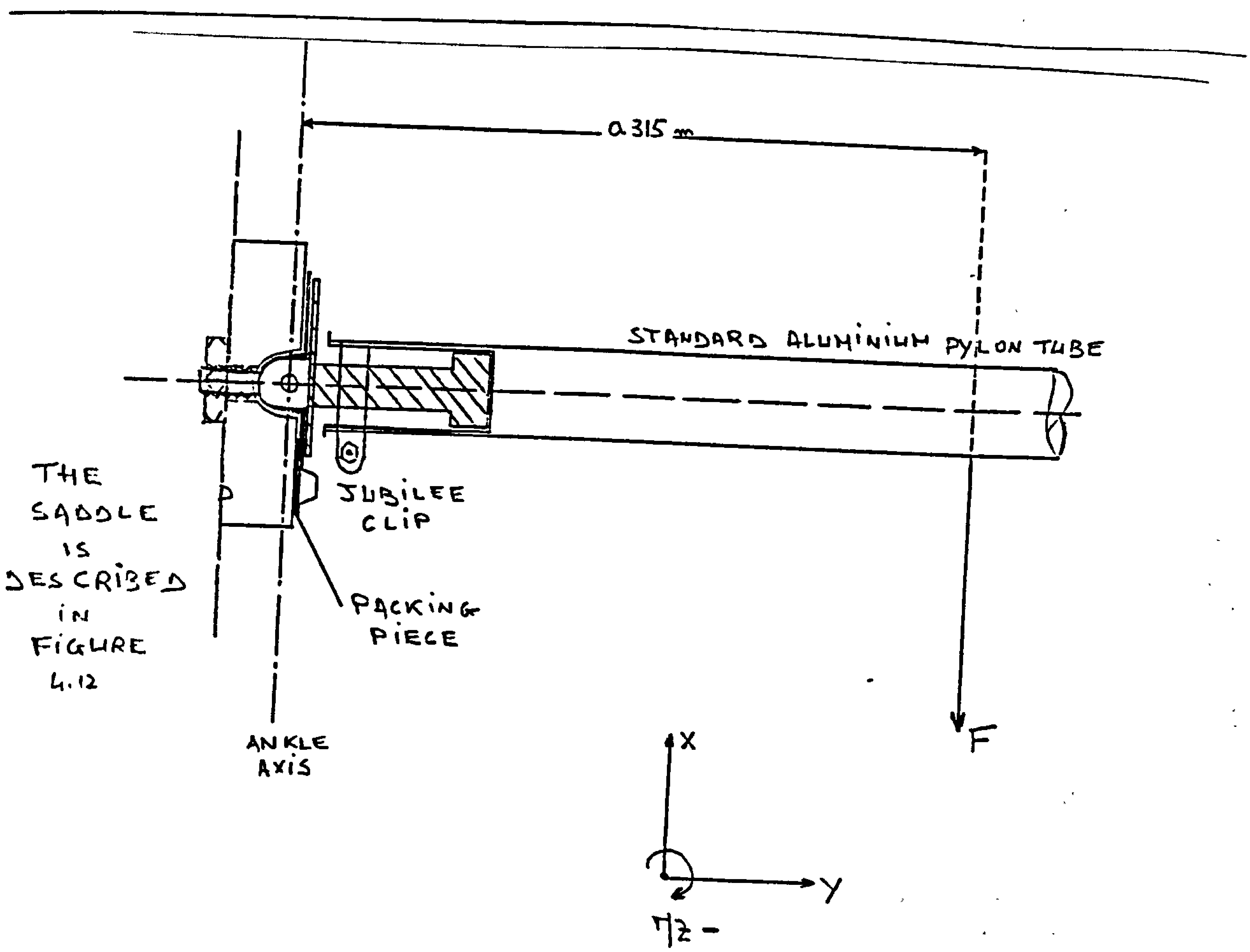


Figure IV.1: The set up for A/P bending moments: a cantilever configuration and details of the complete assembly of the transducer.
The aluminium pylon tube has standard dimensions: 26/30 mm

	SOLID SPINDLE (Model II) diameter = 0.015 m		HOLLOW SPINDLE (Model III) outer diameter = 0.015 m inner diameter = 0.008 m	
	stress σ MPa	strain με	stress σ MPa	strain με
axial load along the Y axis 2560 N	14.48	72.44	20.24	101.2
Bending moment about Z axis (dorsiflexion) 307 N.m and shear force 990 N	926	4630	1008	5040

Table IV.1: Summary of theoretical strains and stresses when the ISO recommendations were applied on the two models.

$$I = \frac{\pi}{4} * (R_0^4 - R_i^4) = 2284 \text{ mm}^4 = 22.84 * 10^{-10} \text{m}^4$$

in which R_o and R_i are respectively the outer (6.5 mm) and the inner (4 mm) radius.

The stress is the intensity of a force applied to, or distributed over a surface, i.e. the force per unit area written σ as direct or normal stress and τ as shear stress (unit is $Pa = N * m^{-2}$ or $MPa = N * mm^{-2}$). In practice, it should be noted that the stress cannot be measured directly. It can only be calculated from a knowledge of the strain in the material or from the applied load actions. The associated strain is the deformation resulting from any stress measured by the fractional change in length of a line due to a linear strain and symbol ε. Stress and strain are linked by Hooke's law, within the linear elastic region in which E is a coefficient named the Young's modulus of elasticity, a property of the material:

$$\sigma = E*\varepsilon$$

The modulus of elasticity of stainless steel, at room temperature, is:

200×10^3 MPa.

11.IV.1.2 STUDY OF THE TWO TENSILE (MODEL II AND III) SPECIMENS FOR APPLIED AXIAL LOAD

Strain ε and normal stress σ are related to the longitudinal applied load (Fy) by the following equation, in which A is the area of the section (Roark 1954, p. 76):

$$\varepsilon = \frac{\sigma}{E} = \frac{Fy}{A*E} \tag{IV.1}$$

This gives for the solid spindle under an axial load of 2560 N, a maximum stress equal to 14.48 MPa with a strain equal to 72.44 $\mu\varepsilon$. For the hollow spindle, the maximum stress is equal to 20.24 MPa with a strain equal to 101.2 $\mu\varepsilon$.

11.IV.1.3 STUDY OF THE TWO TENSILE SPECIMENS (MODEL II AND III) FOR BENDING MOMENTS

Strain ε and normal stress σ are related to the bending moments about the X or Z axes by the following equation (Buhot & Thuillier, 1986, p. 82):

$$\sigma = \pm \frac{M_{xz}}{I} R_0 \tag{IV.2}$$

This gives for the solid spindle under a maximum dorsiflexion bending moment of 307 N.m, a stress equal to 926.5 MPa with a strain equal to 4630 $\mu\varepsilon$. For the hollow spindle, the corresponding values are respectively 1008 MPa and 5040 $\mu\varepsilon$. Figure IV.1 shows the set up for the bending tests. It is a cantilever configuration. Therefore, it has a combined load: shear force (990 N) and bending moment (307 N.m with a lever arm of 0.315 m). Hence, a single set up explores two load cases. Therefore, it is possible to summarise as shown in table IV.1.

11.IV.1.4 DEFINITIVE CHOICE OF THE MATERIAL

Therefore, the absolute maximum stress applied on the transducer shall be 1008 MPa. Thus, the material must have a tensile strength sufficient to resist a static bending stress of 1008 MPa. There are also some more requirements. The material must also have enough rigidity to be able to be used in strain gauge measurement technology. Because the transducer will be used on an artificial limb, distally situated, the density of the material should be as low as possible. The manufacture should be the easiest and finally, the cost should be low.

Considering the little time of use expected for the transducer, i.e., about two and four tests a week, each of them having an average gait duration of thirty minutes (less than one thousand

	C	Si	Mn	S	P	Ni	Cr	Mo	Cu
Cast N 8673 in %	0.045	0.22	0.84	< 0.003	0.018	4.13	13.87	0.08	3.137

Cast acceptance tests	Tensile test			Impact test	Hardness
	Tensile strength MPa	Proof stress MPa	Minimum elongation (5d)		
Heat treatment conditions 480°C — 1 h — air cooling	1370	1227	15.2	KV = 217	HB = 415

The company certify that the order has been manufactured in its steelworks from a cast the composition and mechanical properties of which are detailed here above

Young's modulus of elasticity E	$200 * 10^3$ MPa	200 GN $* m^{-2}$
Poisson's ratio ν	0.285	
shear modulus $G = \dfrac{E}{2(1+\nu)}$	$77.82 * 10^3$ MPa	77.82 GN $* m^{-2}$

Table IV.2: The composition of the chosen material: hard stainless steel alloy (international registration number: X17U4) as specified by the manufacturer; Young's modulus of elasticity is known only after the heat treatment steps with a gait rate about 2 s.stride^{-1}, see section 8.2), a dynamic study has not been considered necessary. A full cyclic test procedure is $5*10^6$ loading cycles at the frequency of 1 Hz (ISO 10328-3, 1993) and therefore this extensive procedure has not been conducted. These requirements could be shown in a comparative table summarising the typical properties of the three possible materials (Laboisse, 1991):

	maximum required values	stainless steel alloy X17U4	wrought titanium alloy Grade TA1	beryllium bronze Be 0.2 %
tensile strength	1008 MPa	1350 MPa	900 MPa	800 MPa
proof stress	the highest	1200 MPa	830 MPa	600 MPa
Density	the smallest	6.6	4.5	8.25
Cost	the lowest	not expensive	expensive	not expensive

It is easy to see that only the stainless steel alloy X17U4[5] will provide sufficient tensile strength, even if a hollow spindle was chosen (Model III). In addition, it is better to use the material at a stress no higher than 75 % of its own tensile strength (Laboisse, 1991). Therefore, the X17U4 stainless steel has been chosen despite its relatively high density. It is principally a steel alloy containing chromium (17 %), nickel (4 %) and copper (3.1 %). The complete description of the material is given in table IV.2. It has to be subjected to heat treatment at 480°C for one hour followed by a simple air cooling to improve its hardness (HB = 415).

11.IV.2 Results concerning the mechanical behaviour of the two prototypes

Two prototypes were built, 1) having the spindle of the body of the transducer solid, 2) having the spindle hollow. These two prototypes were mechanically tested by the mean of a clock-gauge to measure the deflexion. To increase the accuracy of the results to ensure that the conclusions were reliable, the tests were performed using: 1) the usual aluminium bell (the one used in calibration, validation and patients tests) and 2) a reverse bell made of steel (see description in section 6.4.2). Only one example in each configuration is shown. The different results are shown in the following order:

Table IV.3a (solid spindle) and b (hollow spindle): A/P bending moment Mz + which is dorsiflexion, averaging 8 tests for each prototype (4 with the usual bell and 4 with the reverse bell). Between each test, the set up was dismantled. For heat treatment reasons, i.e., the hollow prototype was not yet heat treated to be able to modify or if necessary, the hollow prototype was weaker than the solid one. Therefore, the maximum bending moment for the hollow transducer 145.7 N.m and 269.4 N.m for the solid spindle prototype. The application point of the force F was at 0.315 m from the ankle axis. The measurement needle of the clock gauge was at 0.07 m from the ankle axis. At full load, a stop of five minutes was observed to check if there was a beginning of any creep, which could justify more investigations. The results found in A/P bending moment Mz – which is plantarflexion were similar and thus are not shown under the form of a table. They are shown in figure IV.2. Because of the expected value of the plantarflexion during amputees' gait, the maximum value was 86.8 N.m for both prototypes. Concerning the gap of the results expressed by the two prototypes, see section 6.4.1 for further explanations.

Table IV.4 shows the statistical regression analysis of 5 tests performed with the prototype having the hollow spindle in A/P bending moment positive (dorsiflexion). The

[5]Acieries Aubert et Duval, 41 rue de Villiers, 92200 Neuilly sur Seine, France

A/P Bending Moment				BELL	BELL	REVERSE	REVERSE
Mz positive						BELL	BELL
Dorsiflexion	Mass	Weight	Moment	Clock-gauge	Clock-gauge	Clock-gauge	Clock-gauge
F at 0.315 m	kg	N	N.m	mm	mm	mm	mm
Clock-gauge at 0.07 m				mean 2 tests	mean 2 tests	mean 2 tests	mean 2 tests
from ankle axis	0.9	8.7	2.7	0.00	0.00	0	0.00
	10.0	97.7	30.8	0.20	0.26	0.2	0.25
Solid	19.0	186.6	58.8	0.45	0.54	0.44	0.49
Spindle	28.1	275.6	86.8	0.70	0.78	0.67	0.73
	37.2	364.6	114.8	0.93	1.02	0.89	0.96
	47.2	462.7	145.7	1.16	1.25	1.11	1.17
	57.2	560.8	176.6	1.40	1.50	1.34	1.41
	67.2	658.9	207.5	1.66	1.75	1.58	1.65
	77.2	757.0	238.5	1.90	1.99	1.82	1.88
	87.2	855.1	269.4	2.13	2.25	2.06	2.12
5 minutes later	87.2	855.1	269.4	2.16	2.27	2.08	2.13
	77.2	757.0	238.5	1.91	2.01	1.85	1.90
	67.2	658.9	207.5	1.68	1.78	1.63	1.68
	57.2	560.8	176.6	1.43	1.54	1.39	1.41
	47.2	462.7	145.7	1.19	1.29	1.17	1.21
	37.2	364.6	114.8	0.97	1.06	0.96	1.01
	28.1	275.6	86.8	0.73	0.82	0.74	0.76
	19.0	186.6	58.8	0.48	0.58	0.51	0.53
	10.0	97.7	30.8	0.21	0.30	0.25	0.28
	0.9	8.7	2.7	0.00	0.01	0.01	0.01

Table IV.3a: The results (A/P Bending Moment + versus Deflection) from 8 tests with the prototype having the solid spindle.

A/P Bending Moment				BELL	BELL	REVERSE	REVERSE
Mz positive						BELL	BELL
Dorsiflexion	Mass	Weight	Moment	Clock-gauge	Clock-gauge	Clock-gauge	Clock-gauge
F at 0.315 m	kg	N	Nm	mm	mm	mm	mm
Clock-gauge at 0.07 m				mean 2 tests	mean 2 tests	mean 2 tests	mean 2 tests
from ankle axis	0.9	8.7	2.7	0.04	0.06	0.06	0.06
	10.0	97.7	30.8	0.14	0.19	0.18	0.17
Hollow	19.0	186.6	58.8	0.24	0.28	0.27	0.27
Spindle	28.1	275.6	86.8	0.32	0.37	0.37	0.36
	37.2	364.6	114.8	0.40	0.46	0.46	0.46
	47.2	462.7	145.7	0.48	0.54	0.55	0.55
5 minutes later	47.2	462.7	145.7	0.49	0.55	0.55	0.55
	37.2	364.6	114.8	0.42	0.41	0.48	0.47
	28.1	275.6	86.8	0.34	0.33	0.39	0.39
	19.0	186.6	58.8	0.26	0.23	0.20	0.21
	10.0	97.7	30.8	0.16	0.10	0.08	0.08
	0.9	8.7	2.7	0.05	0.05	0.00	0.03

Table IV.3b: The results (A/P Bending Moment + versus Deflection) from 8 tests with the prototype having the hollow spindle.

results show a good linearity (R square = 0.98 and x_1 intercept (slope) = 0.0034). See explanations in section 6.4.1.

Figure IV.2 shows the mechanical deflection of the prototype with the hollow spindle under a M/L bending moment positive and negative. The prototype was tested with the usual bell and the reverse bell. The traces are closed to themselves; it is thus possible to conclude that the aluminium bell that will be used in the definitive Villiers Pylon Transducer does not affect the deflection of the body of the transducer. As above in A/P bending moments, the application point of the force F was at 0.315 m from the ankle axis. The measurement needle of the clock gauge was at 0.07 m from the ankle axis.

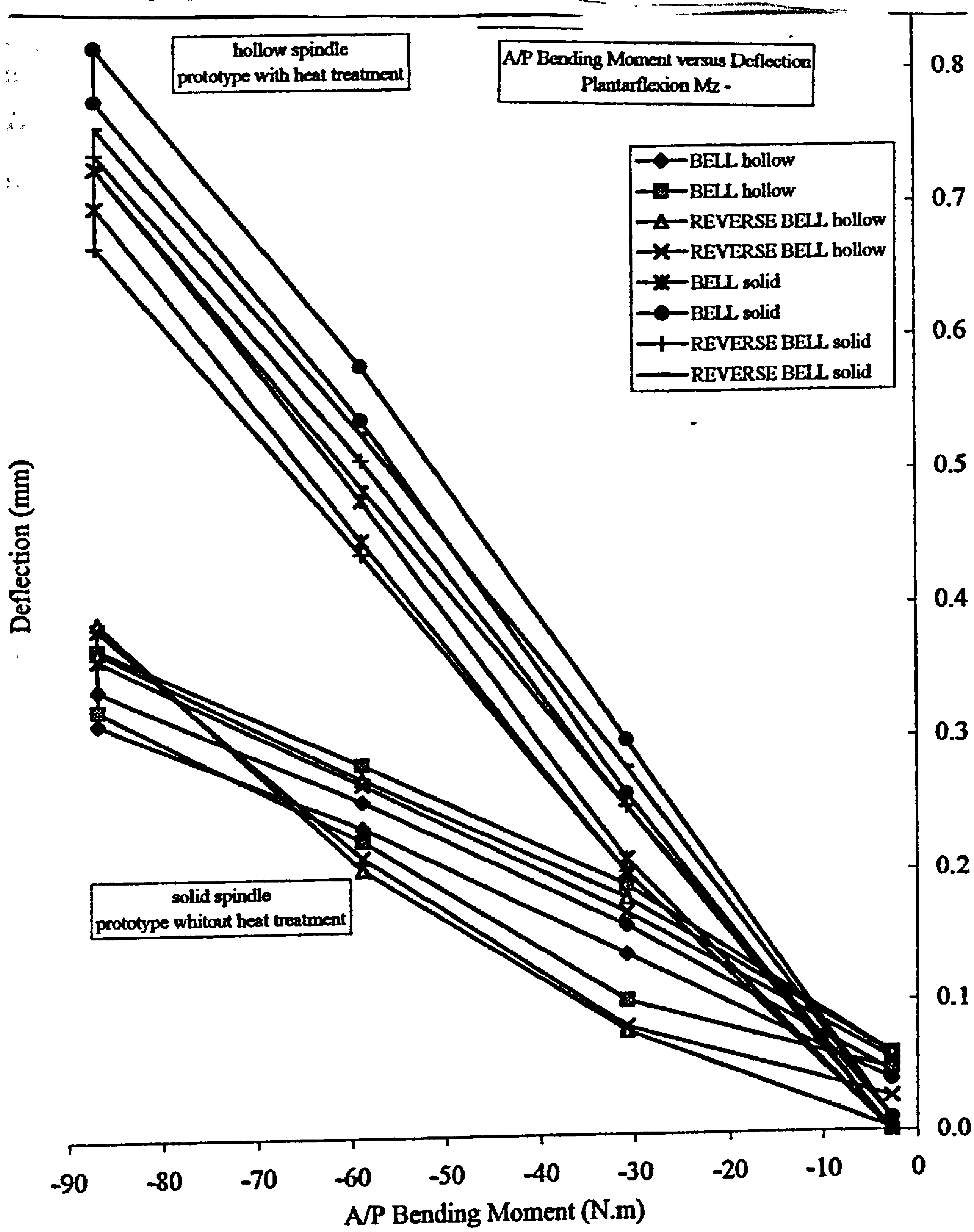


Figure IV.2: The results of the mechanical study of A/P bending moment Mz – (plantarflexion) expressed by the two prototypes using the two bells. No differences were found using one bell or the other one. However, the two devices showed a gap in the results.

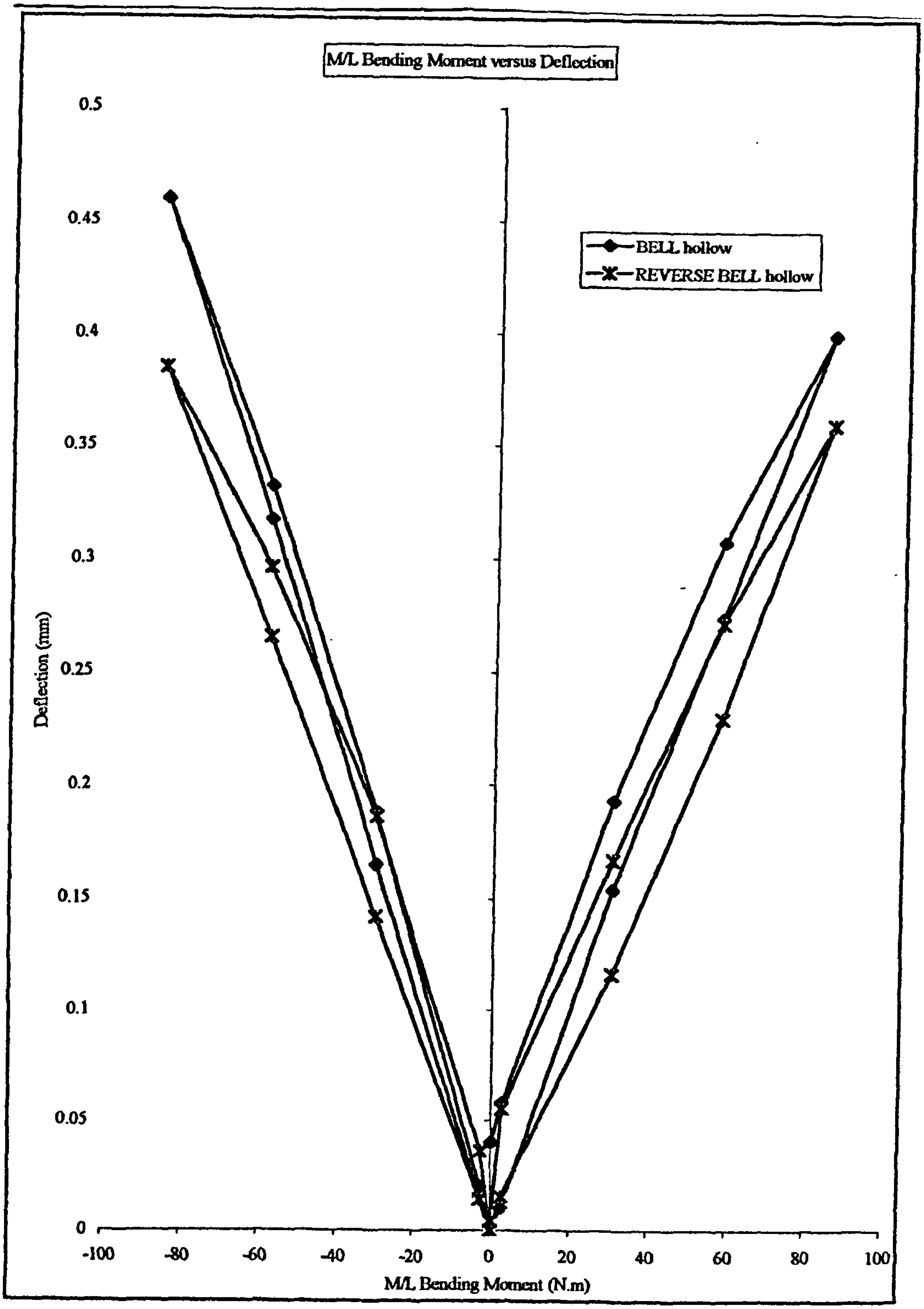


Figure IV.3: The deflection of the prototype having the hollow spindle tested with the usual and the reverse bell under a M/L bending moment Mx positive and negative in N.m. The traces are approximately closed to themselves: the aluminium bell does not change the deflection relative to the reverse bell.

11.IV.3 Study of the electrical behaviour of the chosen prototype (Model III)

11.IV.3.1 DESCRIPTION OF THE GAUGES

Low cost 120 Ω gauges from SHOWA Measuring Instruments Co.[6] were used. Their type is shown in table IV.5. The gauge design is given in figure IV.4 and they were located as shown in figure IV.5 in a development view of the transducer's surface. The position of the gauges was strictly in the anterio-posterior plane. The zero position, that is the reference point for all gauge bridges, is in front of the transducer as shown in figure IV.6 in a horizontal view. This is the position and the grid's configuration of strain gauges recommended by Murray & Stein (1957) for measurement of bending moments. Regarding the temperature compensation, it was for aluminium but the mounting surface was stainless steel. However, gauges are in a bridge arrangement which automatically compensates for temperature effects, especially for a temporary used in stabilised room temperature.

11.IV.3.2 WHEATSTONE FULL BRIDGE DESCRIPTION

A full Wheatstone bridge configuration was used: four gauges whose characteristic is represented by a resistance G_1, G_2, G_3 and G_4, one of them in each arm of the bridge.

The bridge has to be supplied with an input voltage Vs. The choice of this input depends on several factors that are:

1. strain gauge grid area (active gauge length x active grid width)

2. gauge resistance: a high resistance allows a higher voltage for a given power level and thus a higher sensitivity

3. heat-sink properties of the mounting surface

The chart on optimising strain gauge excitation level from Vishay Measurement Group[7] (TN-502, 1979) is shown in table IV.6. This technical note allows the choice of the best bridge voltage. For the new transducer's material, having a power density of 3 $kw.m^{-2}$ (see section 4.8.3) (line AB), with these gauges having a grid area of 4 mm^2 (line AC), the recommended voltage is three volts (BV = 3V) (line AD). In all tests, this BV will be used without any change.

11.IV.3.3 OUTPUT VOLTAGE

The output of the circuit is the voltage V_o as shown in figure IV.6. The ability of strain gauges to detect strain is based upon the fact that strain modifies the shape of the gauges' grid and therefore, the gauges' resistance, having the result of proportionally adjusting the output voltage. Hence, it could be possible to detect any strain under a given load. The V_o output voltage is related to the bridge voltage supply V_s by the following formula:

$$V_o = KV_s \frac{dL}{L} \qquad \text{(IV.3)}$$

In equation IV.3, K is the common gauge factor for all gauges (here, 2.15 ± 0.2, range = 1.95 to 2.35) while $\frac{dL}{L}$ is the linear strain of the gauges due to the applied load. This equation can also be written as follows:

$$V_o = KV_s\varepsilon \qquad \text{(IV.4)}$$

In equation IV.4, the units are volts for the output voltage V_o and volts for bridge voltage V_s. Therefore, the strain ε could be written (RS Data Library, Technical Note,

[6]Showa Measuring Instruments Co., Tokyo, Japan

[7]Vishay Measurements Group, Inc. P.O. Box 27777, Raleigh, North Carolina 27611, USA

Load Case	Test 1	Test 2	Test 3	Test 4	Test 5		*Regression Statistics*			
N.m										
2.73	0.040	0.060	0.060	0.056	0.054		Multiple R	0.993932598		
30.76	0.137	0.190	0.180	0.169	0.169		R Square	0.987902009		
58.79	0.235	0.283	0.272	0.268	0.265		Adjusted R Square	0.98669221		
86.82	0.315	0.370	0.368	0.362	0.354		Standard Error	0.020606835		
114.85	0.395	0.455	0.460	0.457	0.442		Observations	12		
145.75	0.481	0.543	0.552	0.549	0.531					
145.75	0.486	0.549	0.554	0.551	0.535		*Analysis of Variance*			
114.85	0.419	0.414	0.478	0.472	0.446			*df*	*Sum of Squares*	*Mean Square*
86.82	0.340	0.325	0.390	0.385	0.360		Regression	1	0.346755375	0.346755375
58.79	0.255	0.225	0.203	0.212	0.224		Residual	10	0.004246416	0.000424642
30.76	0.159	0.102	0.079	0.082	0.106		Total	11	0.351001792	
2.73	0.046	0.048	0.002	0.027	0.031				*F*	*Significance F*
									816.583544	6.41014E-11
								Coefficients	*Standard Error*	*t Statistic*
							Intercept	0.036457815	0.01076713	3.386028922
							x1	0.003499573	0.000122466	28.57592595
								P-value	*Lower 95%*	*Upper 95%*
								0.006077407	0.012467149	0.06044848
								1.1312E-11	0.003226702	0.003772443

Table IV.4: The regression statistical analysis of 5 tests performed with the prototype having the hollow spindle in A/P bending moment positive (dorsiflexion). The results are linear (R square = 0.99).

1997)[8]:

$$\varepsilon = \frac{1}{K}\frac{V_o}{V_s} \qquad \text{(IV.5)}$$

If the results have to be given in microstrain for ε, the V_o must be in microvolts while V_s remains in volts. It was demonstrated how it was possible to use this equation to check the results and to anticipate the behaviour of the transducer (see section 4.8.4).

11.IV.3.4 A/P BENDING MOMENT POSITIVE: DORSIFLEXION

According to the table 4.1 (see section 4.6.2), 9 tests in Mz + (dorsiflexion) and 4 tests in Mz – (plantarflexion) were performed. Some results are shown in the following figures in complement of the figures 4.17 and 4.19 (see section 4.6.4).

Figure IV.8 shows the traces processed from test 0, 1, 2, 3, and 5. They had two common characteristics: A/P bending moment positive (dorsiflexion) and a maximum load case of 140 N.m. The differences were as follows:

The test 0 had an Acquire software zero line adjusted at the level of 2000 computer units; the tests 1, 2 and 3 had a zero line adjusted at the level of 1000. The traces are parallel; it is thus proved that the accuracy of the results is independent of the level of the zero line chosen in the Acquire software.

The test 5 was performed with the reverse steel bell instead of the usual aluminium bell in the tests 1, 2 and 3. The four traces processed from the four tests are totally superimposed. It is thus proved that the aluminium bell, which covers the gauging area of the new Villiers Pylon Transducer, does not affect the results in this particular channel Mz (A/P bending moment positive).

All these tests were performed with the prototype having the hollow spindle and before heat treatment. The gain was always 500 with a bridge voltage of 3 V.

Table IV.8 shows the numerical results of the test 4 performed to check creep with a maximum positive bending moment Mz of 171 N.m during 140 min. No creep was found: 3523 cu at the beginning of the full bending moment versus 3524 cu, 140 minutes later with the same bending moment.

Figure IV.9 shows the graph of such a test.

Figure IV.10 shows simultaneously the positive A/P bending moment versus computer units and deflection in mm. The traces are linear for the computer units recording but less linear for the deflection. It seems that the set up deflects less when the bending moment is over 60 N.m than when it is lower. However, no formal proof of this assertion could be provided.

Table IV.9 shows the processed data recorded from the tests 7 and 8 having a gain of 200 to be compared with the test 1 (randomly chosen) having a gain of 500. Bridge voltage, load case and set up were identical. The different calculated ratios are close to 2.5 = 500 / 200 except when the load case are very low, i.e., higher than 3 N.m (the two first rows). It is thus proved that the accuracy of the prototype is independent of the level of the gain setting.

[8] RS Components Ltd. PO Box 99, Corby, Northants, NN17 9RS. Great Britain

Type	N11-MA-2-120-23
Gauge Length	2 mm
Resistance	120 Ω
Temp. Compensation for	Aluminium
Gauge factor	2.15 ± 2 %
Thermal output	± 2 µε.C^{-1}

Table IV.5: The temporary SHOWA low cost strain gauges

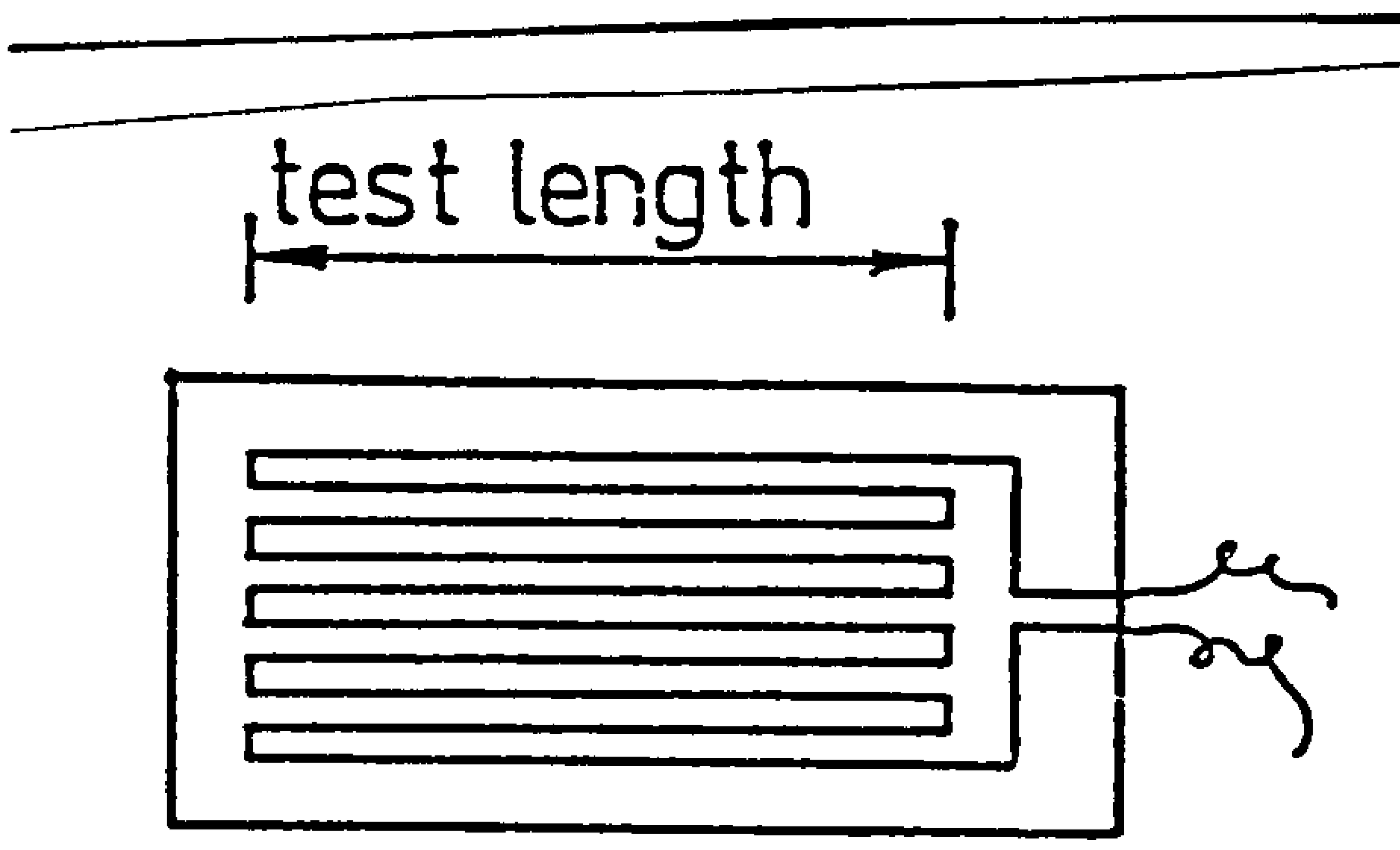
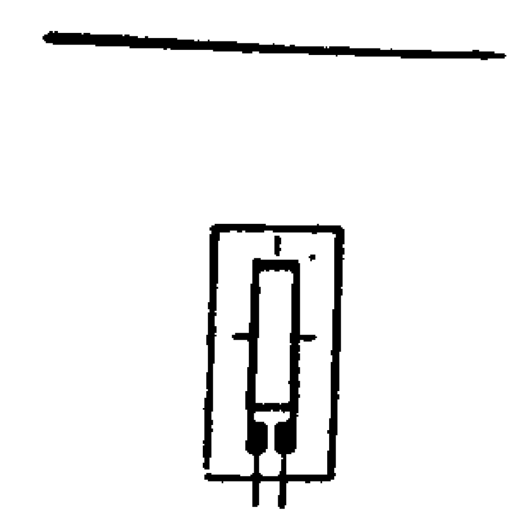


Figure IV.4: Grid and foil gauges description



Details of the gauges (x 4)

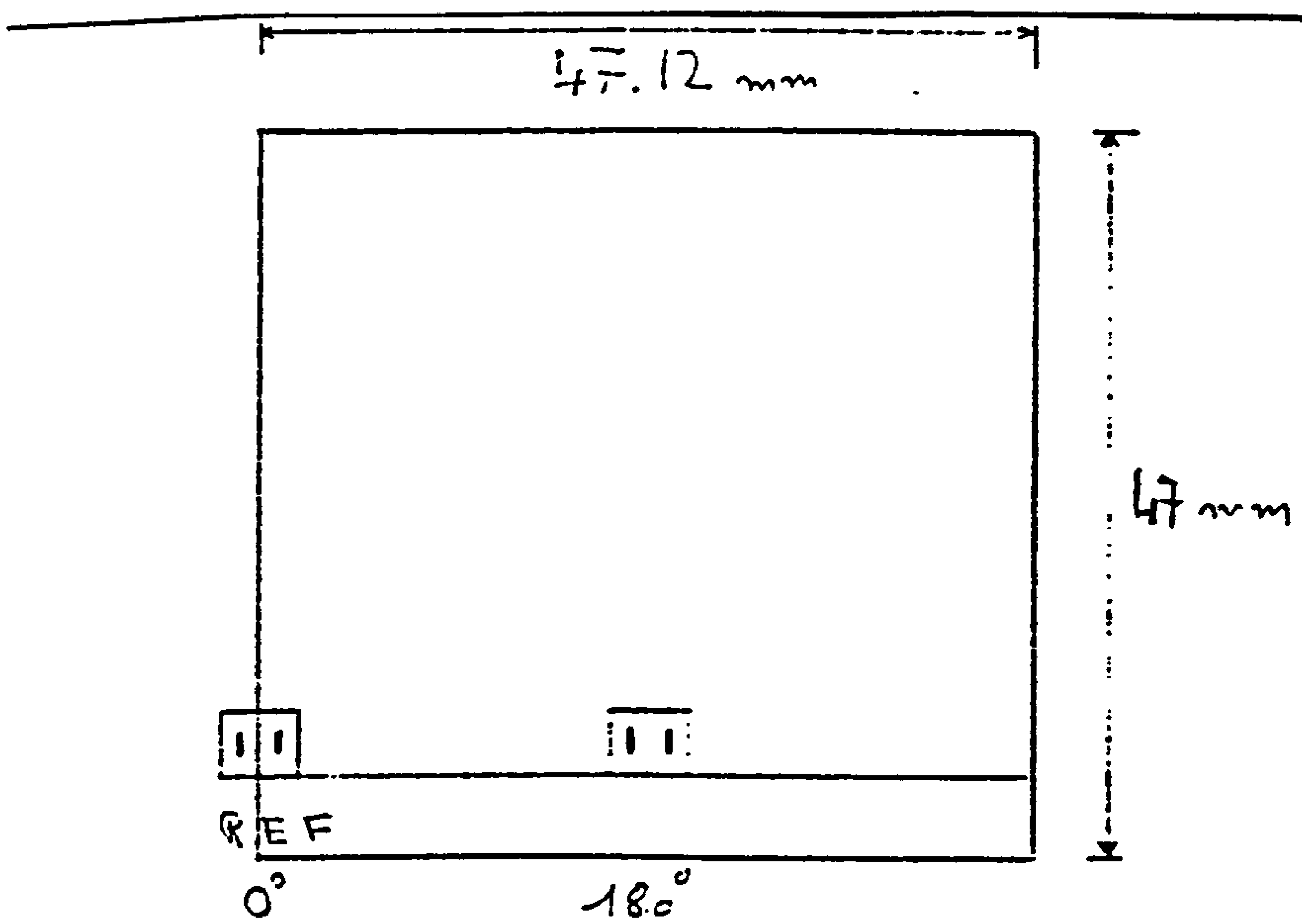


Figure IV.5: Development of the transducer's surface showing the strain gauge location

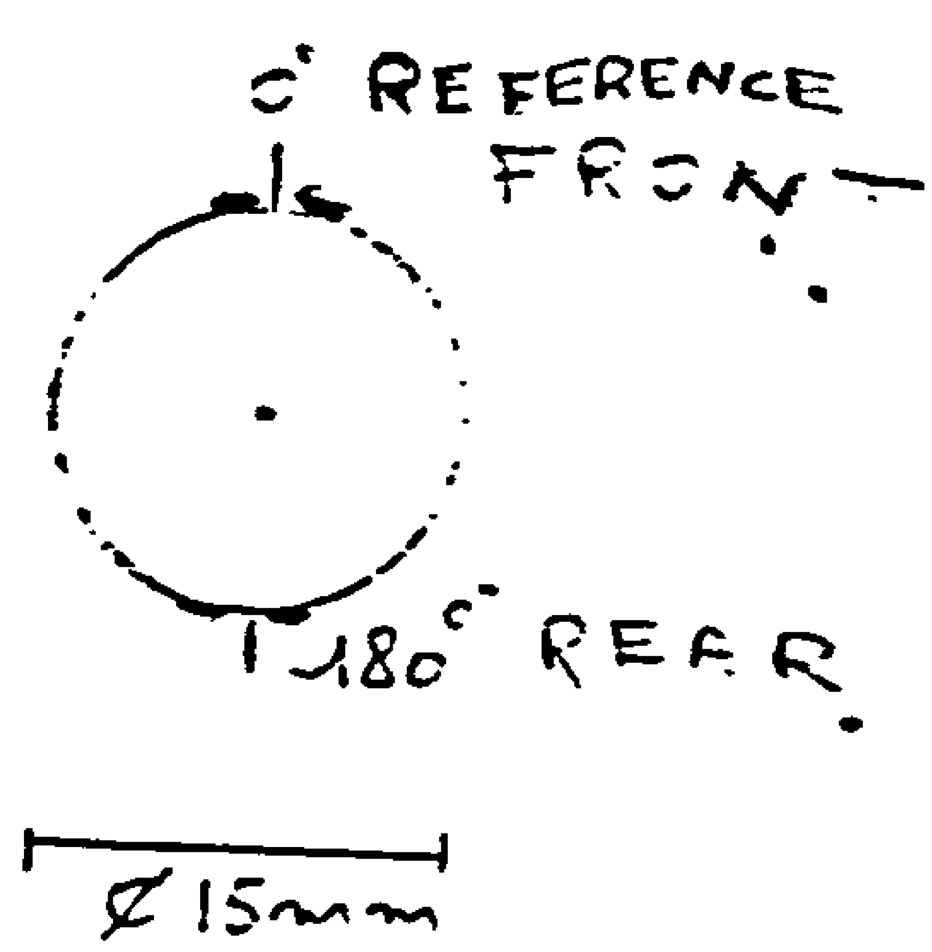


Figure IV.6: Strain gauges location (horizontal view)

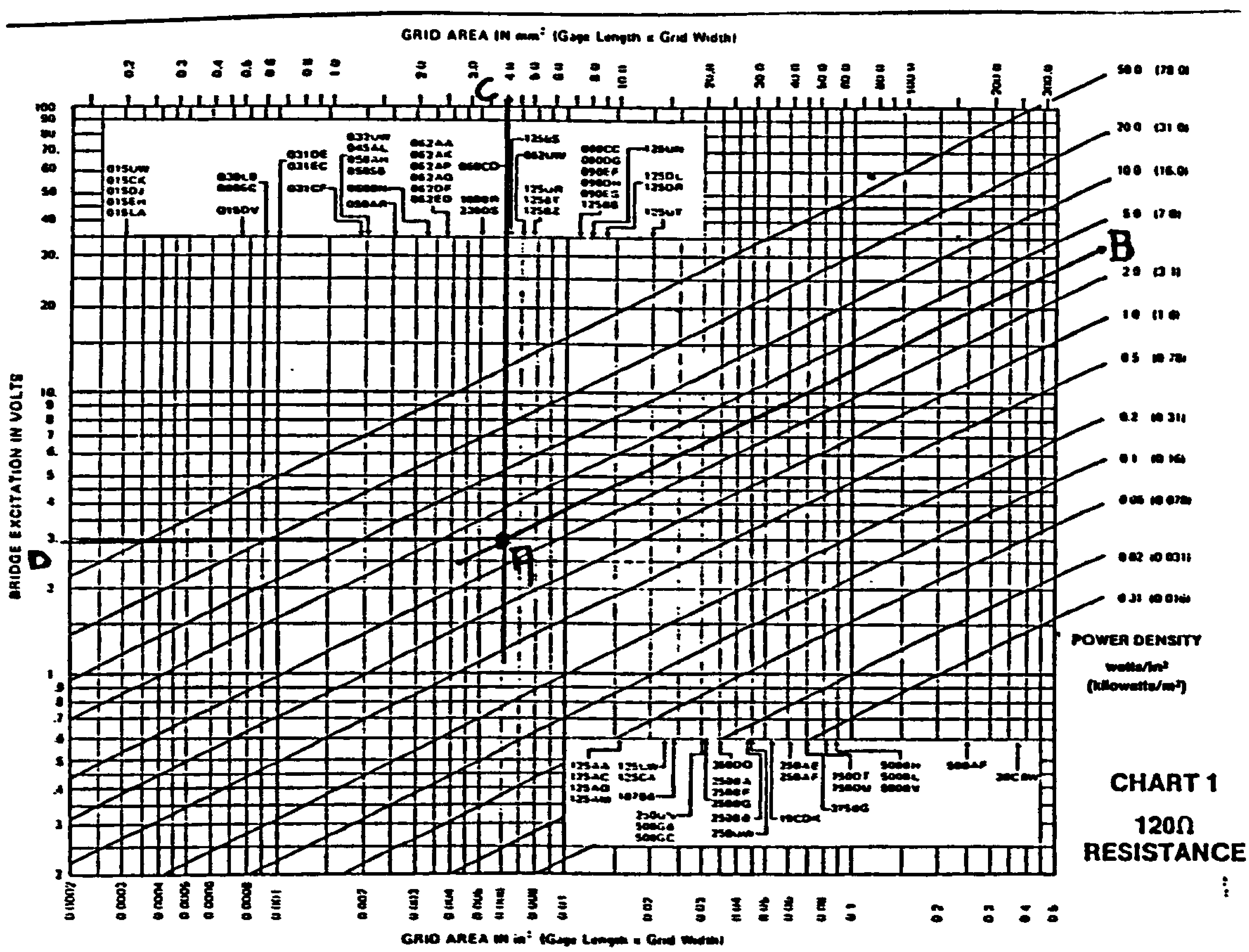
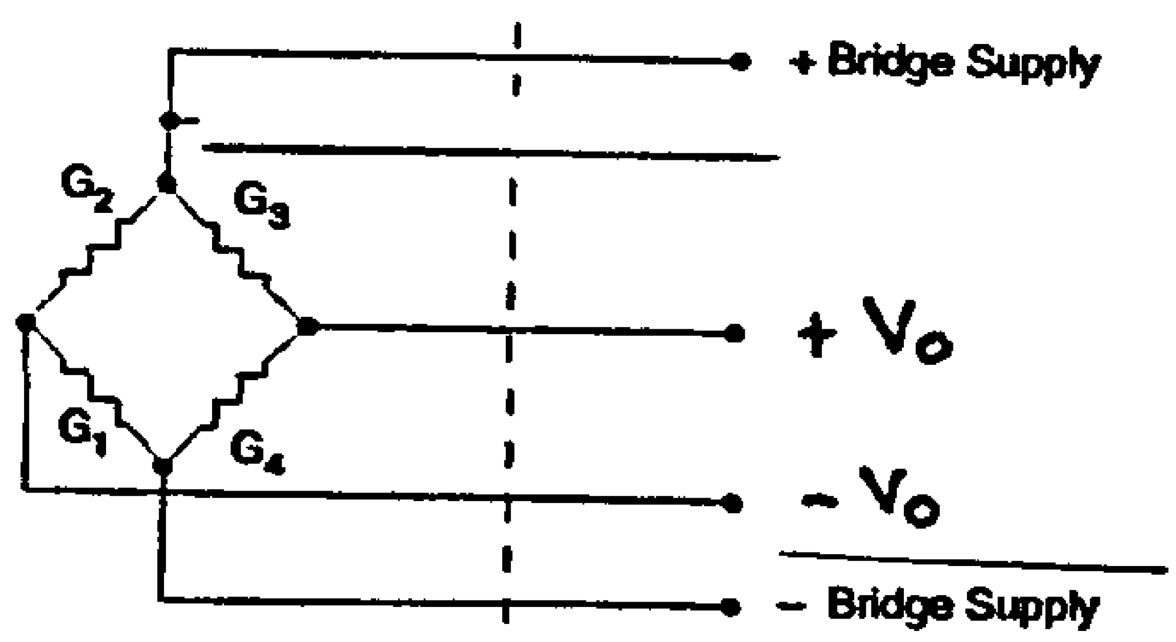


Table IV.6: Chart extracted from Vishay Measurements Group catalogue optimising strain gauge excitation levels

F at 0.315 m from the ankle axis Gain = 500 Bridge Voltage = 3 V	
Dorsiflexion 140.6 N.m	
theoretical value	14.88 mV
mean test value	9.97 mV
Plantarflexion 85.44 N.m	
theoretical value	9.04 mV
mean test value	6.52 mV

Table IV.7: Comparison between theoretical and experimental values in positive and negative A/P bending moments.



$$V_o = e \times V \times K$$

where
V_o is in μV
e is strain in microstrain
V is bridge voltage
K is gauge factor

G_1, G_2, G_3, G_4 are all active gauges.
(adapted from RS Data Library, Technical Note, 1997)

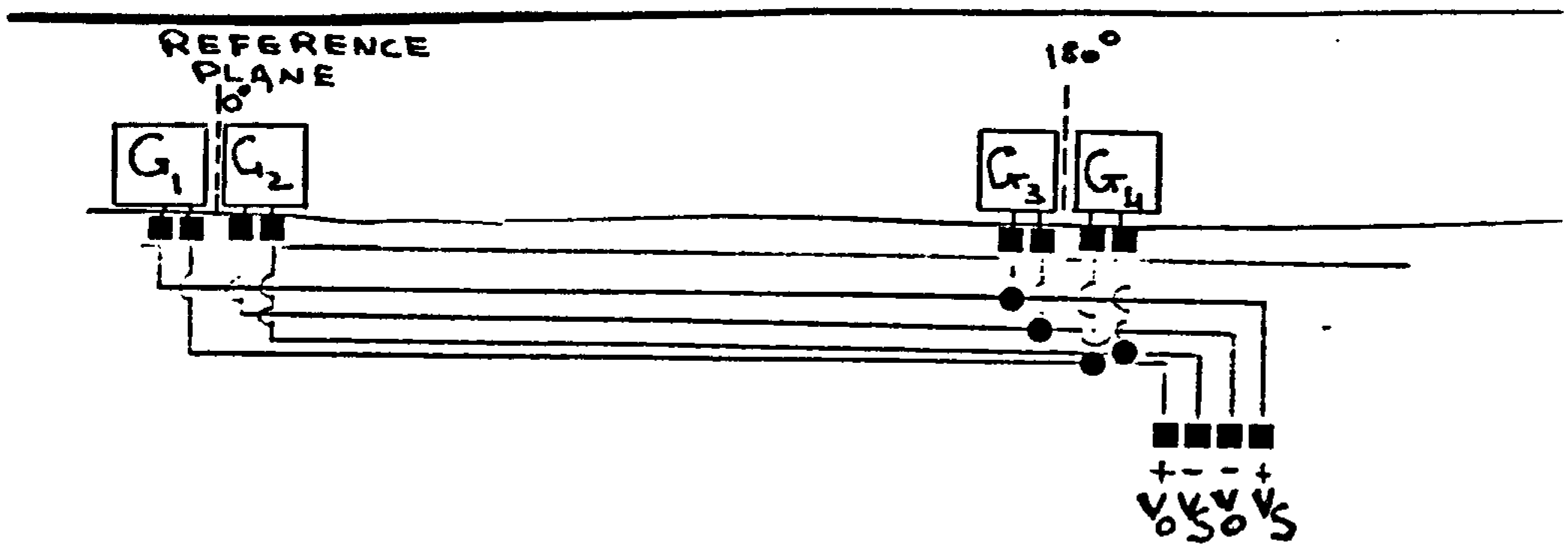


Figure IV.7: The circuit diagram of the full Wheatstone bridge

	Loading Case N.m	Test 4 Computer Units
	0.00	1004
	2.69	1047
	30.27	1450
	57.85	1842
	85.44	2240
	113.02	2638
	140.60	3061
	171.01	3523
140 minutes later	171.01	3524
	140.60	3112
	113.02	2713
	85.44	2313
	57.85	1917
F at 31.5 cm from the ankle axis	30.27	1492
Gain 500	2.69	1050
BV 3 V	0.00	1007

Table IV.8: The numerical results of the test 4 performed to check creep: a stop and a record of 140 min was observed at full bending moment Mz + dorsiflexion.

Load Case	*Test 7*	*Test 8*	*Test 1*	*Ratio Test 7 / Test 1*	*Ratio Test 8 / Test 1*
N.m	*Gain 200*	*Gain 200*	*Gain 500*		
0	1003.1	1001.4	1001.8	0.58	1.29
3	1020.3	1018.4	1045.2	2.23	2.46
30	1193.7	1192.2	1480.3	2.48	2.50
58	1363.3	1361.6	1903.2	2.49	2.50
85	1523.7	1518.6	2292.4	2.47	2.49
113	1674.1	1668.7	2669.9	2.48	2.50
141	1826.8	1822.3	3056.1	2.49	2.50
171	1999.1	1996.1	3503.7	2.51	2.51
171	1998.3	1996.9	3503.8	2.51	2.51
141	1835.7	1833.9	3095.4	2.51	2.51
113	1680.3	1678.6	2704.7	2.51	2.51
85	1527.2	1524.1	2313.3	2.49	2.51
58	1370.2	1367.9	1918.8	2.48	2.50
30	1195.7	1194.1	1484.7	2.48	2.50
3	1019.7	1018.3	1045.2	2.29	2.47
0	1003.4	1001.4	1001.5	0.44	1.07

Table IV.9: In A/P bending moment, positive direction (dorsiflexion), two tests with a gain of 200 and one test with a gain of 500 (BV = 3 V). The ratio is closed to 2.5, the results are thus independent of the gain setting.

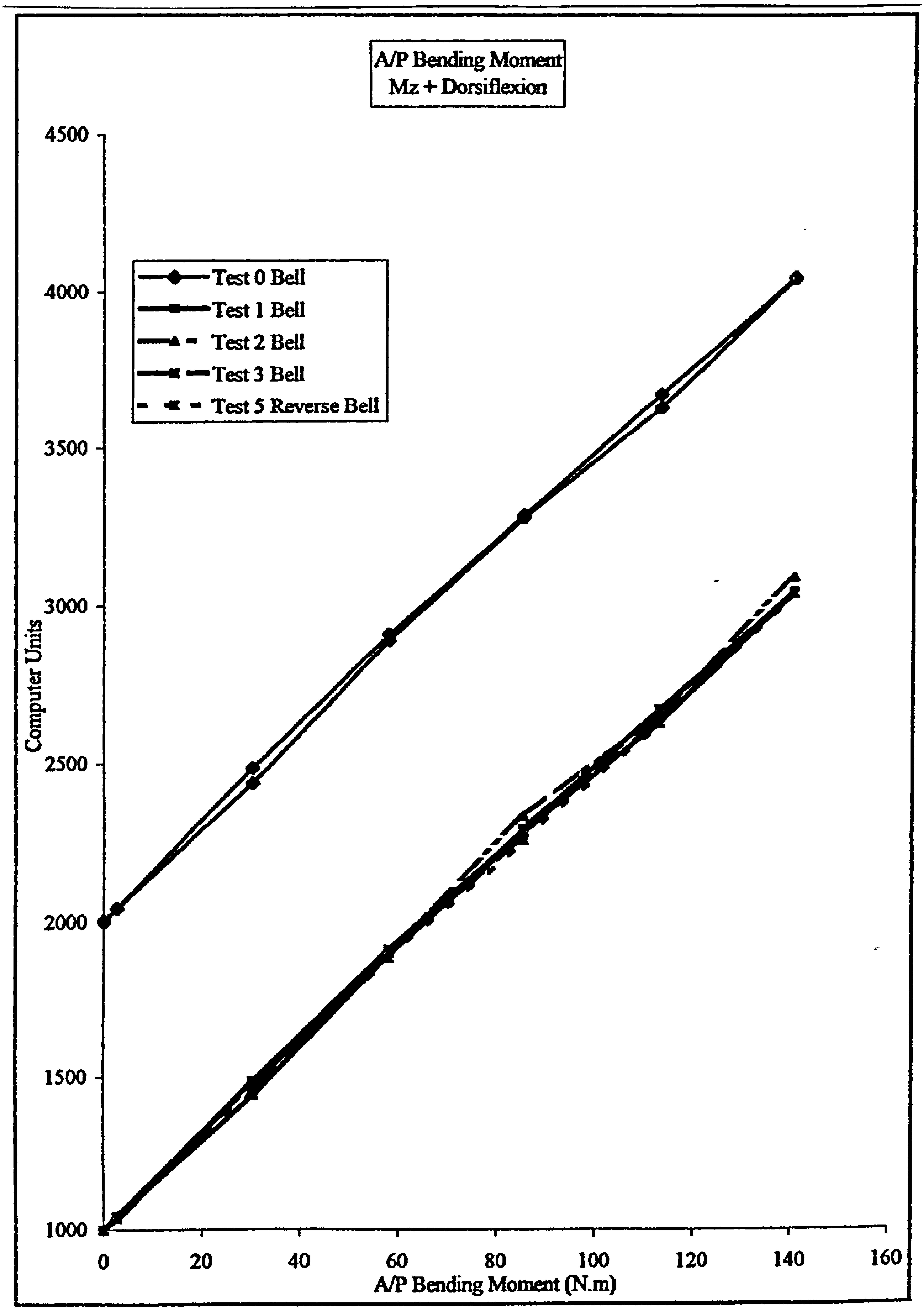


Figure IV.8: The traces from the following tests: 0 (zero line = 2000 cu); 1, 2 and 3 (zero line = 1000 cu). These 4 tests were performed with the usual aluminium bell. The set up of the test 5 was the reverse steel bell. Positive A/P bending moment (N.m) versus Computer Units (1 cu = 2.442 mV).

11.IV.3.5 *A/P BENDING MOMENT NEGATIVE: PLANTARFLEXION*

Figure IV.11 shows the traces processed from the different tests performed in A/P bending moment negative (plantarflexion). Referring to table 4.1, the tests are labelled 9, 10 and 11. All of them have the same gain (500), the same bridge voltage (3 V) but the loading point is different (31.5 cm from the ankle axis for the test 9 and 10; 16 cm for the test 11).

The traces shown by figure IV.11 exhibits a similar pattern as dorsiflexion (see figure IV.10), namely, deflection is less linear than computer tests. The traces reflecting the negative A/P bending moment versus computer units are linear. Moreover, the traces processed from the two tests having the same loading point application (tests 9 and 10) are totally superimposed.

The last test (test 12, see table 4.1) performed in A/P bending moment negative was undertaken to check the proportionality of the results expressed by a gain of 200 versus a gain of 500. Table IV.9 shows the numerical results with a constant ratio (0.4) between the tests. Figure IV.12 is the chart extracted from the table IV.9. It is shown to exhibit how linear is the behaviour of the prototype tested, having a hollow spindle.

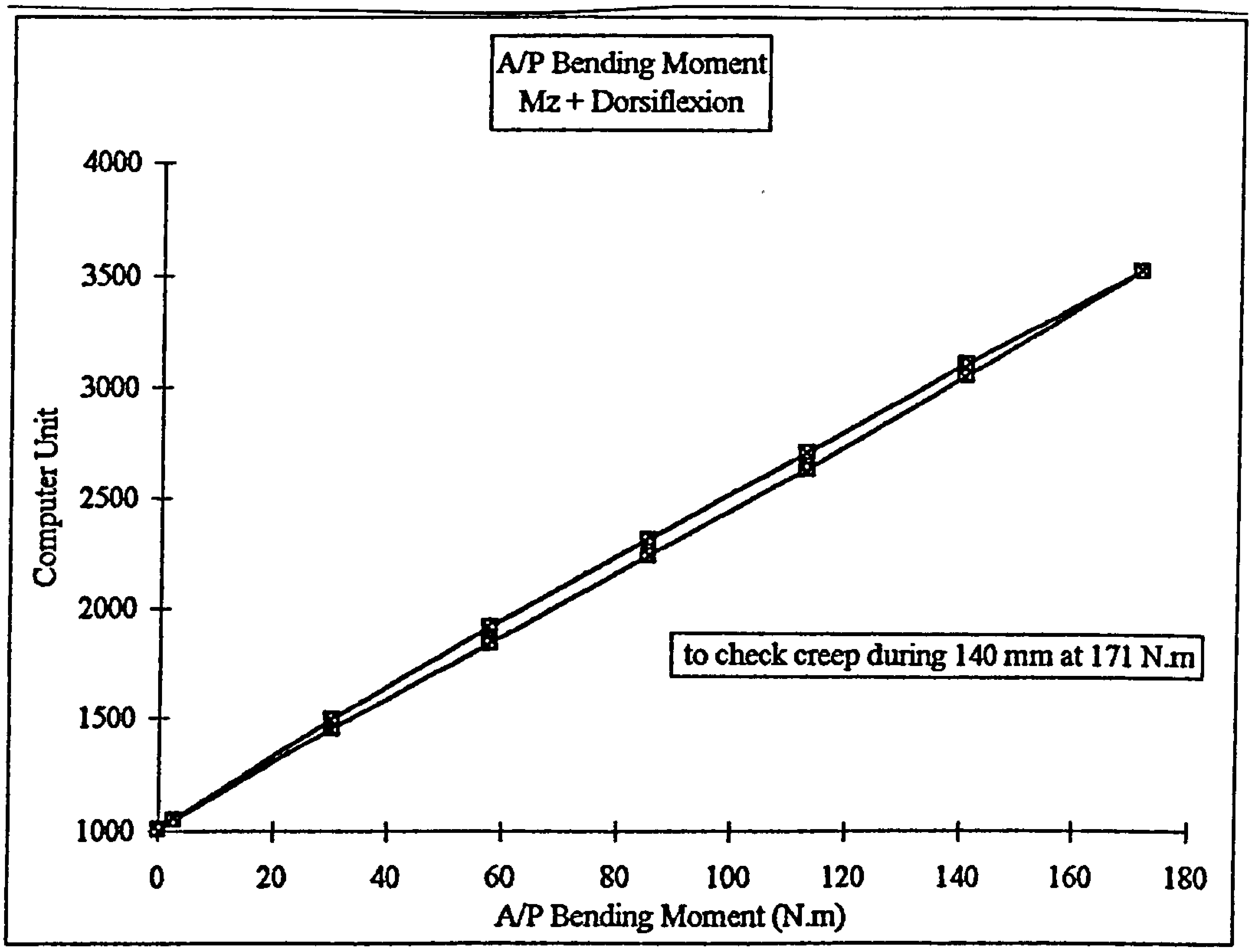


Figure IV.9: The traces from table IV.8. Positive A/P bending moment (N.m) versus Computer Units.

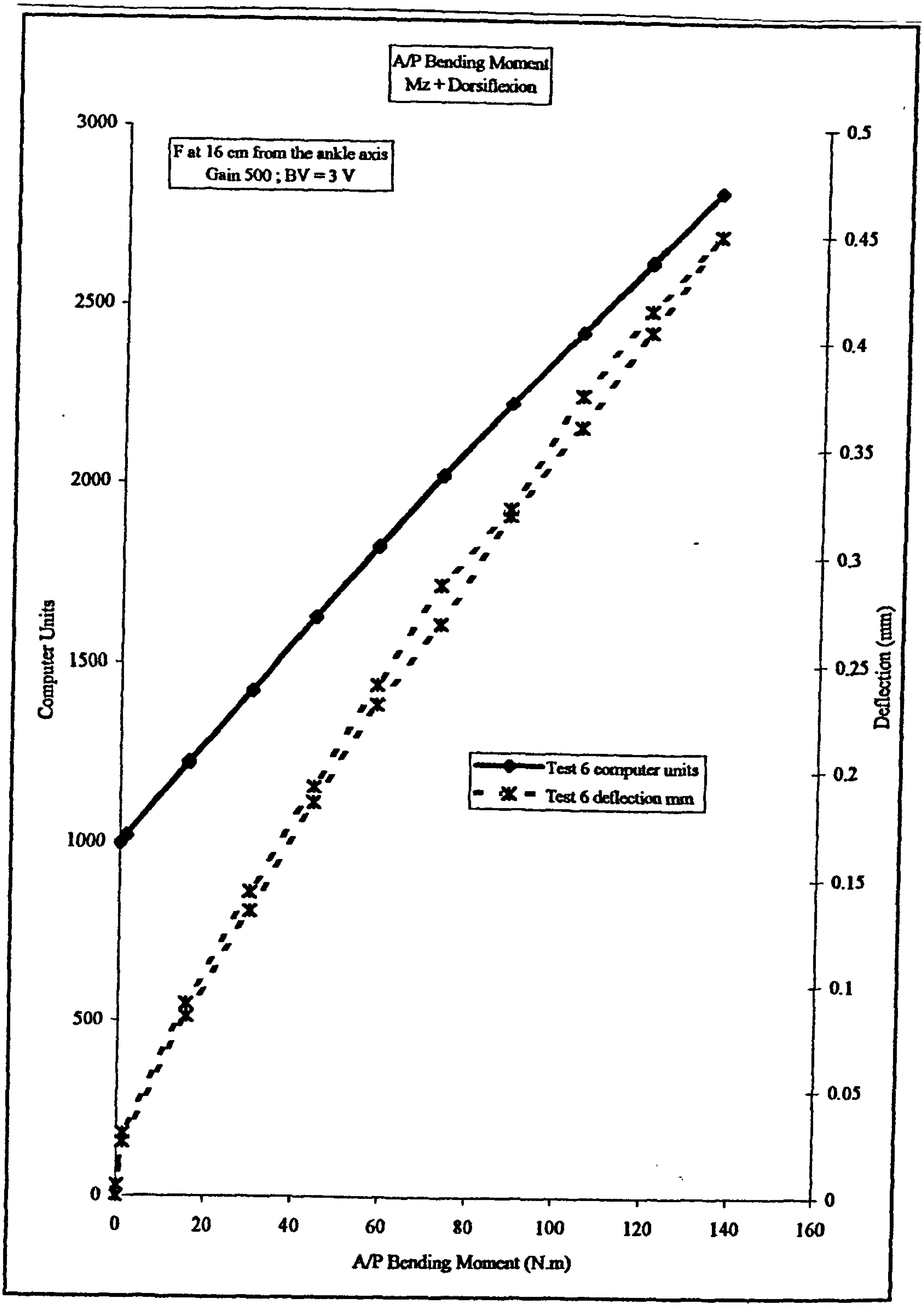


Figure IV.10: The traces processed from the test 6 in positive A/P bending moment versus computer units and deflection in mm. Maximum bending moment (135 N.m) with an application point of the force at 16 cm from the ankle axis.

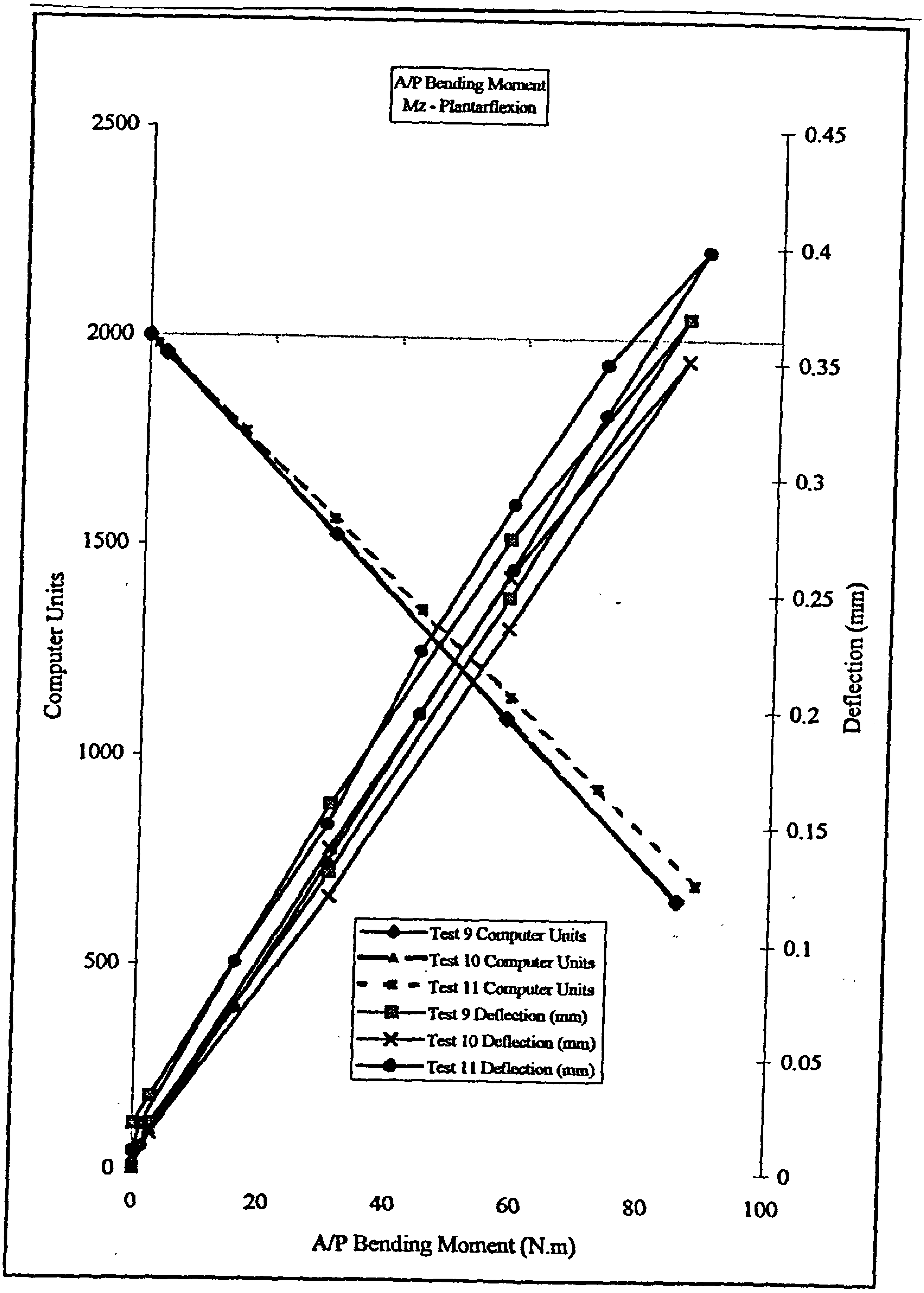


Figure IV.11: The traces processed from the tests 9, 10 and 11 in negative A/P bending moment versus computer units and deflection. The test 11 was performed with an application point of the force at 16 cm from the ankle axis. The two other tests were undertaken with a lever arm of 31.5 cm from the ankle axis. BV = 3 V, Gain = 500.

Load Case	*Test 12*	*Test 9*	*Test 10*	*Ratio Test 12 / Test 9*	*Ratio Test 12 / Test 10*
N.m	*Gain 200*	*Gain 500*	*Gain 500*		
0	2001.4	1999.6	2000.3	-3.500	4.667
3	1983.9	1955.8	1957.1	0.364	0.375
30	1810.2	1525.3	1524.3	0.400	0.399
58	1636.9	1093.7	1092.4	0.401	0.400
85	1463.2	660.5	660.3	0.401	0.401
85	1463.8	663.2	661.7	0.401	0.401
58	1636.7	1091.2	1094.5	0.400	0.401
30	1810.1	1526.1	1526.6	0.401	0.401
3	1983.6	1959.9	1960.3	0.409	0.413
0	2001.3	2000.5	1999.5	2.600	-2.600

Table IV.10 In A/P bending moment negative direction (plantarflexion), one test (test 12) with a gain of 200 and two tests (tests 9 and 10) with a gain of 500 (BV = 3 V). The ratio is constant and close to 0.4 (200/500), the results are thus independent of the gain setting.

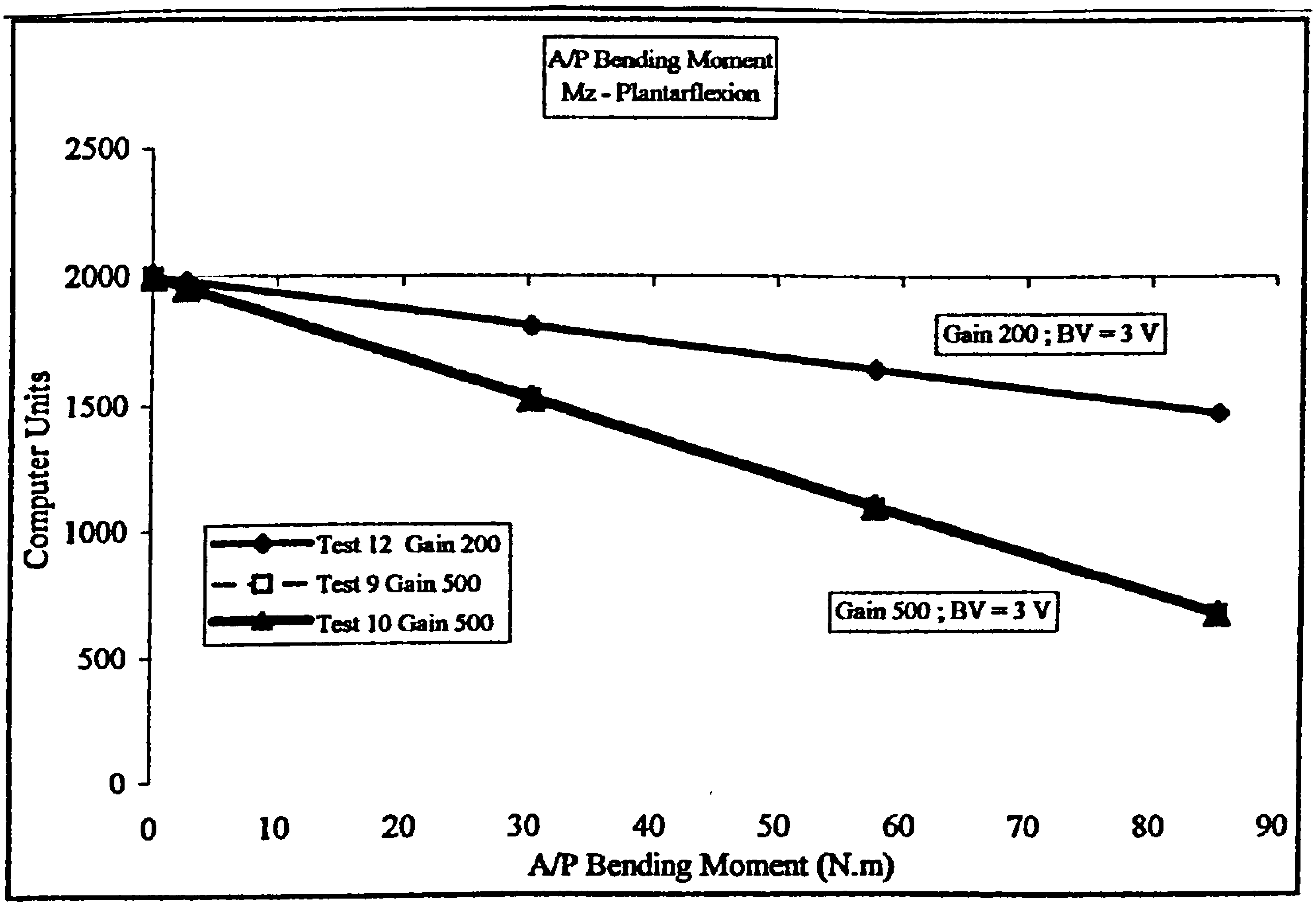


Figure IV.12: The traces processed from the table IV.9. The behaviour of the chosen prototype is linear in the considering channel: A/P bending moment, negative direction (plantarflexion).

11.IV.4 Comparison between the experimental results and previous theoretical calculation

If a comparison between previous calculations is made for the transducer's choice (see section 4.4) and current results obtained from the loading tests (see section 4.6), it is possible to give a chart:

theoretical calculation		
A/P Bending Moment Dorsiflexion	Stress σ	Strain $\mu\varepsilon$
140.6 N.m	461.7 MPa	2308

If the equation IV.4 is used:

$$V_o = KV_s\varepsilon$$

The result for V_o becomes: 14.88 mV with a bridge voltage V_s = 3V and a gauge factor K = 2.15.

The mean value in computer units for a loading case of 140.6 N.m, with a gain of 500 is 2044 cu. which represents 4986.4 mV. Hence, the result being divided by the gain:

$$2044 * 2.44 = 4987.4$$

$$\frac{4987.4}{500} = 9.97 \text{ mV}$$

In summary, with the same calculation in plantarflexion (Mz-), the results are shown in table IV.7.

Both theoretical results have approximately the same range (50 to 40 %) from those obtained from the mean of the conducted tests. In dorsiflexion, the difference between theory and experiment, for a gain setting of 500, is 4.91 mV in dorsiflexion and 2.52 mV in plantarflexion. It is interesting to note that the theoretical values are always bigger than the calculated one. Here also, the discussion will be re-opened later when comments on the calibration will be given (see chapter 6).

11.IV.5 Theoretical analysis for a first approximation of the strain gauge response of the new Villiers Pylon Transducer

11.IV.5.1 INTRODUCTION

To confirm the definitive locations of strain gauges onto the body - test of the new transducer and to corroborate all the taken decision about wiring, a theoretical qualitative and quantitative analysis of stresses and strains is an important prerequisite.

The aim is to check and define the theoretical strain-stress behaviour of the new transducer to confirm the name of the different bridges and to assess the wiring diagram of each bridge gauge.

The target is to develop the logic of the strain responses, the calibration and the validation of the new transducer.

The ultimate target would be to prove that the new transducer can be seen to be equal to other transducers described in literature, especially the Strathclyde Pylon Transducer, despite:

- the new design with the bell and the four layers of strain gauges,
- the small size of the gauging area,
- the non - symmetrical shape of the flat flange of the new transducer.

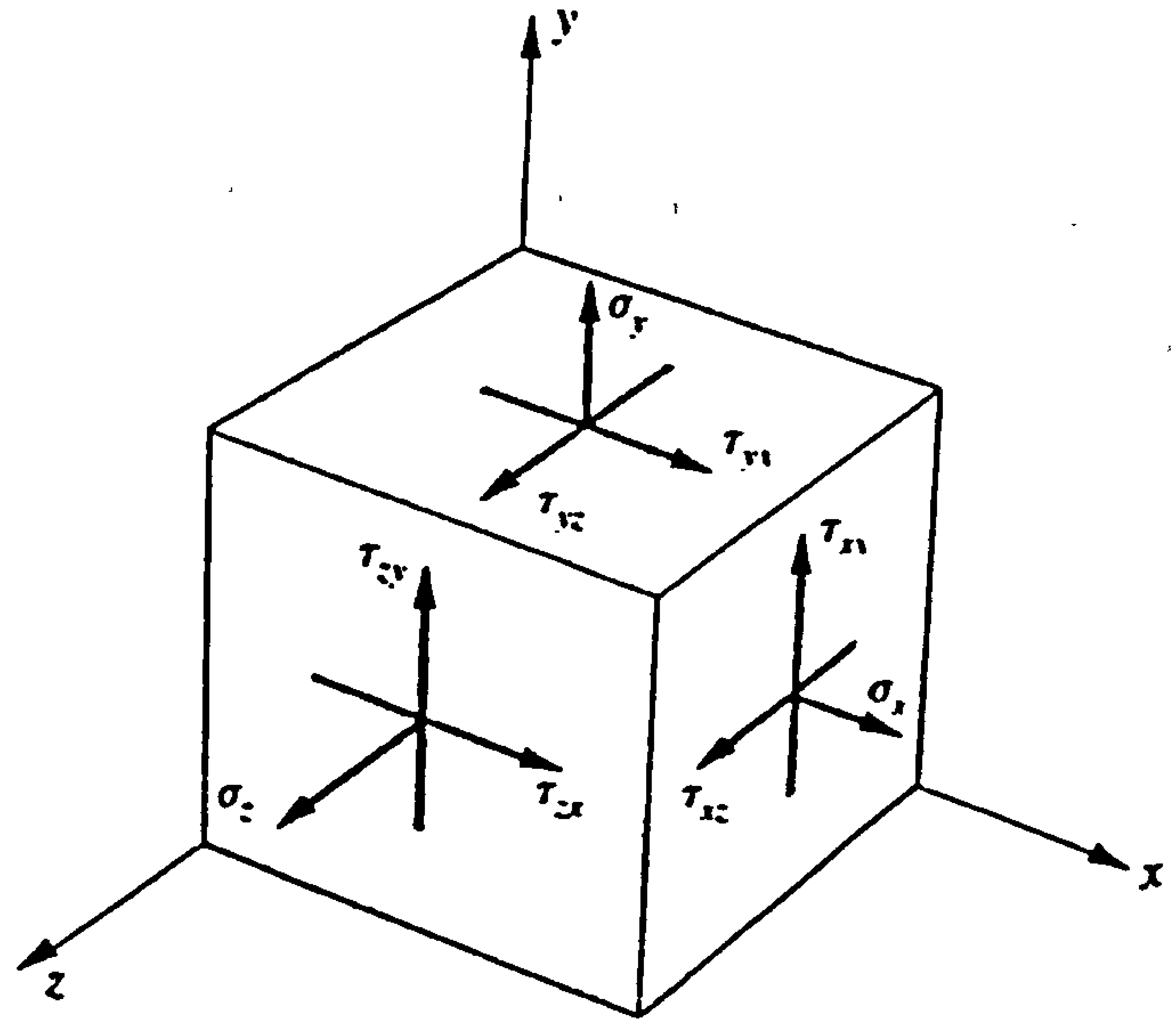


Figure IV.13: A general three-dimensional stress system showing the subscript notation

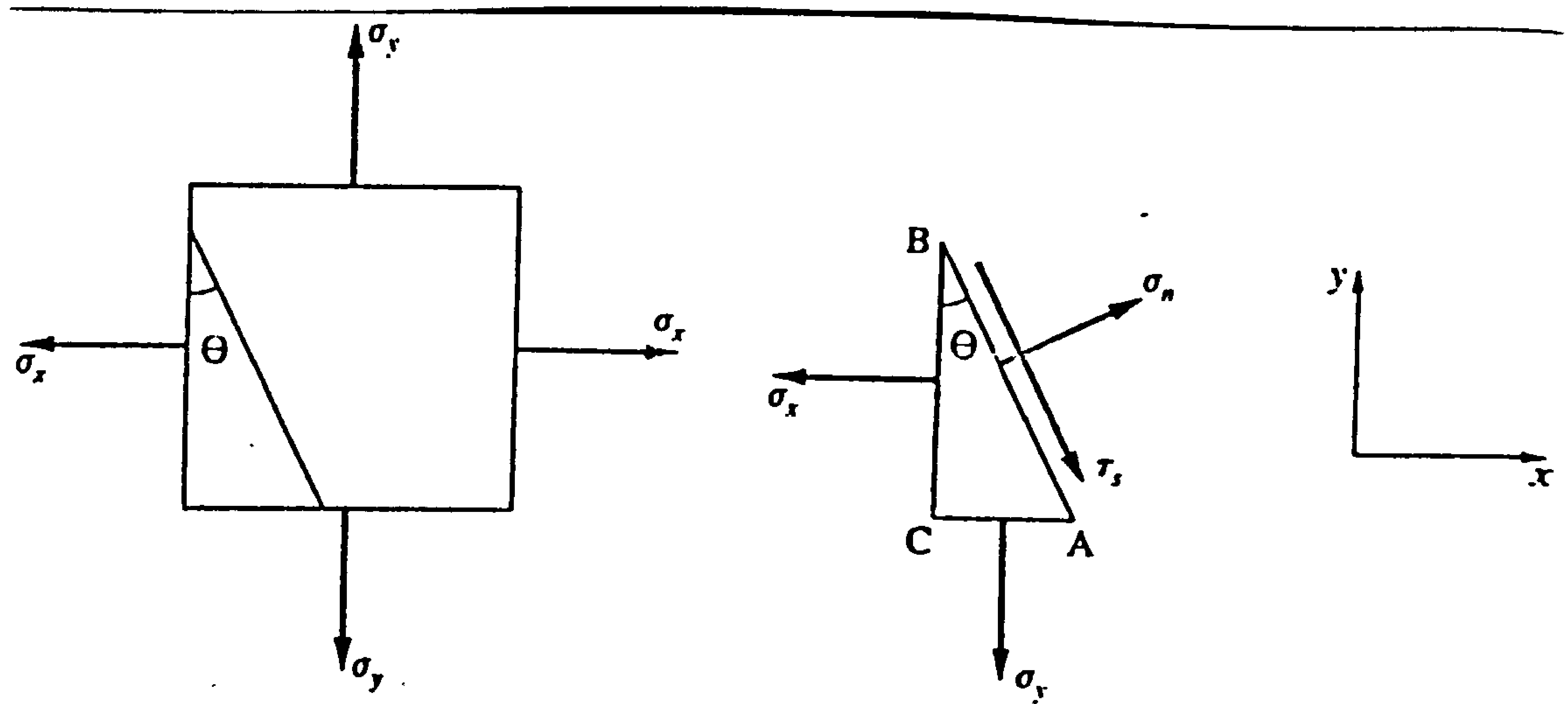


Figure IV.14: Tensile stresses on an element having unit thickness

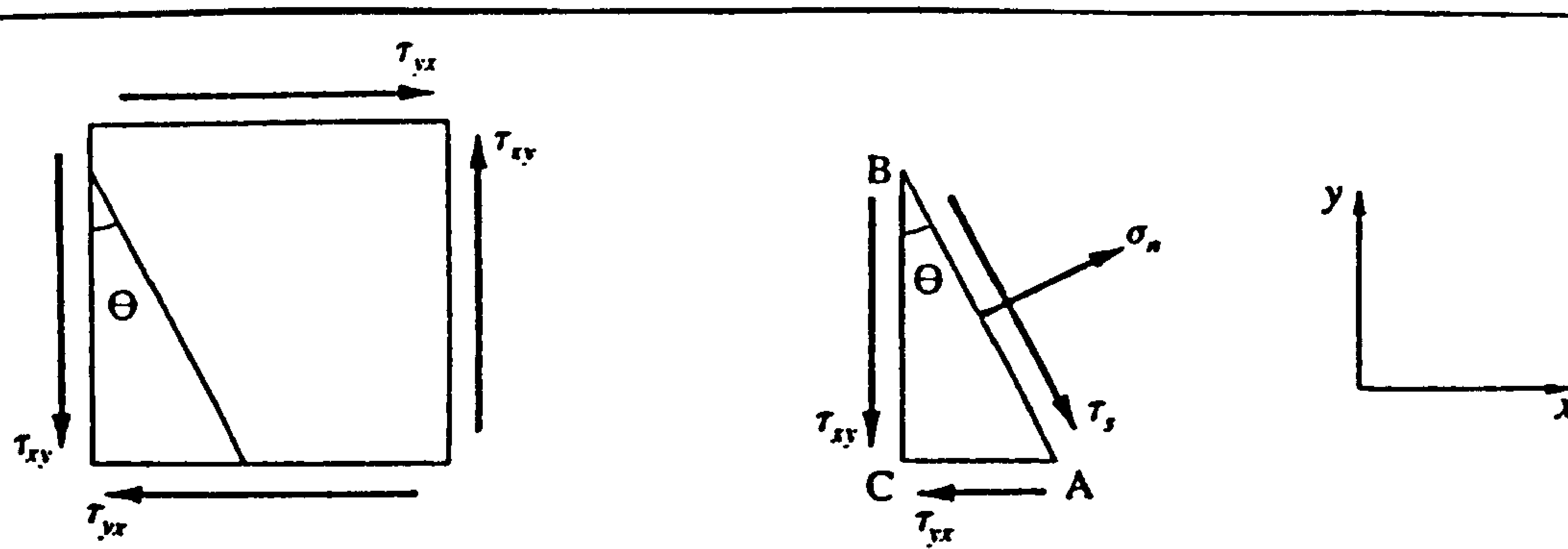


Figure IV.15: Normal stresses on an element having unit thickness (all these figures extracted from Benham & Crawford, 1988)

In other words, the overall goal would be to assess the new transducer. This is done by stress and strain analysis using classical formulas, (Roark, 1954), (Benham & Crawford, 1988).

11.IV.5.2 INITIAL CONSIDERATIONS AND ASSUMPTIONS

11.IV.5.2.1 Material properties

In a previous chapter, the new transducer was presented. The material used is a stainless steel whose mechanical properties are given by the supplier (see table IV.2).

11.IV.5.3 ASSUMPTIONS ABOUT TRANSDUCER AND GAUGES

The following assumptions about the transducer have to be made:

1. the pylon is considered to be machined to exactly its nominal dimensions without any discrepancies in the transverse plane. In other words, all cylindrical surfaces are co-axial about the device's Y axis and the diameter is constant.

2. the transducer is used only with the aluminium bell but without the aluminium base. It is only encastré at the bottom flat flange, corresponding to fixation by the six cap screws.

3. because the new transducer has a hollowed cylindrical shape, similar to the Strathclyde Pylon Transducer widely used since Berme *et al.*, (1975), gauges are bonded at the same place and wiring diagram followed the convention. The six bridges are named A, B, C, D, E and F as shown in section 4.3.3.1.

11.IV.5.3.1 Vocabulary Convention, Symbols and Signs for load components, stresses and strains

11.IV.5.3.1.1 Symbols and Signs

Stress (σ for normal stress and τ as tangential stress) and Strain (linear strain script ε and shear strain script γ) have been defined in the previous chapter. It is just necessary to remind that the strain is the deformation resulting from stress measured by the percentage change in length of a line or the change in angle of an initially right angle. Strains are non-dimensional (Winter, 1994b).

Since conditions will be studied in which several different stresses occur simultaneously, it is essential to be consistent in the use if distinctive symbols and a sign convention must be established and adhered to.

Normal stress: $\sigma_x, \sigma_y, \sigma_z$

where the subscript denotes the direction of the stress.

Tangential stress: $\tau_{xy}, \tau_{xz}, \tau_{yx}, \tau_{yz}, \tau_{zx}, \tau_{zy}$

where the first subscript denotes the direction of the normal to the plane on which the shear stress acts and the second subscript the direction of the shear stress as shown in figure IV.13. At each of these stresses, a strain is associated, such as:

Normal or direct stress σ — Normal or direct strain $\varepsilon = \dfrac{\sigma}{E}$

Tangential or shear stress τ — Tangential or shear strain $\gamma = \dfrac{\tau}{G}$

Concerning signs, tensile stress (subscript t) will be taken as positive and compressive stress (subscript c) negative. A shear stress is defined as positive when direction of the stress vector and the direction of the normal to the plane are both in the positive sense or both in the negative sense in relation to the co-ordinate axes. If the directions of the tangential shear

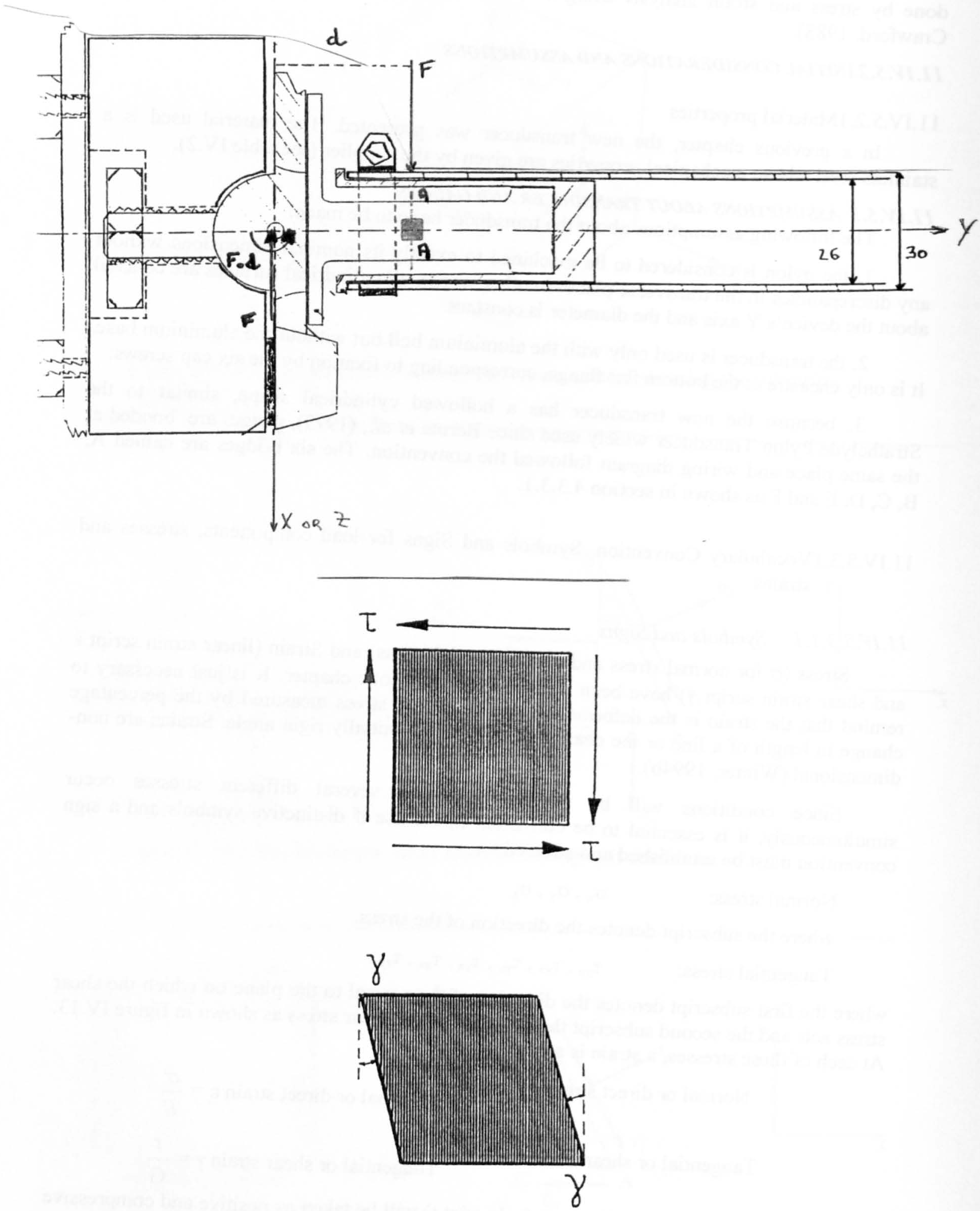


Figure IV.16: Application of a pure shear force. The support loads are shown.
(adapted from Magnissalis, 1992)

stress and the normal to the plane are opposed in sign, then the resulting shear stress is negative. (Benham & Crawford, 1988, p. 304).

The loads acting upon the pylon transducer in this analysis are considered to be applied on a cross-section of the body from a lower (distal) to an upper (proximal) direction being the positive sense. The section is considered passing through a cross - section of the transducer's body which has been instrumented with strain gauges.

For each loading configuration, a rectangular element of material of unit thickness is considered at the boundary of each section. The stresses developed on the elements are then studied to derive the corresponding strains. Knowing both these strains and the behaviour of gauges, it is possible to confirm the best place where gauges must be bonded on the surface of the body of the transducer. This theoretical knowing will confirm the validity of the choice it was made.

11.IV.5.4 THEORETICAL ANALYSIS OF A UNIT ELEMENT SUBJECTED TO NORMAL AND SHEAR STRESSES

11.IV.5.4.1Element subjected to normal stresses

The rectangular infinitesimal element in figure IV.13, is subjected to tensile stresses in the X and Y direction. Considering a corner cut off the element by the plane AB inclined at θ to the Y axis. For equilibrium of ABC, the sum of the forces on AB, BC and CA must be equal to zero. As the element is of constant unit thickness, the areas of the faces are proportional to the length of the sides of the triangle, therefore, resolving forces normal to the plane AB:

$$\sigma_n AB - \sigma_x BC\cos\theta - \sigma_y AC\sin\theta = 0 \qquad \text{(IV.6)}$$

Dividing through by AB,

$$\sigma_n = \sigma_x \cos^2\theta + \sigma_y \sin^2\theta = \frac{1}{2}\left(\sigma_x + \sigma_y\right) + \frac{1}{2}\left(\sigma_x - \sigma_y\right)\cos 2\Theta \qquad \text{(IV.7)}$$

Then, resolving forces parallel to AB:

$$\tau_s = \sigma_x \cos\Theta\sin\Theta - \sigma_y \sin\Theta\sin\Theta = \frac{1}{2}\left(\sigma_x - \sigma_y\right)\sin 2\Theta \qquad \text{(IV.8)}$$

11.IV.5.4.2Element subjected to shear stresses

The rectangular element of the previous section is now considered with shear stresses on the faces instead of normal stresses. The plane AB inclined at θ to the Y axis is subjected to normal and tangential stresses. Triangular portion ABC is in equilibrium. Resolving forces normal to the plane AB as shown in figure IV.14 with, from a consideration of complementary shear stresses $\tau_{yx} = \tau_{xy}$ and dividing by AB (Benham & Crawford, 1988, p.306):

$$\sigma_n = \tau_{xy} \sin 2\theta \qquad \text{(IV.9)}$$

Resolving forces parallel to the plane AB:

$$\tau_s = - \tau_{xy} \cos 2\theta \qquad \text{(IV.10)}$$

The general two-dimensional stress system may be obtained by a summation of the conditions of stress in figures IV.14 and IV.15. The equation obtained for σ_n and τ_s under normal stresses and shear stresses separately must be added together to give values for the normal and shear stress on the inclined plane AB. Therefore, from equations (IV.6) and (IV.9), then from equations (IV.8) and (IV.10) (Benham & Crawford, 1988, p. 308):

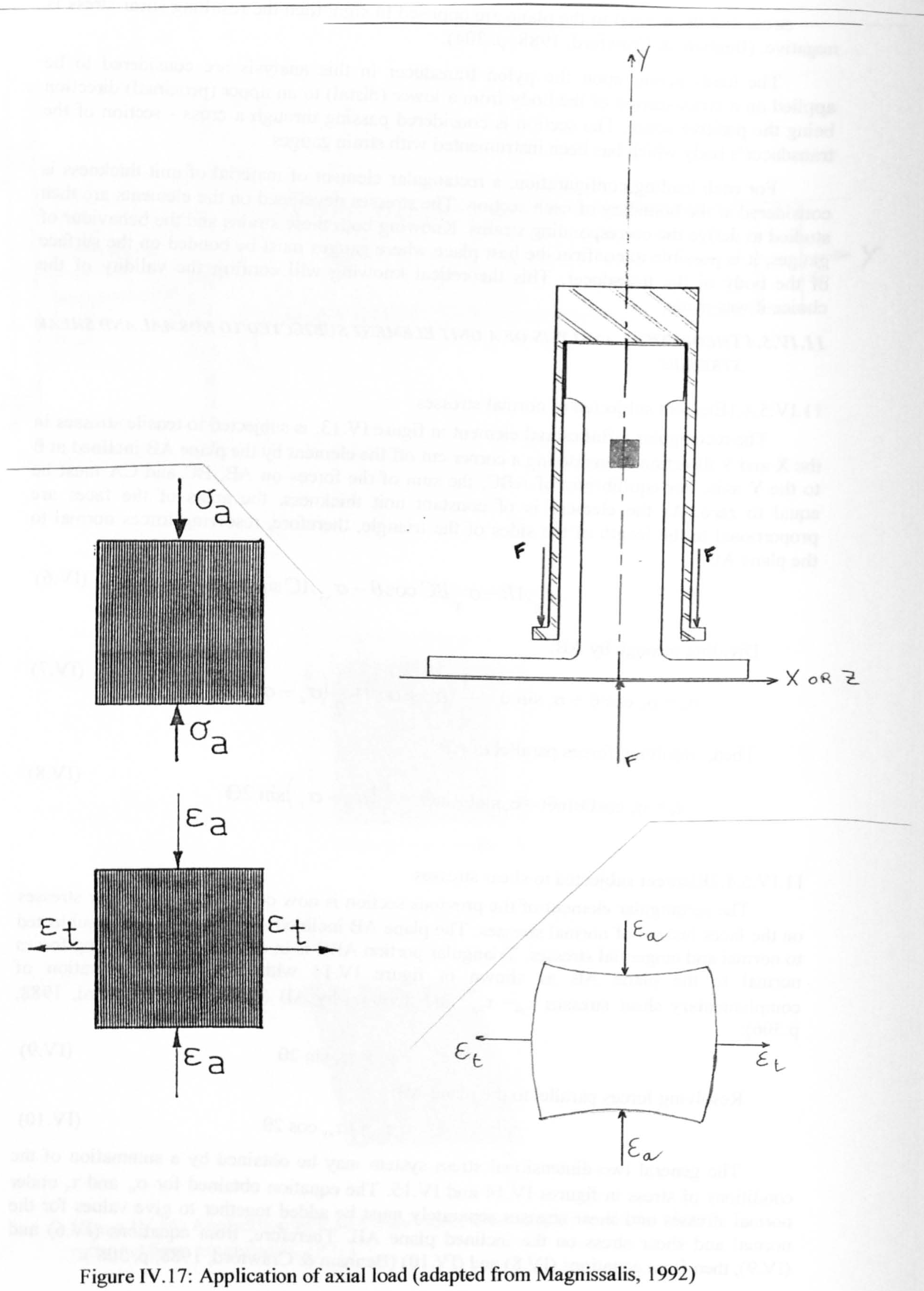


Figure IV.17: Application of axial load (adapted from Magnissalis, 1992)

$$\sigma_n = \frac{1}{2}(\sigma_x + \sigma_y) + \frac{1}{2}(\sigma_x - \sigma_y)\cos 2\Theta + \tau_{xy}\sin 2\Theta \quad \text{(IV.11)}$$

$$\tau_s = \frac{1}{2}(\sigma_x - \sigma_y)\sin 2\Theta - \tau_{xy}\cos 2\Theta \quad \text{(IV.12)}$$

11.IV.5.5 STUDY OF THE NEW TRANSDUCER FOR APPLIED SHEAR FORCES

11.IV.5.5.1 Practical consideration

The set-up of the pure shear tests is shown on figure IV.16. A pure shear force F is applied through a cross-section of the body - test of the new transducer, in the exact plane where shear gauges are bonded. Although all other cross-sections of the device are subjected to bending moments and shear force simultaneously, section A-A is only subjected to the pure shear force F. A symmetry about X - Y or Z - Y planes must be considered for stresses and strains on an element positioned on the opposite side of the shaft.

In this configuration, there are no normal stresses but only shear stresses τ. Longitudinally positioned gauges cannot (theoretically) be affected, as well as all Poisson's gauges. Therefore, bridges A and B (gauges longitudinally positioned) and bridge C (longitudinally and transverse Poisson's gauges) are balanced. This property is independent of the shear bridge plane location along the body - test of the new transducer.

The value of the shear stress varies according to the position of the studied point x_τ. For $R_i < x_\tau \leq R_0$, we have from Magnissalis (1992):

$$\tau = \frac{FR_0}{3I} * \sqrt{R_0^{\,2} - x_\tau^{\,2}} \quad \text{(IV.13)}$$

From equation IV.13, it is easy to see that shear stress τ is zero for $x_\tau = \pm R_0$ and maximum at position $x_\tau = 0$. In that particular case, this maximum stress is:

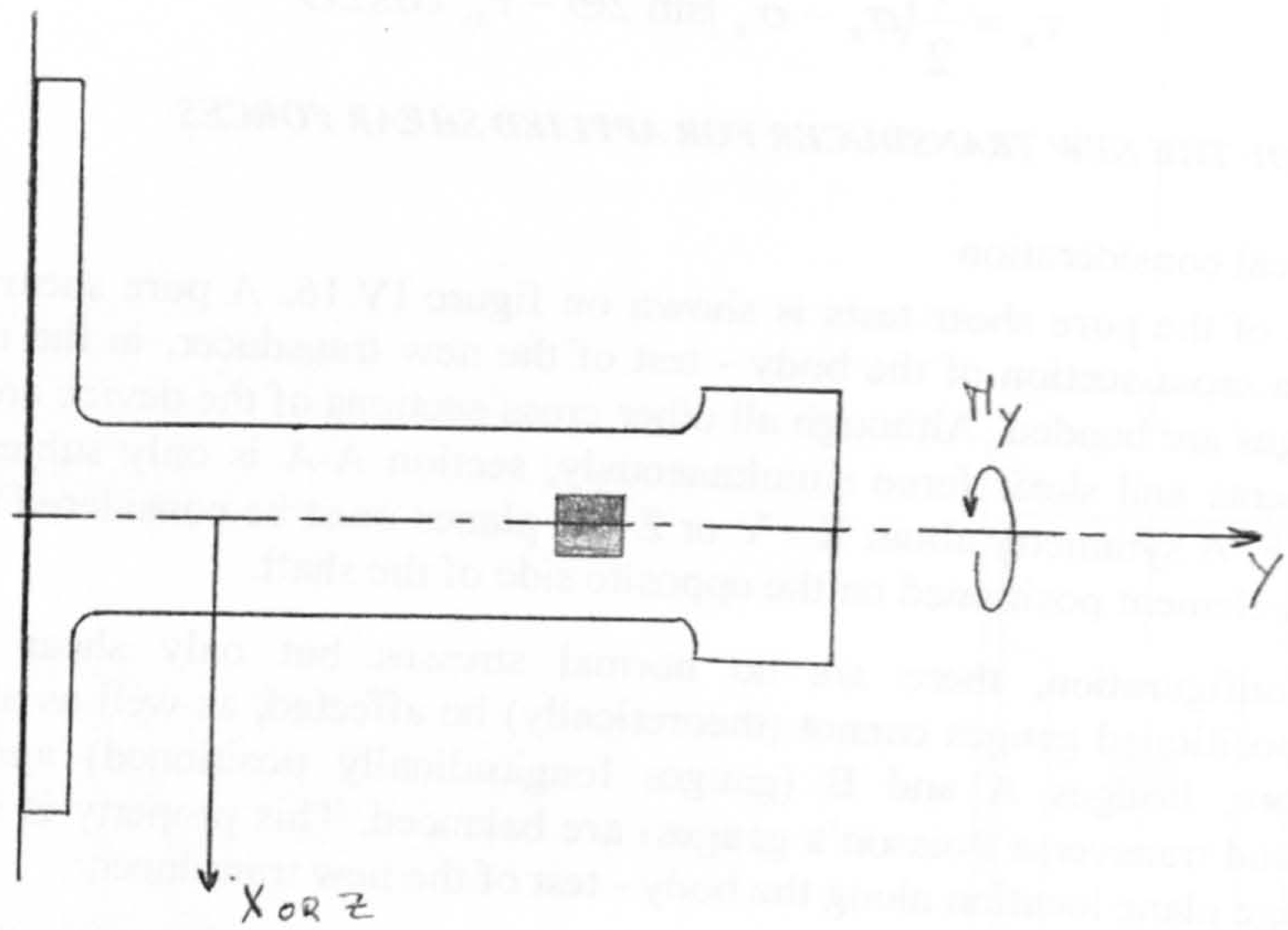
$$\tau = \frac{F}{3I} * \frac{R_o^{\,3} - R_i^{\,3}}{R_o - R_i} \quad \text{(IV.14)}$$

Therefore the gauges corresponding to the first position ($x_\tau = \pm R_0$) will not be affected while the gauges corresponding to the latter position ($x_\tau = 0$) will have an unbalanced bridge. In other words, if:

1. load is applied along the X axis of the transducer, gauges bonded at the top and at the bottom of the new transducer shaft should be balanced, i.e. these gauges, belonging to the bridge D, must be called F shear force bridge with a subscript opposite of the name of the axis (here, X) along of which the load has been applied. Hence, the bridge D must be named Fz. The gauges corresponding to the second position ($x_\tau = 0$), which is a plane perpendicular to the X axis, must be affected by a maximum value, i.e. these gauges, belonging to the bridge E, must be called Fx shear force bridge.

2. load is applied along the Z axis of the transducer, gauges bonded at the top and at the bottom of the transducer shaft should be balanced, i.e. these gauges, belonging to the bridge E, must be called F shear force bridge with a subscript opposite of the name of the axis (here, Z) along of which the load has been applied. Hence, the bridge E must be named Fx. Gauges corresponding to the second position ($x_\tau = \pm R_0$), which is a plane perpendicular to the Z axis, must be affected by a maximum value, i.e. these gauges, belonging to the bridge D, must be called Fz shear force bridge.

From the above considerations, it is possible to start naming the layout of the shear



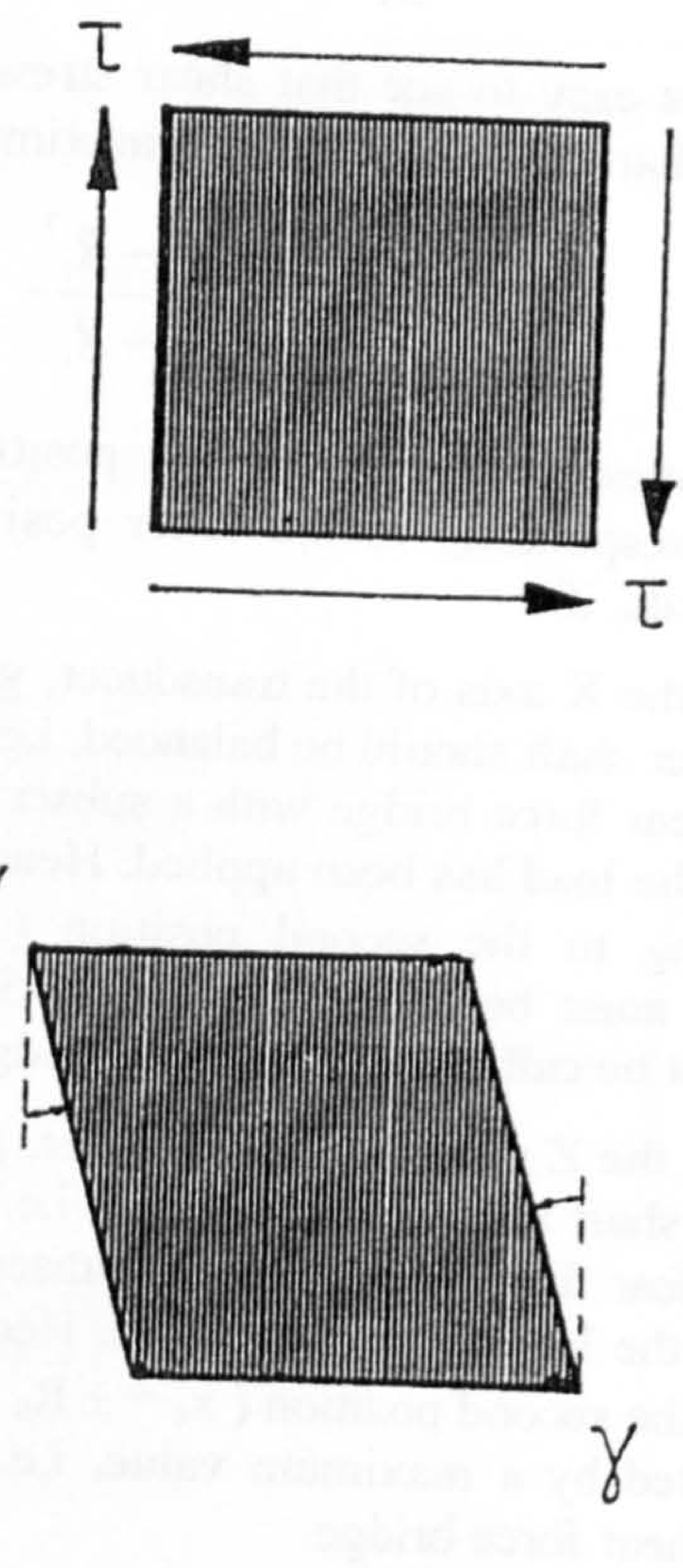


Figure IV.18: Application of torque My (adapted from Magnissalis, 1992) force strain gauges on the developed surface of the element (figure 4.32). The bridge E is named shear Fx channel while the bridge D is named shear Fz channel. Is it allowed to remind the reader that all bridges used with this transducer are full Wheatstone bridges. Each arm of the bridges has equal numbers of similar gauges.

About wiring diagram, some considerations must be done: the gauges of bridge Fx (consider F = Fx) are subjected to equal and opposite strains which cause resistance changes ΔR as following:

- gauges (E_1 and E_3) above the 90°-270° plane are subjected to a change - ΔR_E
- gauges (E_2 and E_4) below the 90°-270° plane are subjected to a change + ΔR_E

Because the Fx bridge is not balanced and according to the Wheatstone bridge theory which is: two adjacent resistors are working in the reverse while the two opposite resistors are working in the same way, the wiring diagram of this bridge is shown in figure 4.29.

Because the bridge is unbalanced, it provides an output signal V_{Eo}:

$$V_{Eo} = V_s * \frac{\Delta R_E}{R} = V_s * K * \varepsilon \qquad \text{(IV.15)}$$

where V_s is the bridge supply (see below the bridge supply adopted) and K the gauge factor, which is assumed to be common for all gauges, having a value of 2.

Strain ε is related to the shear stress τ by the following equation:

$$\varepsilon = \frac{\tau}{2G} \qquad \text{(IV.16)}$$

Correspondingly, for the Fz shear bridge, the wiring diagram of this channel D is shown in figure 4.29.

The theoretical discussion of the torque circuit response is indicated in section 6.4.7.

In summary, it has been possible:

1. to name two channels among the six: channel D = Fz ; channel E = Fx
2. to quantify the moment from equations IV.13 and IV.14
3. to establish the relation between stress σ and strain ε from equation IV.16
4. to evaluate the magnitude of the output voltage V_s from equation IV.15.

From these equations, it will be possible to establish the required equation relating shear forces Fx or Fz and the output signal V_s.

From these considerations, a numerical application has been calculated, it is presented in section 11.IV.5.10.

11.IV.5.6 THEORETICAL ANALYSIS OF A UNIT ELEMENT SUBJECTED TO AXIAL FORCE

The axial force Fy is now considered applied as shown in figure IV.17. A pure axial load is applied through a ring cross-section of the transducer. In this case, there is only one stress configuration. It consists of the axial normal stress σ_c (c stands for compression). This stress causes the strains ε_c and ε_t = - $\nu\varepsilon_c$ (t stands for tension) shown in figure IV.17. In the inclined directions, the predominant compressive strain ε_c generates a compressive strain:

$$\varepsilon_{c1} = \frac{1}{2} * \varepsilon_c * (1 - \upsilon) \qquad \text{(IV.17)}$$

Longitudinally positioned gauges are subjected to the same decrease of their resistance values due to ε_c. Similarly, forty-five degrees rosettes gauges are also subjected to the same

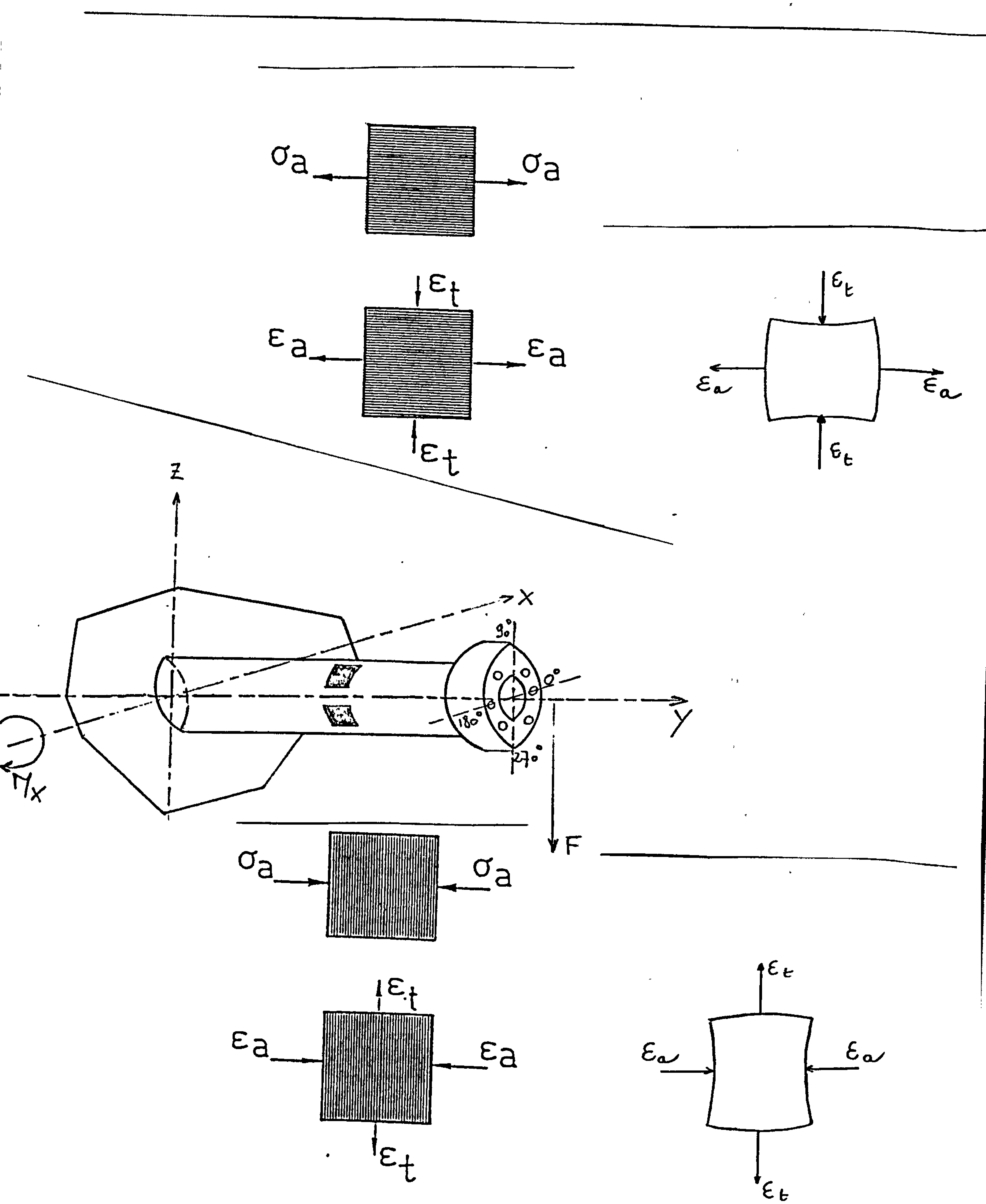


Figure IV.19: Application of bending moment Mx (adapted from Magnissalis, 1992) decrease of their resistance values due to ε_{cl}. Although, all these gauges cannot (theoretically) respond to the application of the axial load. However, it is obvious that all gauges have a change in resistance due to the axial load; the bridge circuits allow separation of the signals.

Therefore, gauges which might respond must have a special configuration taking account of these three strains (ε_c, ε_t and ε_{cl}) . The only way is having two grids at ninety degrees to themselves: one grid is longitudinally positioned along the Y axis while the second one is transverse, perpendicular to the Y axis. The only bridge which does so is the bridge C.

These gauges are specially supplied Poisson's gauges for axial load monitoring. The responses are (Vishay Shear & Stress Analysis Encyclopaedia, quoted by Laboisse, 1991):

1. longitudinal grids, ε_l:

$$\varepsilon_l = \frac{F}{\pi * E\left(R_o^2 - R_i^2\right)} \tag{IV.18}$$

2. transversal grids, ε_2:

$$\varepsilon_2 = \frac{\upsilon * F}{\pi * E\left(R_0^2 - R_i^2\right)} \tag{IV.19}$$

This could be summarise having that:

- longitudinal gauges are subjected to $-+\Delta R_C$
- transversal gauges are subjected to $-\nu\ \Delta R_C$

As stated in section IV.4, strain ε_c is related to the applied load Fy by equation (Roark, 1954, p.76):

$$\varepsilon_c = \frac{\sigma_c}{E} = \frac{Fy}{AE} \tag{IV.20}$$

and stress is:

$$\sigma_c = \frac{Fy}{A} \tag{IV.21}$$

Because the bridge C is unbalanced, it provides an output signal V_o:

$$V_o = V_s(1+\nu)\frac{K}{2}\varepsilon_c \tag{IV.22}$$

11.IV.5.7 PRACTICAL STUDY OF THE NEW TRANSDUCER FOR APPLIED AXIAL FORCE

Thus, the bridge C is named axial load Fy. From equation IV.21, it could be deduced that the magnitude of the strain ε_c is very low because the denominator (AE) has a high value. Therefore, to have an output voltage Vo large enough to be recorded, the only thing it can be done from equation IV.22, is to increase the bridge voltage V_s. The factor K is a constant from the gauges and ν from the material. So that, in this loading case, all transducers are comparatively insensitive. This is particularly true for the new Villiers Pylon Transducer. Therefore, each bridge arm must have four gauges. This allows an increase on the value of the bridge voltage V_s.

From all these considerations, it is possible to discover another step of the layout shown above in figure 4.32; the axial load bridge C is shown onto the developed surface of the body shaft of the transducer.

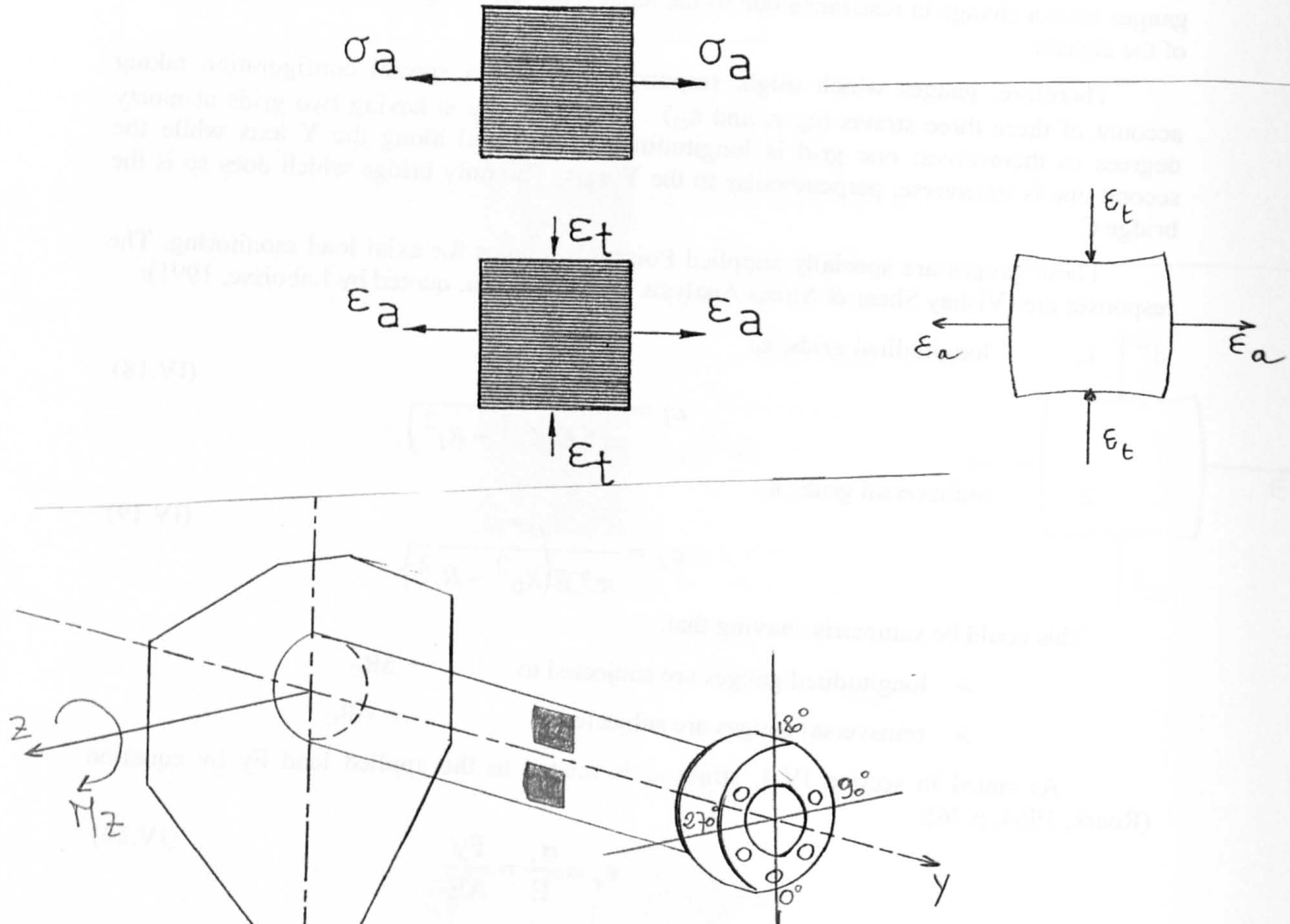


Figure IV.20: Application of bending moment Mz (adapted from Magnissalis, 1992)

In summary, it has been possible:

1. to name one channel among the six: channel C = Fy
2. to obtain a relationship between applied load Fy and bridge signal V_o.

From these considerations, a numerical application has been calculated, it is presented in section 11.IV.5.10.

11.IV.5.8 PRACTICAL STUDY OF THE NEW TRANSDUCER FOR APPLIED TORQUE

In this case, figure IV.18, the stress configuration purely consists of the shear stress τ. Theoretically, all gauges in longitudinal and transverse directions are not subjected to any stress. Thus, bridges A, B, C and E are balanced.

However, bridge F has its opposite gauges F_1, F_3 and F_2 and F_4 having an opposite sign. It is also important to remark that these gauges F_1, F_3 and F_2 and F_4 have a parallel grid orientation. Therefore, the bridge F is unbalanced and it is the only one which responds. It is named torque bridge, that is My channel.

The bridge F result to an output signal V_o is given by the usual formula:

$$V_o = V_s * \frac{\Delta R_F}{R} = V_s * K * \frac{\gamma}{2} \qquad \text{(IV.23)}$$

Regarding the behaviour of this bridge F in pure shear force configuration, the same comment may be done. The gauges of bridge F are subjected to equal and opposite strains which cause resistance changes ΔR_{FC} as following: gauges F_1 and F_4 = - ΔR_{FC} while F_2 and F_3 = + ΔR_{FC}, because the gauges of the bridge F have, two by two; a parallel direction while the gauges of the bridges D and E are, two by two, perpendicular. From the wiring diagram of figure IV.18, it follows that bridge F is able to compensate for the changes and remain eventually balanced.

Thus, it is proved that for a purely applied torque the only bridge which responds is the bridge F, named torque My. The requirement is to obtain a My / V_o relationship.

In summary, it has been possible:

1. to name one channel among the six: channel F = My
2. to explain why the bridge F does not respond with any shear force

From these considerations, a numerical application has been calculated, it is presented in section11.IV.5.10.

11.IV.5.9 PRACTICAL STUDY OF THE NEW TRANSDUCER FOR APPLIED BENDING MOMENTS

Because of their influence on the various bridge responses, bending moments Mx and Mz will be studied separately.

11.IV.5.9.1Bending moment Mx

A bending moment Mx is now purely applied onto the distal end of the transducer as shown in figure IV.19. This moment has a twin effect: moment Mx (positive for a right side) causes tension in the top half of the shaft (the half above the 0° - 180° plane, corresponding at 0°, 60°, 90° and 180° for gauges location) and compression in the bottom half of the shaft (the half below the 0° - 180° plane, corresponding at for 180°, 240°, 270° and 380° gauges location). The junction of these halves is named the neutral plane and transverse lines in this neutral plane are called the neutral axe. For bending moment Mx, the neutral plane passes through the angular position of 0° and 180°.

The stress σ (positive for tension and negative for compression) is in the longitudinal direction, mixed up with the Y axis. This stress causes strains in the axial (ε_a), the

	Strathclyde Pylon Transducer designed by Berme *et al.* (1976)					**New Villiers Pylon Transducer**				
	stress MPa	strain μstrain	Vs μV	Sensitivity μV/N	Sensitivity per unit Vo	stress MPa	strain μstrain	Vs μV	Sensitivity μV/N	Sensitivity per unit Vo
Applied shear force Fx and Fz	0.974	17.8	107	1.07	0.357	1.492	9.62	144	1.443	0.192
Applied axial load Fy	4.89	70.97	536	0.536	0.09	7.91	39.5	407	0.407	0.051
Applied Moment Mx or Mz	74.27	1078	6468	64.67	21.56	328	1640	24600	246	32.8
Applied Torque My	11.14	408.01	1224	40.81	13.6	49.27	633	4747	158	21.1

Table IV.11: Comparison of the theoretical responses of two particular transducers transverse (ε_t) and the 45° inclined directions (ε_i). Inclined strain is equal to:

$$\varepsilon_i = \frac{\varepsilon_a}{2} * (1-\upsilon) \tag{IV.24}$$

In other words, all gauges bonded on the surface of the top half (from 0° to 180°) are subjected to stresses and strains in tension, whereas those bonded on the surface of the bottom half (from 180° to 360°) are subjected to stresses and strains in compression. This tension and compression are equal provided that the gauges are at the same distance from the neutral plane.

Since the various gauges are bonded in the plane of the bending moment to be measured, all gauges are on opposite ends of a diameter, therefore they "self compensate". The individual strain and stress values must be considered. The individual stresses are all expressed in terms of the maximum value, that is at the maximum distance from the neutral plane (Magnissalis, 1992; Buhot et Thuillier, 1986, p.82):

$$\sigma_{ct} = \pm \frac{M_x}{I} R_0 \tag{IV.25}$$

0°	neutral plane		$\sigma * \sin 0° = 0$
60°	tension	$+\sigma_{t60}$	$\sigma_t * \sin 60°$
90°	tension	$+\sigma_t =$ max.	$\sigma_t * \sin 90° = \sigma_t = +\frac{Mx}{I} R_0$
180°	neutral plane		$\sigma * \sin 180° = 0$
240°	compression	$-\sigma_{t60}$	$\sigma_c * \sin 60°$
270°	compression	$-\sigma_t =$ σ_c max.	$\sigma_c * \sin 90° = \sigma_c = -\frac{Mx}{I} R_0$
360°	neutral plane		$\sigma * \sin 360° = 0$

(IV.26)

From equations IV.26 and figure 4.29, it is appreciated that all gauges laid across or on either side of the neutral plane, cannot (theoretically) respond to the applied bending moment Mx. Two bridges are in such a position: the bridge D, already named shear force Fz. and the bridge A, which, consequently must be named Mz.

A contrario, all other bridges are affected and it is mandatory to determine which of these can compensate and remain balanced and which cannot. According to equations IV.25, IV.26 and the position of the gauges of the bridge E, shear force Fx and the bridge F, torque My, the following resistance changes can be deduced:

- gauges above the neutral plane (E_1 and E_2) are subjected to a tensile change

$$+\Delta R_E$$

- gauges below the neutral plane (E_3 and E_4) are subjected to a compression change

$$-\Delta R_E$$

where

$$\Delta R_E = K * R * \frac{\varepsilon}{2} * (1-\upsilon) \tag{IV.27}$$

and

- gauges above the neutral plane (F_1 and F_2) are subjected to a tensile change

$$+\Delta R_F$$

M/L Bending Moment Mz			
Load Case	Test 13	Test 14	Test 15
N.m	cu	cu	cu
0	2003	2004	2005
-2.69	2003	2004	2004
-30.27	1997	1996	1997
-57.85	1987	1988	1988
-85.44	1981	1979	1979
-85.44	1981	1979	1979
-57.85	1986	1988	1988
-30.27	1997	1996	1996
-2.69	2004	2005	2005
0	2004	2006	2006
2.69	2005	2006	2006
30.27	2012	2013	2013
57.85	2018	2019	2019
85.44	2024	2026	2026
85.44	2024	2026	2026
57.85	2018	2019	2019
30.27	2012	2013	2013
2.69	2005	2006	2006
0	2005	2005	2005

Table IV.12: Typical values from 3 tests recorded in A/P bending gauges when M/L bending moment positive and negative was applied.

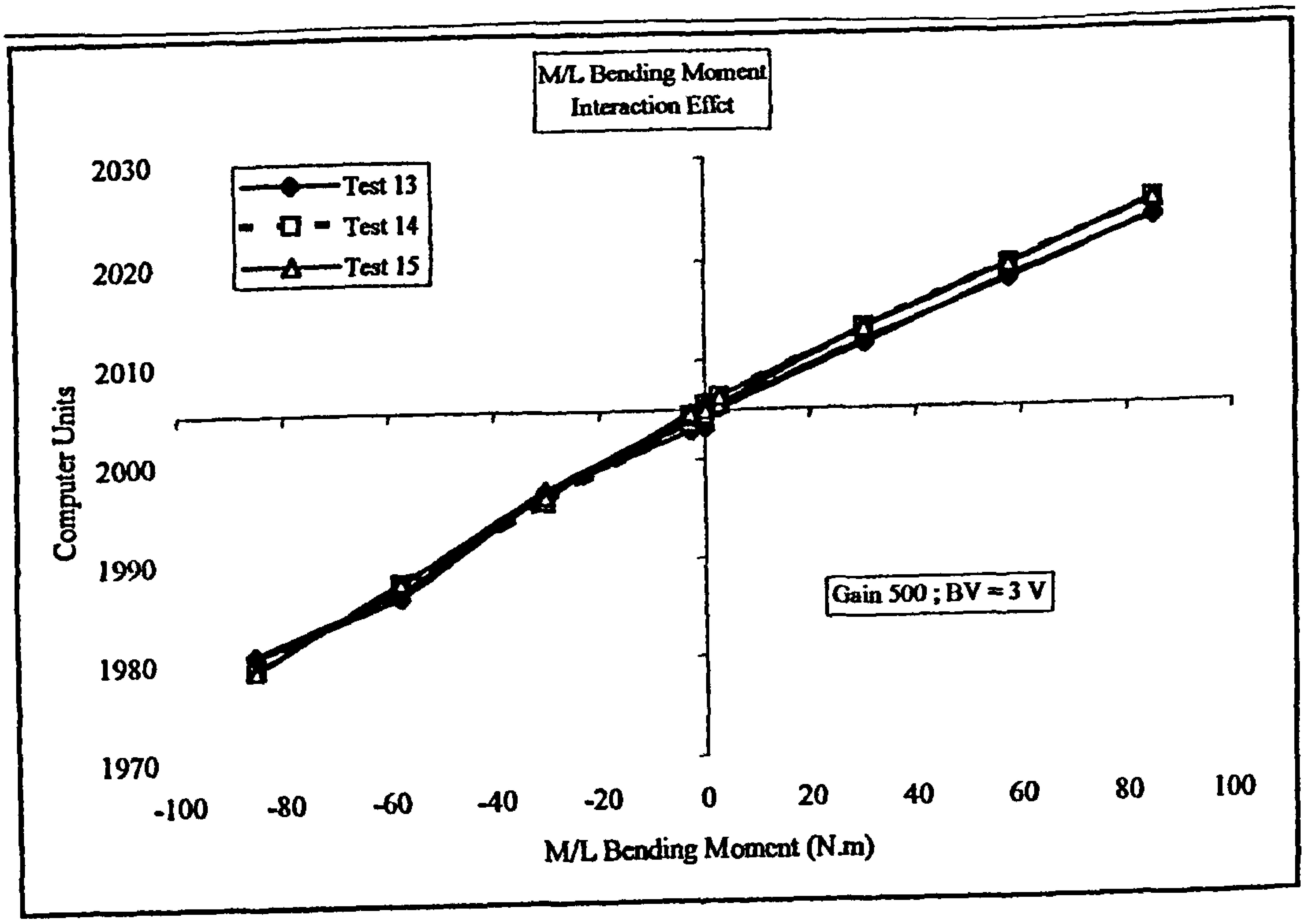


Figure IV.21: The traces processed from Table IV.12. The behaviour of the prototype in this particular configuration is linear.

- gauges below the neutral plane (F_3 and F_4) are subjected to a compression change

$$- \Delta R_F$$

where

$$\Delta R_F = K * R * \frac{\varepsilon_{60}}{2} * (1 - \upsilon) \tag{IV.28}$$

In these expressions ε and ε_{60} are the strains corresponding to the stresses $\pm \sigma_{ct}$ and $\pm \sigma_{60}$ respectively in the equation IV.26.

Consulting figures 4.29 and 4.30, it is proved that these bridges can compensate for the changes and are therefore balanced.

Regarding the gauges of bridge B in figure 4.29, gauges B_1 and B_2 are subjected to a tension while gauges B_3 and B_4 are subjected to a compression. The following resistance changes can be deduced:

- gauges B_1 and B_2 are subjected to a tensile change of $+ \Delta R_B$
- gauges B_3 and B_4 are subjected to a compression change of $- \Delta R_B$

where

$$\Delta R_B = K * R * \varepsilon \tag{IV.29}$$

According to the Wheatstone bridge theory, the wiring diagram of this channel should be as it is in figure 4.30, which proves that this bridge is unbalanced and provides an output signal V_{Bo} of:

$$V_{Bo} = V_s \frac{\Delta R_B}{R} = V_s * K * \varepsilon \tag{IV.30}$$

The strain ε is related to the axial stress by the equation of the Hook's law:

$$\varepsilon = \frac{\sigma}{E} = \frac{Mx * R_0}{E * I} \tag{IV.31}$$

Therefore, this bridge B is named Mx and it is the main channel in this configuration. Figure 4.29 shows the layout and wiring diagram of the sensor section of the new Villiers Pylon Transducer.

11.IV.5.9.2Bending moment Mz

The analysis is similar for a purely applied bending moment Mz. As shown in figure IV.20, the neutral plane is perpendicular as Mx bending moment and it passes through the angular position of 90° and 270°. For a positive Mz bending moment and a right side, that gives a compression from 90° to 270° through 180° (bottom half) and a tension from 90° to 270° through 0° (top half).

No bridges lying across or on either side of the neutral plane can, theoretically, respond to the applied load: bridges B (Mx) and E (Fx). Bridges D (Fz) and F (My) are affected but can compensate and, therefore, they remain eventually balanced.

Regarding the gauges of bridge A in figure 4.29, gauges A_1 and A_2 are subjected to a tension and gauges A_3 and A_4 to a compression. Resistance changes are identical to the Mx configuration. Bridge A is unbalanced and provides an output signal V_{Ao} having the value of:

$$V_{Ao} = V_s \frac{\Delta R_A}{R} = V_s * K * \varepsilon \tag{IV.32}$$

The strain ε is related to the to the applied load by equation:

Load Mass kg	Load Weight N	Test 1 computer units	Test 2 computer units
0.0	0.0	2000.2	1998.9
0.8	7.8	2005.5	2001.1
9.9	96.8	2005.0	1998.5
18.9	185.8	2004.7	2002.3
28.0	274.8	2006.5	2005.7
37.1	363.8	2001.8	2002.0
46.2	452.7	2007.0	2007.0
56.2	550.8	2005.6	2003.9
66.2	648.9	2005.3	2003.9
76.2	747.0	2008.2	2004.3
86.2	845.1	2002.9	2005.0
96.2	943.2	2005.7	2003.5
101.2	992.3	2005.8	2005.6
96.2	943.2	2011.2	2002.8
86.2	845.1	2010.1	2007.6
76.2	747.0	2009.1	2004.1
66.2	648.9	2010.0	2005.1
56.2	550.8	2007.1	2005.0
46.2	452.7	2009.5	2003.3
37.1	363.8	2009.6	2003.2
28.0	274.8	2010.3	2004.7
18.9	185.8	2008.5	2000.1
9.9	96.8	2007.3	2001.8
0.8	7.8	2008.0	2002.9
0.0	0.0	2002.0	1998.7

Table IV.13: The numerical values recorded in A/P bending gauges when a pure axial load is applied on the prototype having a hollow spindle (Gain = 500 ; BV = 3V).

Load Case N.m	Test 1	Test 2
0.0	2004.5	
-2.0	1995	
-11.8	1994.7	
-21.6	1990.7	
-11.8	1998.4	
-2.0	1993.7	
0.0	2005.3	
2.0	2013.5	2004.7
11.8	2009.5	2012.8
21.6	2015.4	2007.1
11.8	2004.9	2012.5
2.0	2006.1	2010.7
0.0	2005.9	2003.9

Table IV.13: The numerical values recorded in A/P bending gauges when a pure transverse torque is applied on the prototype having a hollow spindle (Gain = 500 ; BV = 3 V).

$$\varepsilon = \frac{\sigma}{E} = \frac{Mz * R_0}{E * I} \qquad \text{(IV.33)}$$

Consequently, this bridge A is named Mz and it is the main channel in this configuration.

Therefore, the layout of strain gauges and wiring diagram of the bridges (see figure 4.29) is now completely described.

In summary, it has been possible:

1. to name two channels among the six: channel B = Mx and A = Mz
2. to establish the required relationship between Mx / V_o and Mz / V_o

From these considerations, a numerical application has been calculated, it is presented in the following section.

11.IV.5.10 QUANTITATIVE RESULTS

Using the equations presented in the previous sections, it is hence possible to quantify the effect of various loads on the bridges and to determine the theoretical sensitivity of the bridges to any applied loads. The equations determined above have been derived relating to the output signal V_s of each channel to the load applied onto the new transducer. About the bridge excitation level, the values used are 7.5 V for all channels, except Fy which is 8 V. For more details and explanations about this choice (see chapter 5).

Various geometrical properties of a cross-section of the transducer will be used in this study. This cross-section is considered through an instrumented periphery of the transducer. These properties are the following:

- area A = π * (Ro2 - Ri2) = 126.45 * 10-4 m²
- second moment of area I (about X or Z axis)

$$\frac{\pi}{4} * (R_0^{\,4} - R_i^{\,4}) = 2284 \text{ mm}^4 = 22.84 * 10^{-10} \text{ m}^4$$

- polar moment of inertia J (about Y axis)

$$\frac{\pi}{2} * (R_0^{\,4} - R_i^{\,4}) = 4567 \text{ mm}^4 = 45.67 * 10^{-10} \text{ m}^4$$

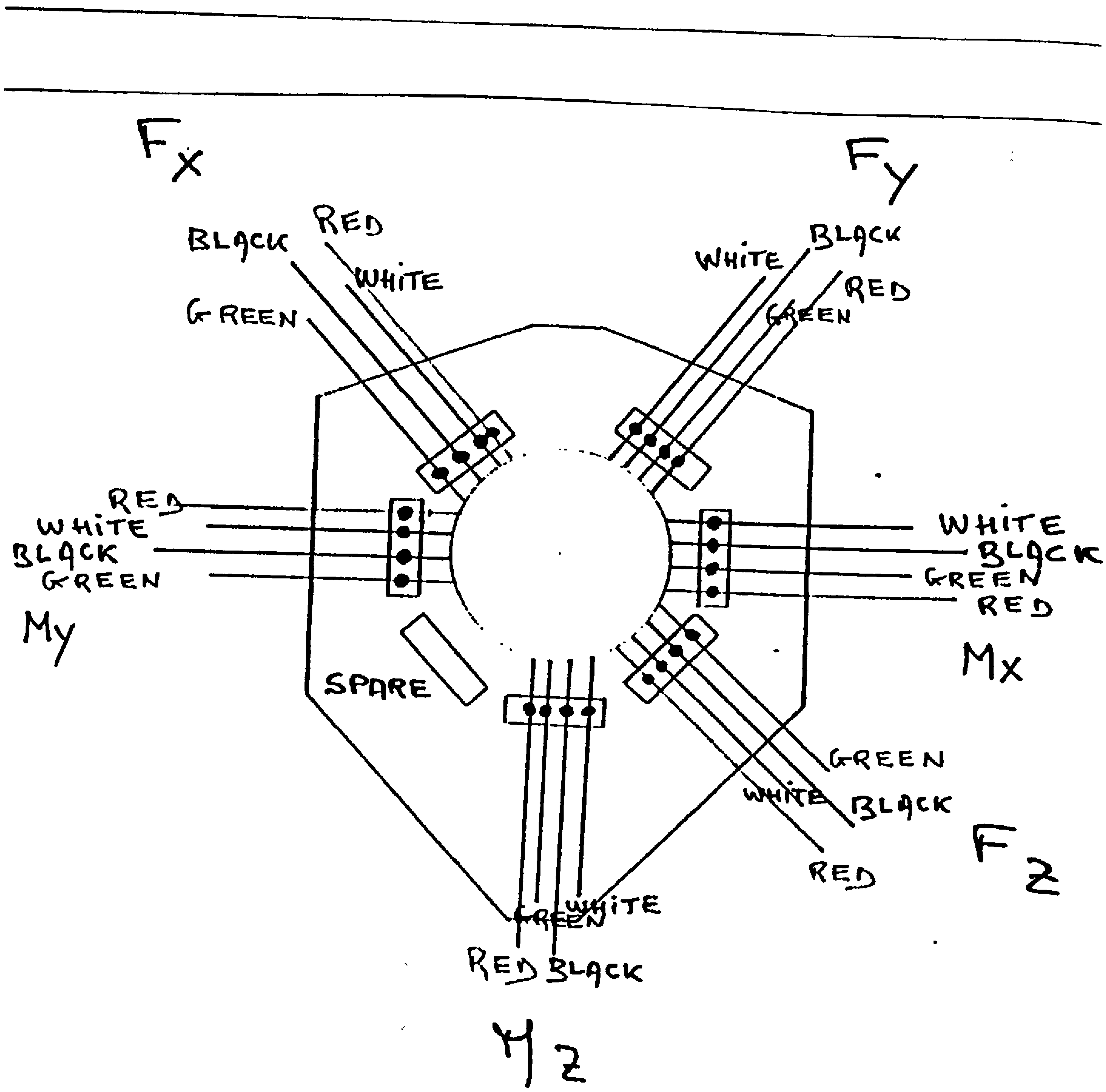
in which R_0 is the outer radius of the central body of the transducer (0.0075 m) and R_i the inner radius (0.004 m), (partially repeated from section 4.2.3).

1. APPLIED SHEAR FORCE FX OR FZ (along X or Z axes) = 100 N

   shear stress τ (from equation 4.14) = 1.492 MPa
   strain ε (from equation 4.17) = 9.62 μstrain
   <u>for the corresponding channel only:</u>
   output signal V_{Eo} (from equation 4.16) = 144.3 μV
   sensitivity = 1.443 μV / N
   sensitivity per unit power supply (7.5 V) = 0.192 μV / N

2. APPLIED AXIAL LOAD FY = 1000 N

   stress σ_c (from equation 4.23) = 7.91 MPa
   strain ε_c (from equation 4.22) = 39.5 μstrain
   <u>for the corresponding channel only:</u>
   output signal V_{Co} (from equation 4.24) = 407.1 μV
   sensitivity = 0.407 μV / N
   sensitivity per unit power supply = 0.051 μV / N



RED + ve supply : + V_o

BLACK - ve supply : - V_o

WHITE - ve signal : - V_s

GREEN + ve signal : + V_s

Figure IV.22: The bridge connections with the wiring colours convention used.

3. APPLIED BENDING MOMENT MX OR MZ = 100 N.m

stress σ_{α} (from equation 4.30) = 328 MPa
strain ε (from equation 4.34) = 1640 µstrain
<u>for the corresponding channel only:</u>
output signal V_{Co} (from equation 4.33) = 24 600 µV
sensitivity = 246 µV / N.m
sensitivity per unit power supply = 32.8 µV / N.m

4. APPLIED TORQUE MY = 30 N.m

shear stress τ (from equation 4.23) = 49.27 MPa
shear strain γ (from equation 4.22) = 633 µstrain
<u>for the corresponding channel only:</u>
output signal V_{Co} (from equation 4.24) = 4747.5 µV
sensitivity = 158.25 µV / N.m
sensitivity per unit power supply = 21.1 µV / N.m

Table IV.11 compares the theoretical results given by Magnissalis (1992) for the Strathclyde Pylon Transducer with those found above. As first approximation, it is possible to establish that the new Villiers Pylon Transducer seems less sensitive in shear and axial load than the SPT and more in bending moments and torque.

These theoretical results will be compared with those found by calibration and validation (see chapters 6 and 7).

11.IV.6 Results found when inter actions effects were studied

The principle was to apply a load in a different direction as the one for which bending gauges were fitted. In other words, the prototype studied was instrumented with gauges able to record the A/P bending moment Mz only. Therefore, the question is: what data will be recorded in these gauges if 1) a M/L bending moment then 2) a pure axial load and finally 3) a transverse torque are applied. The prototype used has a hollow spindle. The gain is always 500 with a bridge voltage of 3 V.

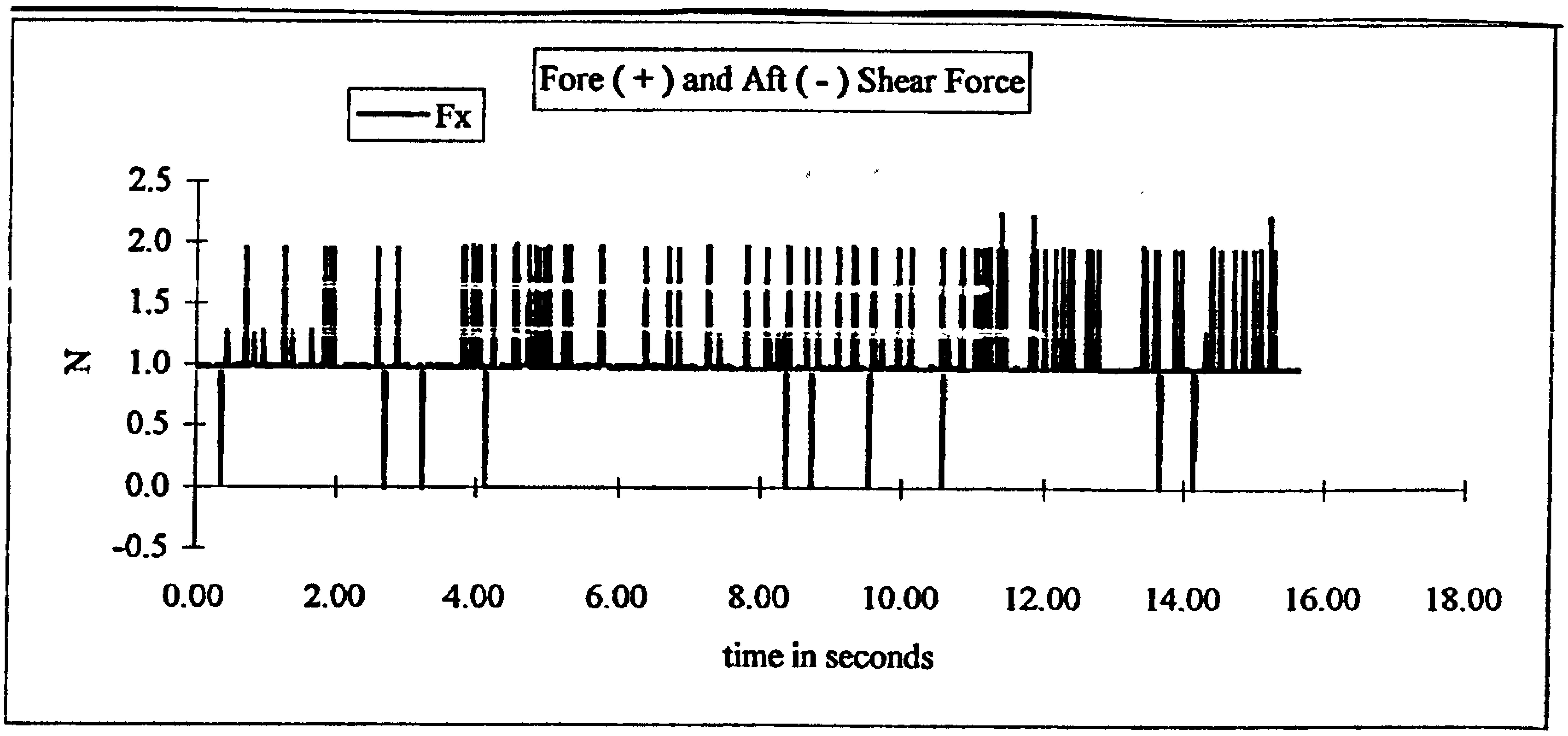
Concerning the M/L bending moment Mx, the numerical values are shown in table IV.12 (3 tests, 13, 14 and 15, one test was not mentioned in section 6.6.5, while the corresponding graph is shown in figure IV.21. The interaction effects in this particular channel have a low magnitude (25 cu versus 1400 cu in the main channel). The cross-talk is also linear. Concerning the axial load, the numerical values are shown in table IV.13 (2 tests) while the corresponding graph is shown in figure 4.21 in section 4.6.5.2.

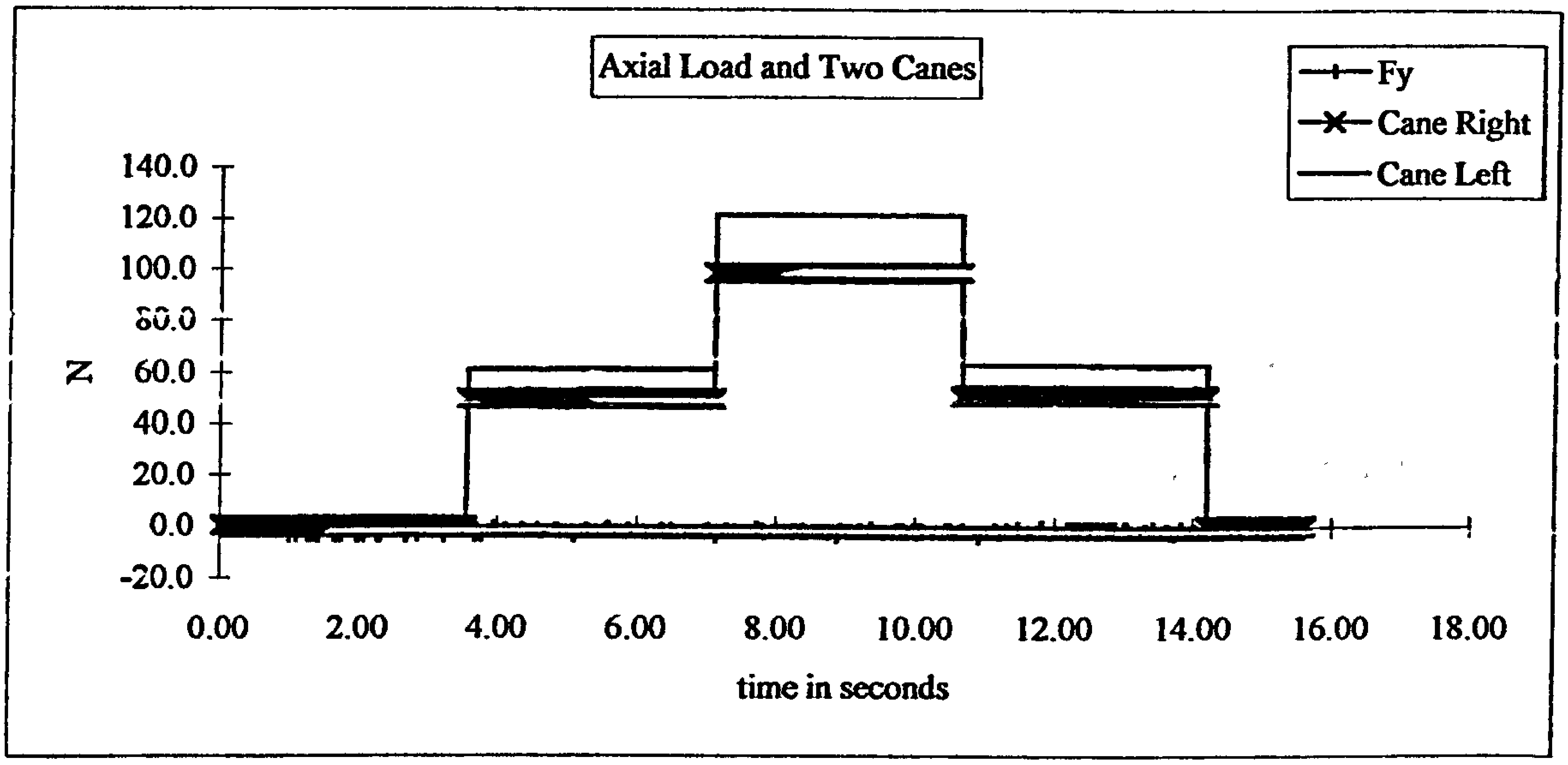
Table IV.14 shows the results processed when a transverse torque was applied and recorded through A/P bending gauges. The corresponding graph is shown in 4.22 in section 4.6.5.3. Two tests in the positive direction were performed while only one was conducted in the negative direction. Concerning the results expressed by these different interaction effects, see table 4.7 and comments in sections 4.6.5.3 and 4.7.

11.IV.7 The bridge connections of the new Villiers Pylon Transducer

The bridge connections are shown in figure IV.22, with the standardised wiring colours for $\pm$ V_s (signal o/p voltage: green positive and white negative) and $\pm$ V_o (power supply: red positive and black negative), as recommended by the ISA.

The pin connections, viewed from the pin ends, are shown in table IV.14.





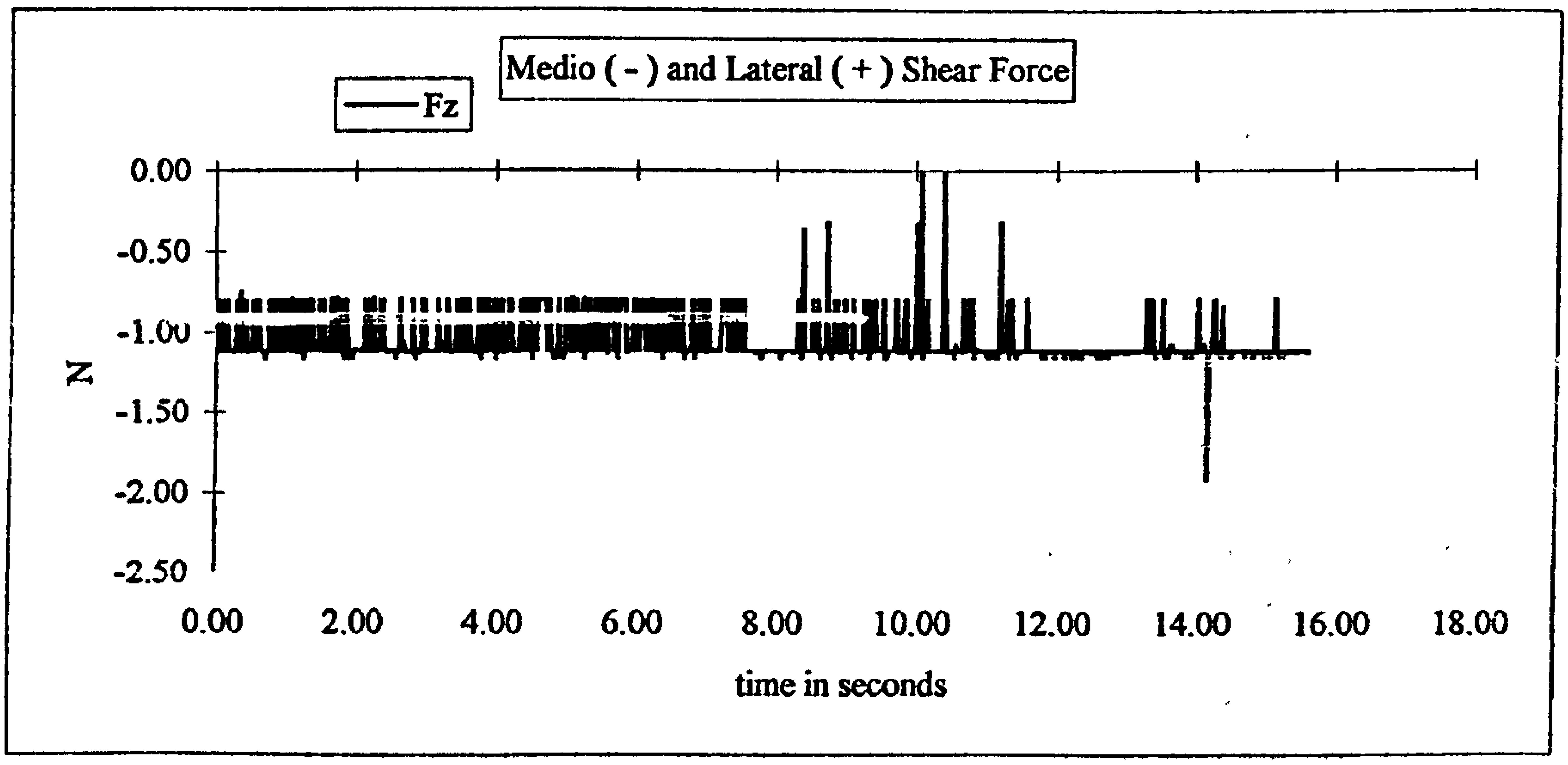
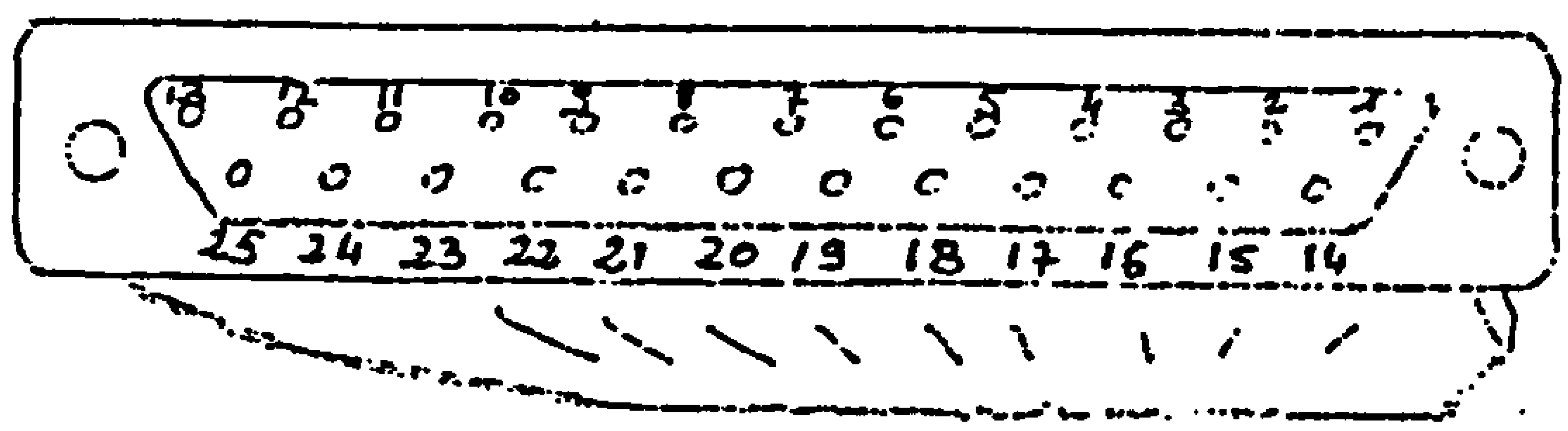


Figure V.1a: The three forces recorded simultaneously with the two walking assistive devices to investigate the possibility of cross sensitivity

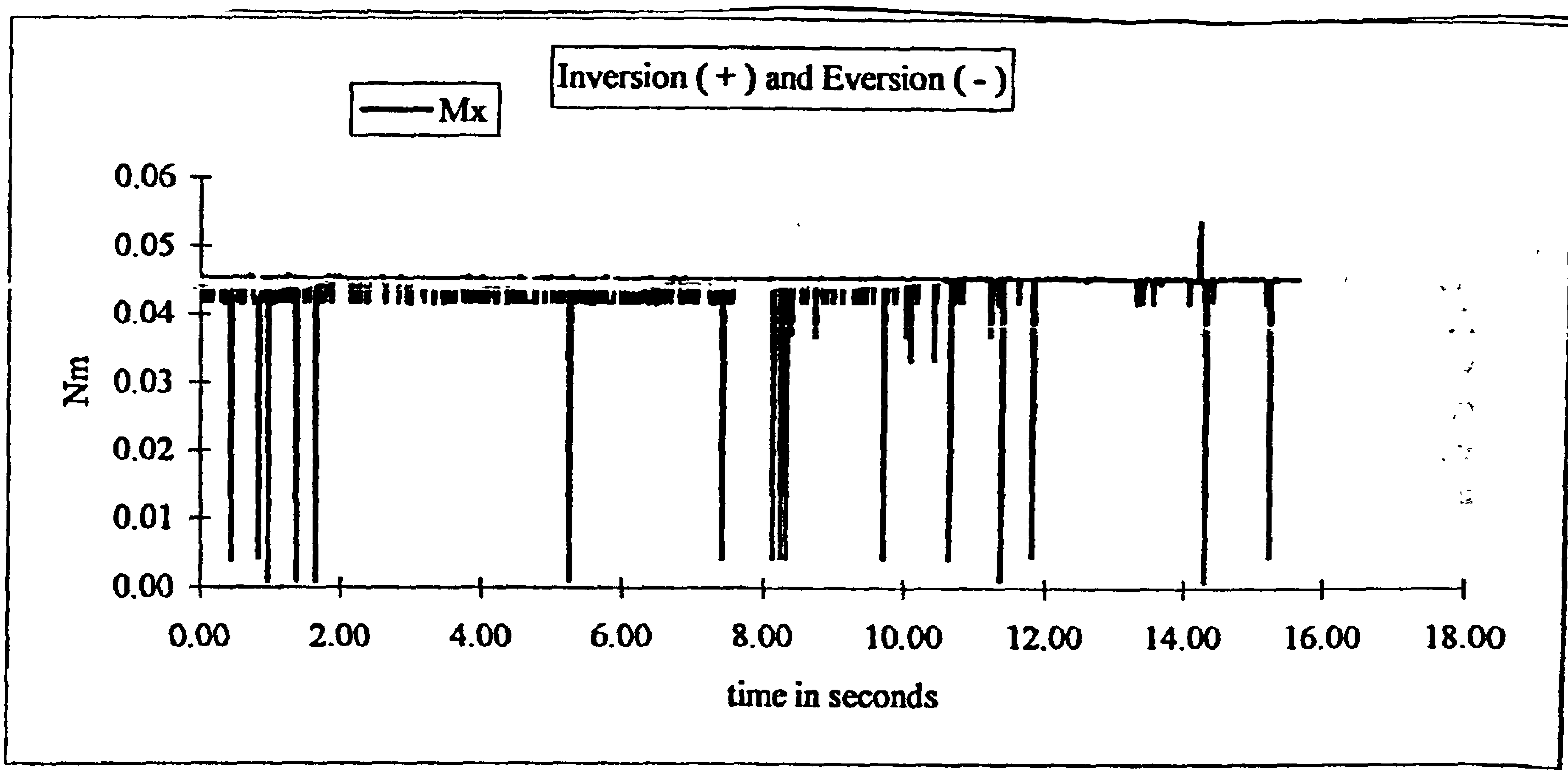
It is a description of the 25 way-out female socket viewed from the pins end. As stated above, the input / output socket was fastened onto a special bracket bolted on the flat flange of transducer. Its main direction was parallel to the frontal plane and the pins were vertically aligned. Hence, the plug took place along the shank tube of the prosthesis. This gave enough room to use the new transducer in staircase. The cable which way out the plug was not cumbersome and could be attached, on the prosthetic socket, by the mean of an adhesive tape.

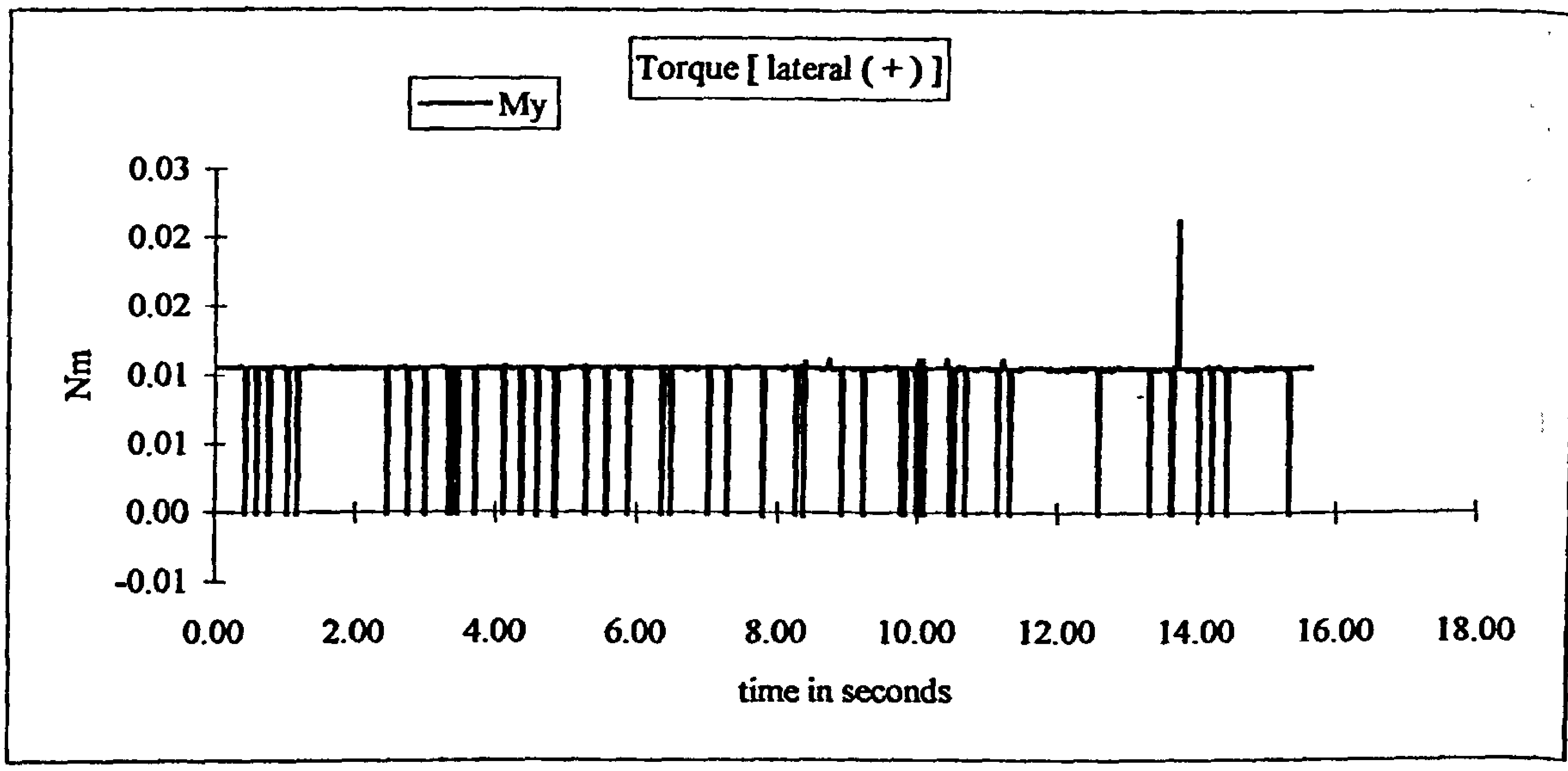
SOCKET VIEWED FROM PINS END
INPUTS / OUTPUTS ANKLE TRANSDUCER
25 WAY SOCKET



Channel n°1	**Fx**	pin n° 1	+ V_s supply	red
	ant-post shear	pin n° 14	- V_s supply	black
		pin n° 2	- V_o signal	white
		pin n° 15	+ V_o signal	green
Channel n°2	**Fy**	pin n° 3	+ V_s supply	red
	axial load	pin n° 16	- V_s supply	black
		pin n° 4	- V_o signal	white
		pin n° 17	+ V_o signal	green
Channel n°3	**Fz**	pin n° 5	+ V_s supply	red
	lateral shear	pin n° 18	- V_s supply	black
		pin n° 6	- V_o signal	white
		pin n° 19	+ V_o signal	green
Channel n°4	**Mx**	pin n° 7	+ V_o supply	red
	m/l moment	pin n° 20	- V_o supply	black
		pin n° 8	- V_s signal	white
		pin n° 21	+ V_s signal	green
Channel n°5	**My**	pin n° 9	+ V_o supply	red
	torque	pin n° 22	- V_o supply	black
		pin n° 10	- V_s signal	white
		pin n° 23	+ V_s signal	green
Channel n°6	**Mz**	pin n° 11	+ V_o supply	red
	a/p moment	pin n° 24	- V_o supply	black
		pin n° 12	- V_s signal	white
		pin n° 25	+ V_s signal	green

Table IV.15: The pin connections of the new Villiers Pylon Transducer of the 25 way inputs – outputs socket viewed from the pin ends.





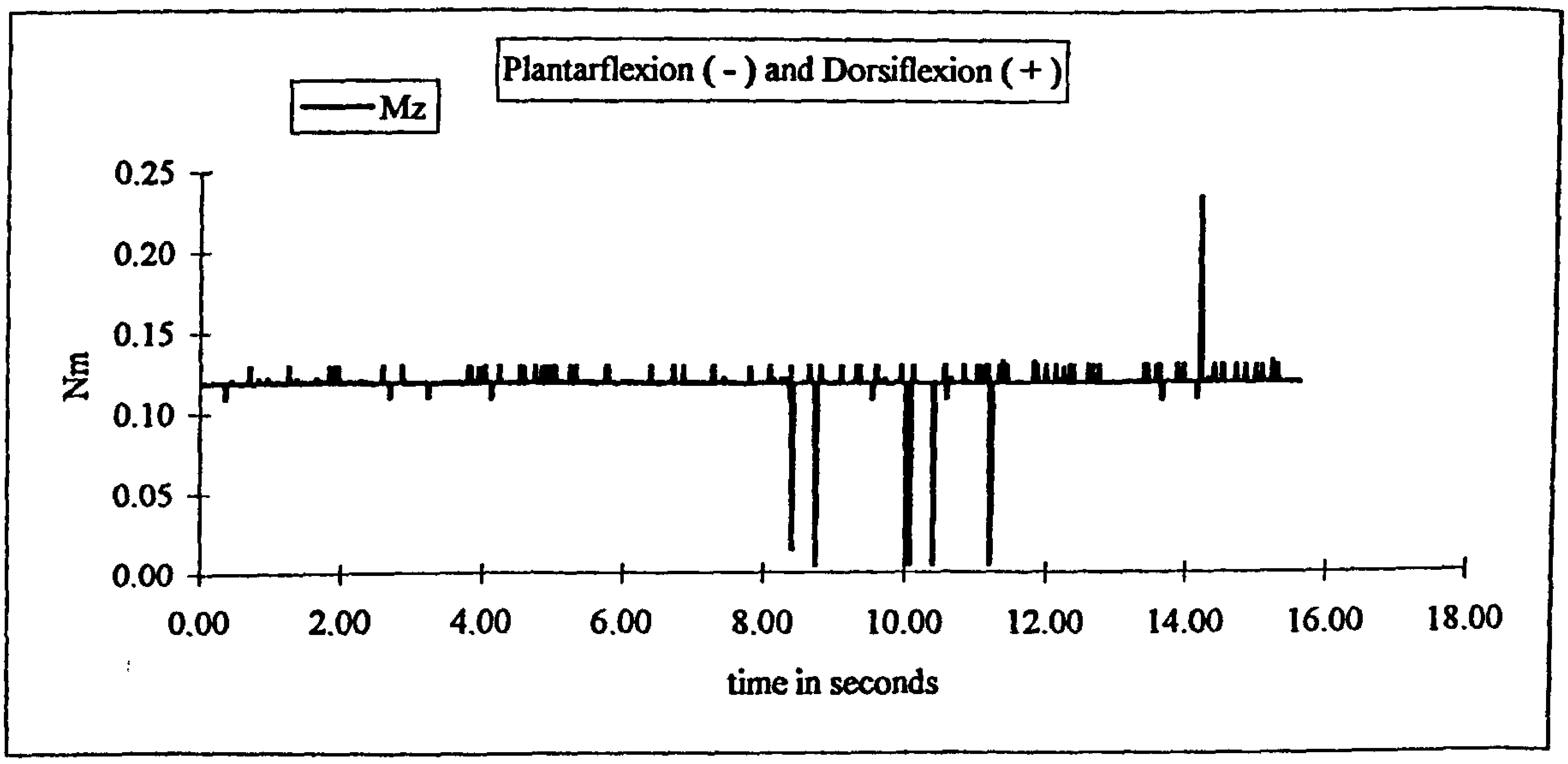


Figure V.1b: The three bending moments recorded simultaneously with the two walking assistive devices to investigate the possibility of cross sensitivity

11.V CALIBRATION AND VALIDATION OF THE TWO INSTRUMENTED WALKING ASSISTIVE DEVICES

11.V.1 Validation of the two walking assistive devices: The two canes were simultaneously recorded

Figures V.1a and V.1b show the validation test performed when the two canes are simultaneously recorded with the six other channels. This was conducted to verify if there were some inter – action effects between the two walking assistive devices (channels 7 and 8) with the three forces and moments (channels 1 to 6).

The calibration matrix described in section 6.7 was applied for the channels 1 to 6. Equations 5.8 and 5.9 were applied to the raw data recorded in channels 7 to 8. The set up is described in figure 5.10 and the load schedule is shown in table V.1.

Therefore, the results can be analysed as follows:

A/P shear force Fz: low cross-sensitivity ± 1 N

Axial Load: low cross-sensitivity ± 2 N

M/L shear force: very low cross-sensitivity ± 0.25 N

M/L bending moment: very low cross-sensitivity ± 0.2 N.m

Torque: very low cross-sensitivity ± 0.01 N.m

A/P bending moment: very low cross-sensitivity ± 0.1 N.m

Concerning the walking assistive devices, the results are conform as it is expected (see the following section 11.V.2).

11.V.2 The different load cases and the results of the validation tests

The set up for the validation tests performed to check the calibration tests is described in figure 5.10. For set up reason such as 1) instability of the weights along the stick handle; 2) contact between the weights and the axial rod of the cane; 3) difficulty to use the forearm counter load with a sufficient accuracy; it was not possible to conduct tests with the rod of the cane frontward, medialward or lateralward the vertical line.

The weights used were calibrated sandbags used in rehabilitation. The accuracy of such a weight was approximately 5 %, which is not very high. For practical reasons (lack of accurately calibrated weights), the applied load cases were not equivalent in both sides.

Table V.1 shows the results obtained from two tests recording simultaneously the two walking assistive devices. Table V.1 exhibits the values of each test, the arithmetic mean values from the two tests with the corresponding standard deviation, confidence level at a threshold of 95 % and the Pearson coefficient. This coefficient must be as close to 1 as possible. When it is so, the ratio between predicted and applied loads is close to 1 and thus the predicted load is practically equal to the applied load.

As previously stated in section 5.4.5, the cross-sensitivity due to bending or transverse torque was not investigated. It is obvious that is lack of accuracy and further research should be undertaken in this direction. Furthermore, it can be noted that there is a lack of research reported in literature concerning the biomechanic of the cane – assisted gait.

Left	**Cane**					
Loading Mass	Applied Load	Test N°1	Test N°2	Mean	Standard Deviation	Pearson Coefficient
kg	N	N	N	N		
0.0	0.0	0.30	0.45	0.38	0.07	0.999
7.0	63.5	61.20	62.09	61.65	0.45	0.998
13.0	118.0	120.90	122.90	121.90	1.00	0.999
7.0	63.5	62.90	63.20	63.05	0.15	1.000
0.0	0.0	2.50	2.86	2.68	0.18	0.999
Right	**Cane**					
Loading Mass	Applied Load	Test N°1	Test N°2	Mean	Standard Deviation	Pearson Coefficient
kg	N	N	N	N		
0.0	0.0	0.90	1.30	1.10	0.20	0.000
5.0	45.4	47.55	46.30	46.93	0.63	0.967
10.0	90.8	94.51	92.41	93.46	1.05	0.971
5.0	45.4	49.73	47.3	48.52	1.21	0.935
0.0	0.0	2.6	2.3	2.45	0.15	0.000

Table V.1: The validation tests performed to verify the accuracy of the equations 5.8 and 5.9, established from the calibration tests of the two walking assistive devices. For practical reasons, the load schedule was not similar on both canes (see also the traces in figures V.1a and V.1b).

Figure V.2 shows the graph of the predicted versus the applied load recorded from the left-instrumented cane. Figure V.3 is the same for the right cane.

The linearity can be considered as sufficient regarding the requirement and the mean accuracy indispensable for the conducted tests shown in chapter 8. There are also no hysteresis or drift. However, the duration of the tests does not allow any accurate conclusion concerning creep, but the tests performed with the patients (see chapter 8) are usually short enough to do not show any creep problems.

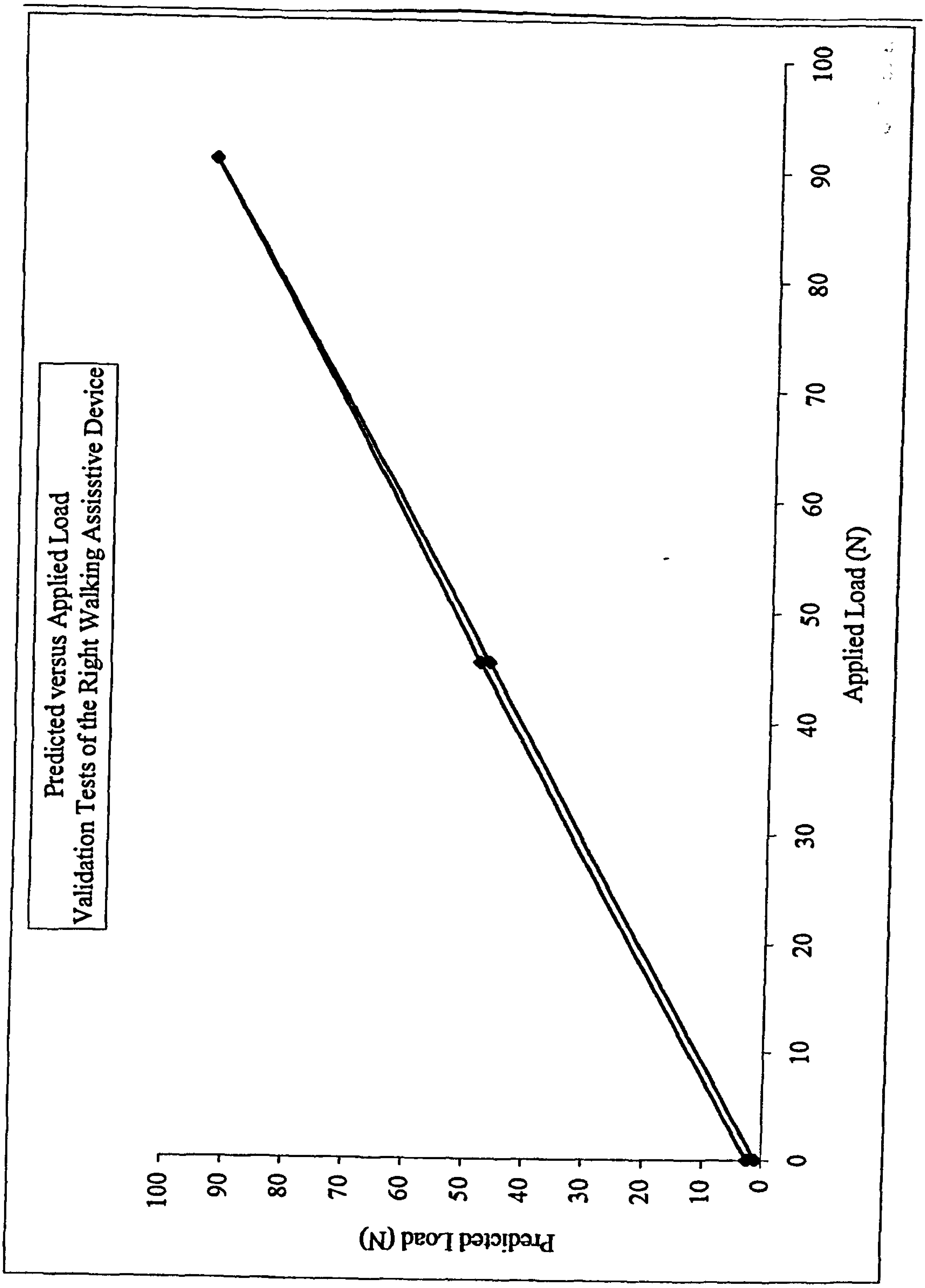


Figure V.3: Predicted versus Applied Load for the right walking assistive device. The rod of the cane is inclined backward of an angle of 22°31. No tests were conducted in the other directions. The cross sensitivity due to bending was not controlled.

Pure Shear	Force	Negative		Main	Channel	Fx			
Load applied									
along X axis		*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
at 0.0355 m		*4*			*INTERVALS*	*4*			*INTERVALS*
from ankle axis		*tests*			*LEVEL*	*tests*			*LEVEL*
					95%				*95%*
Loading mass	Loading								
kg	N	SFx				SFy			
0.0	0.0	1999.8	1999.8	0.7594	0.7442	2001.0	2001.2	0.4690	0.4597
0.8	7.6	1998.4	1998.4	0.8057	0.7896	2000.7	2000.9	0.4193	0.4109
9.8	96.6	1984.4	1984.4	0.9695	0.9501	2000.5	2000.7	0.5188	0.5084
18.9	185.5	1970.5	1970.2	1.1150	1.0927	2000.3	2000.5	0.6449	0.6319
28.0	274.5	1956.5	1956.0	1.4640	1.4347	1999.9	2000.0	0.5377	0.5270
37.1	363.5	1942.8	1942.5	1.5174	1.4870	1999.8	1999.5	0.5000	0.4900
46.1	452.5	1928.7	1928.1	1.8982	1.8602	1999.1	1999.0	0.7890	0.7732
46.1	452.5	1928.7	1928.1	1.8982	1.8602	1999.1	1999.0	0.7890	0.7732
37.1	363.5	1942.6	1942.2	1.5735	1.5420	1999.2	1999.2	0.2872	0.2815
28.0	274.5	1956.8	1956.5	1.2623	1.2370	1999.5	1999.5	0.5315	0.5209
18.9	185.5	1970.4	1970.1	1.0279	1.0074	1999.7	1999.8	0.5377	0.5270
9.8	96.6	1984.4	1984.4	0.7550	0.7399	2000.4	2000.7	0.6000	0.5880
0.8	7.6	1998.3	1998.2	0.7832	0.7675	2000.2	2000.3	0.3559	0.3488
0.0	0.0	1999.6	1999.6	0.7616	0.7463	2000.4	2000.5	0.2363	0.2316
		MEAN	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
		4			*INTERVALS*	*4*			*INTERVALS*
		tests			*LEVEL*	*tests*			*LEVEL*
Loading mass	Loading				*95%*				*95%*
kg	N	SFz				SMx			
0.0	0.0	2001.7	2001.4	0.8505	0.8335	2000.2	2000.3	0.8287	0.8121
0.8	7.6	2001.5	2001.4	0.7141	0.6998	2000.2	2000.1	0.8461	0.8291
9.8	96.6	2001.9	2001.5	1.1690	1.1456	2000.4	2000.4	0.4992	0.4892
18.9	185.5	2002.2	2002.0	1.1846	1.1609	2000.1	2000.2	0.4796	0.4700
28.0	274.5	2002.2	2002.3	1.0813	1.0596	2000.1	2000.1	1.1500	1.1270
37.1	363.5	2002.6	2003.0	1.2500	1.2250	1999.9	2000.1	1.7877	1.7519
46.1	452.5	2002.7	2003.3	1.4166	1.3882	1999.8	2000.0	2.3528	2.3057
46.1	452.5	2002.7	2003.3	1.4166	1.3882	1999.8	2000.0	2.3528	2.3057
37.1	363.5	2002.6	2002.9	1.3000	1.2740	1999.8	2000.0	1.6998	1.6657
28.0	274.5	2002.5	2002.8	1.0149	0.9946	1999.9	2000.0	1.0472	1.0263
18.9	185.5	2002.0	2002.1	1.0532	1.0321	1999.9	2000.0	0.6245	0.6120
9.8	96.6	2002.0	2001.7	0.9678	0.9484	2000.0	2000.0	0.4573	0.4482
0.8	7.6	2001.7	2001.4	1.0017	0.9816	2000.0	2000.0	0.8461	0.8291
0.0	0.0	2001.7	2001.2	1.1372	1.1145	1999.9	1999.9	0.7365	0.7218
		MEAN	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
		4			*INTERVALS*	*4*			*INTERVALS*
		tests			*LEVEL*	*tests*			*LEVEL*
Loading mass	Loading				*95%*				*95%*
kg	N	SMy				SMz			
0.0	0.0	1999.1	1999.0	0.7411	0.7262	2000.0	2000.1	0.4726	0.4631
0.8	7.6	1999.3	1999.4	0.4359	0.4272	1999.4	1999.4	0.1826	0.1789
9.8	96.6	1998.8	1999.0	1.0996	1.0776	1992.8	1992.8	0.3775	0.3699
18.9	185.5	1998.5	1998.0	2.6311	2.5784	1986.7	1986.9	0.8732	0.8557
28.0	274.5	1998.5	1997.8	3.6819	3.6082	1980.3	1980.2	1.3048	1.2787
37.1	363.5	1998.0	1996.8	5.1448	5.0418	1974.0	1974.0	1.9053	1.8671
46.1	452.5	1997.3	1995.7	6.3945	6.2665	1967.4	1967.2	2.6235	2.5709
46.1	452.5	1997.3	1995.7	6.3945	6.2665	1967.4	1967.2	2.6235	2.5709
37.1	363.5	1997.7	1996.5	5.3706	5.2631	1973.8	1973.8	2.1572	2.1140
28.0	274.5	1998.0	1997.2	3.8448	3.7678	1980.2	1980.2	1.4799	1.4502
18.9	185.5	1998.3	1997.9	2.7427	2.6878	1986.6	1986.5	0.9037	0.8856
9.8	96.6	1998.8	1998.8	1.1030	1.0809	1992.8	1992.6	0.6658	0.6525
0.8	7.6	1999.3	1999.3	0.3862	0.3785	1999.4	1999.4	0.3416	0.3347
0.0	0.0	1999.3	1999.3	0.3873	0.3795	1999.9	1999.9	0.3916	0.3837

Table VI.1: Mean raw data from 4 tests, simultaneously recorded in the six channels when negative A/P shear forces Fx were applied, with descriptive statistics.

11.VI COMPLETE RESULTS CONCERNING THE CALIBRATION OF THE NEW REMOVABLE VILLIERS PYLON TRANSDUCER

11.VI.1 Calibration results in A/P (Fx) and M/L (Fz) shear forces

The following tables VI.1, VI.2 and VI.3 show the mean results recorded from 4 calibration tests performed in A/P and M/L planes.

The set up to calibrate the shear force channels Fx and Fz was described in section 6.3.1.The steel cable on which the loads were suspended was positioned on the plane crossing the centre line of the shear gauges. Therefore, a pure shear force was recorded. Nevertheless, because the Villiers Pylon Transducer was fitted on the bench table at the ankle axis level, a small bending moment was applied, having a lever arm of 0.011 m (see figure 6.2). This lever arm was identical in both A/P and M/L planes. The presented tables have the same arrangement as table 6.6 (shear force Fx positive).

The schedule is the following:	table VI.1	A/P Shear force Fx negative
	table VI.2	M/L Shear force Fz positive
	table VI.3	M/L Shear force Fz negative.

The corresponding graphs are shown in figure 6.11 for A/P shear force Fx and 6.13 for M/L shear force Fz.

Pure Shear	Force	Positive		Main	Channel	Fz			
Load applied									
along Z axis		*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
at 0.0355 m		*4*			*INTERVALS*	*4*			*INTERVALS*
from ankle axis	-	*tests*			*LEVEL*	*tests*			*LEVEL*
					95%				*95%*
Loading mass	Loading								
kg	N	SFx				SFy			
0.0	0.0	2001.4	2001.4	0.3416	0.3347	2000.6	2000.6	1.5064	1.4762
0.8	7.6	2001.3	2001.4	0.2160	0.2117	2000.6	2000.7	1.6010	1.5690
9.8	96.6	2001.4	2001.4	0.0957	0.0938	2000.8	2000.7	1.3598	1.3326
18.9	185.5	2001.4	2001.3	0.2380	0.2333	2001.4	2001.5	1.5801	1.5485
28.0	274.5	2000.9	2001.1	0.3594	0.3522	2001.6	2001.8	1.5987	1.5667
37.1	363.5	2000.6	2001.1	1.1413	1.1184	2001.7	2002.0	1.9942	1.9542
46.1	452.5	2001.0	2000.9	0.1732	0.1697	2002.1	2002.2	1.6761	1.6425
46.1	452.5	2001.0	2000.9	0.1732	0.1697	2002.3	2002.4	1.5801	1.5485
37.1	363.5	2001.2	2001.2	0.1732	0.1697	2001.7	2001.9	1.7877	1.7519
28.0	274.5	2001.0	2001.0	0.1915	0.1877	2001.5	2001.6	1.5022	1.4721
18.9	185.5	2001.3	2001.3	0.3304	0.3238	2000.9	2001.0	1.3226	1.2961
9.8	96.6	2001.4	2001.4	0.4203	0.4119	2000.6	2000.9	1.4975	1.4675
0.8	7.6	2001.5	2001.5	0.2062	0.2020	2000.2	2000.4	1.6317	1.5991
0.0	0.0	2001.5	2001.6	0.3403	0.3335	2000.0	2000.2	1.5253	1.4948
		MEAN	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
		4			*INTERVALS*	*4*			*INTERVALS*
		tests			*LEVEL*	*tests*			*LEVEL*
Loading mass	Loading				*95%*				*95%*
kg	N	SFz				SMx			
0.0	0.0	2001.0	2001.1	0.9605	0.9412	1999.0	1999.1	0.2630	0.2577
0.8	7.6	2002.0	2002.1	0.8617	0.8444	1997.2	1997.2	0.4924	0.4826
9.8	96.6	2015.7	2015.6	1.0033	0.9832	1976.1	-1976.3	0.6185	0.6061
18.9	185.5	2028.9	2028.9	0.9238	0.9053	1955.4	1955.6	0.7632	0.7479
28.0	274.5	2042.4	2042.4	0.8995	0.8815	1934.3	1934.5	0.9430	0.9241
37.1	363.5	2055.6	2055.8	1.2176	1.1932	1909.6	1912.7	7.5496	7.3985
46.1	452.5	2069.4	2069.5	0.8421	0.8253	1892.5	1892.6	1.3026	1.2765
46.1	452.5	2069.4	2069.5	0.8421	0.8253	1892.3	1892.4	1.1730	1.1495
37.1	363.5	2055.7	2055.6	0.8426	0.8257	1913.7	1913.9	1.2936	1.2677
28.0	274.5	2042.4	2042.6	0.9394	0.9206	1934.2	1934.4	0.9179	0.8995
18.9	185.5	2029.1	2029.0	0.8347	0.8180	1955.3	1955.3	0.7848	0.7690
9.8	96.6	2015.7	2015.7	0.7047	0.6906	1976.3	1976.3	0.4924	0.4826
0.8	7.6	2002.0	2002.1	0.9605	0.9412	1997.3	1997.4	0.5354	0.5247
0.0	0.0	2001.2	2001.2	0.8382	0.8214	1999.0	1999.1	0.4992	0.4892
		MEAN	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
		4			*INTERVALS*	*4*			*INTERVALS*
		tests			*LEVEL*	*tests*			*LEVEL*
Loading mass	Loading				*95%*				*95%*
kg	N	SMy				SMz			
0.0	0.0	1998.7	1998.7	0.4243	0.4158	1999.5	1999.5	0.5737	0.5622
0.8	7.6	1998.7	1998.8	0.3948	0.3869	1999.5	1999.6	0.7932	0.7773
9.8	96.6	1999.0	1999.6	1.8157	1.7793	1999.5	1999.5	0.6652	0.6519
18.9	185.5	1998.6	1998.7	1.6422	1.6093	1999.4	1999.4	0.5354	0.5247
28.0	274.5	1997.5	1997.7	2.0353	1.9946	1999.2	1999.2	0.4203	0.4119
37.1	363.5	1998.0	1997.7	1.8910	1.8531	2000.1	1999.8	1.3048	1.2787
46.1	452.5	1998.3	1997.5	2.7049	2.6508	1999.3	1999.3	0.2449	0.2400
46.1	452.5	1998.4	1997.5	2.9319	2.8732	1999.3	1999.3	0.3109	0.3047
37.1	363.5	1998.2	1997.9	1.6460	1.6130	1999.3	1999.4	0.3862	0.3785
28.0	274.5	1997.9	1998.0	0.9899	0.9701	1999.3	1999.4	0.3500	0.3430
18.9	185.5	1998.2	1998.2	0.0816	0.0800	1999.4	1999.4	0.4425	0.4337
9.8	96.6	1997.8	1997.6	0.7528	0.7377	1999.4	1999.4	0.5774	0.5658
0.8	7.6	1998.7	1998.8	0.4546	0.4455	1999.5	1999.5	0.5888	0.5770
0.0	0.0	1998.8	1998.9	0.2062	0.2020	1999.5	1999.5	0.5774	0.5658

Table VI.2: Mean raw data from 4 tests, simultaneously recorded in the six channels when positive M/L shear forces Fz were applied, with descriptive statistics.

Pure Shear	Force	Negative		Main	Channel	Fz			
Load applied									
along Z axis		*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
at 0.0355 m		*4*			*INTERVALS*	*4*			*INTERVALS*
from ankle axis		*tests*			*LEVEL*	*tests*			*LEVEL*
					95%				*95%*
Loading mass	Loading								
kg	N	SFx				SFy			
0.0	0.0	2000.5	2000.6	0.3862	0.3785	2000.1	2000.3	0.6455	0.6326
0.8	7.6	2000.5	2000.6	0.3559	0.3488	2000.1	2000.3	0.7853	0.7696
9.8	96.6	2000.5	2000.5	0.2986	0.2926	1999.6	1999.9	0.7890	0.7732
18.9	185.5	2000.5	2000.5	0.4243	0.4158	1999.3	1999.3	0.7932	0.7773
28.0	274.5	2000.6	2000.8	0.4500	0.4410	1999.1	1999.3	0.7594	0.7442
37.1	363.5	2000.6	2000.6	0.3775	0.3699	1998.3	1998.2	0.8180	0.8016
46.1	452.5	2000.7	2000.7	0.5888	0.5770	1997.6	1997.7	0.8995	0.8815
46.1	452.5	2000.7	2000.7	0.5679	0.5565	1997.6	1997.7	0.8995	0.8815
37.1	363.5	2000.8	2000.8	0.3775	0.3699	1998.1	1998.2	0.8386	0.8219
28.0	274.5	2000.7	2000.7	0.3304	0.3238	1998.3	1998.5	0.6898	0.6760
18.9	185.5	2000.6	2000.6	0.2630	0.2577	1999.0	1999.3	0.7805	0.7649
9.8	96.6	2000.4	2000.5	0.2754	0.2699	1999.5	1999.7	0.8641	0.8468
0.8	7.6	2000.5	2000.5	0.3000	0.2940	1999.4	1999.5	0.6898	0.6760
0.0	0.0	2000.4	2000.6	0.5123	0.5021	1999.4	1999.6	1.0436	1.0227
		MEAN	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
		4			*INTERVALS*	*4*			*INTERVALS*
		tests			*LEVEL*	*tests*			*LEVEL*
Loading mass	Loading				*95%*				*95%*
kg	N	SFz				SMx			
0.0	0.0	1999.7	1999.7	0.9535	0.9344	2000.3	2000.3	1.3329	1.3062
0.8	7.6	1998.6	1998.5	1.0231	1.0026	2002.1	2002.1	1.3304	1.3038
9.8	96.6	1985.0	1985.0	0.8995	0.8815	2022.6	2022.8	1.1343	1.1116
18.9	185.5	1971.6	1971.5	0.9845	0.9648	2043.1	2043.1	1.0847	1.0630
28.0	274.5	1958.1	1958.2	0.7890	0.7732	2063.3	2063.2	0.8544	0.8373
37.1	363.5	1945.0	1945.0	0.8185	0.8021	2083.8	2083.7	0.9883	0.9685
46.1	452.5	1931.1	1931.0	0.7681	0.7527	2104.5	2104.6	1.3342	1.3075
46.1	452.5	1931.1	1931.0	0.7681	0.7527	2104.4	2104.6	1.2339	1.2092
37.1	363.5	1944.8	1944.8	0.8500	0.8330	2083.7	2083.7	0.7703	0.7549
28.0	274.5	1958.3	1958.4	0.7932	0.7773	2063.4	2063.5	0.9032	0.8852
18.9	185.5	1971.8	1972.0	0.8446	0.8277	2043.0	2042.8	1.1673	1.1439
9.8	96.6	1985.2	1985.2	0.6928	0.6790	2022.7	2022.7	1.0408	1.0200
0.8	7.6	1998.5	1998.3	1.0116	0.9913	2002.3	2002.4	1.4728	1.4433
0.0	0.0	1999.6	1999.7	1.0340	1.0133	2000.6	2000.6	1.2997	1.2737
		MEAN	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
		4			*INTERVALS*	*4*			*INTERVALS*
		tests			*LEVEL*	*tests*			*LEVEL*
Loading mass	Loading				*95%*				*95%*
kg	N	SMy				SMz			
0.0	0.0	1998.8	1998.7	0.2363	0.2316	1999.6	1999.5	0.5066	0.4965
0.8	7.6	1998.7	1998.7	0.1826	0.1789	1999.4	1999.4	0.4992	0.4892
9.8	96.6	1999.7	1999.1	1.8464	1.8094	1999.6	1999.6	0.6076	0.5954
18.9	185.5	1998.3	1998.5	1.6820	1.6483	1999.4	1999.4	0.7616	0.7463
28.0	274.5	1997.3	1997.5	0.9535	0.9344	1999.5	1999.5	0.6583	0.6451
37.1	363.5	1997.8	1997.4	1.6132	1.5809	1999.5	1999.5	0.8461	0.8291
46.1	452.5	1997.5	1998.0	2.6090	2.5567	1999.5	1999.5	0.9309	0.9123
46.1	452.5	1997.5	1998.0	2.6090	2.5567	1999.5	1999.6	0.9069	0.8888
37.1	363.5	1997.7	1997.6	2.2867	2.2410	1999.5	1999.5	0.6608	0.6476
28.0	274.5	1998.3	1998.5	1.2028	1.1787	1999.6	1999.5	0.7411	0.7262
18.9	185.5	1998.0	1998.1	0.6500	0.6370	1999.5	1999.5	0.6952	0.6813
9.8	96.6	1998.2	1998.1	0.6994	0.6854	1999.5	1999.5	0.6602	0.6470
0.8	7.6	1998.6	1998.6	0.0957	0.0938	1999.5	1999.4	0.4796	0.4700
0.0	0.0	1998.6	1998.6	0.2517	0.2466	1999.4	1999.5	0.5500	0.5390

Table VI.3: Mean raw data from 4 tests, simultaneously recorded in the six channels when negative M/L shear forces Fz were applied, with descriptive statistics.

Axial Load				Main	Channel	Fy			
Load applied									
along Y axis		*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
		4			*INTERVALS*	*4*			*INTERVALS*
		tests			*LEVEL*	*tests*			*LEVEL*
					95%				*95%*
kg	N	SFx				SFy			
0.00	0.00	2000.9	2000.9	0.1708	0.1674	2000.1	1999.7	0.8180	0.8016
0.60	5.89	2000.8	2000.9	0.1414	0.1386	2014.7	2014.5	0.7042	0.6901
9.67	94.86	2001.1	2001.1	0.3109	0.3047	2029.3	2029.3	0.5377	0.5270
18.74	183.84	2001.1	2001.0	0.1000	0.0980	2043.5	2043.3	0.6702	0.6568
27.81	272.82	2001.5	2001.6	0.3317	0.3250	2058.2	2058.2	0.2646	0.2593
36.88	361.79	2001.3	2001.3	0.2062	0.2020	2072.7	2072.8	0.3464	0.3395
45.95	450.77	2001.8	2001.8	0.0957	0.0938	2088.6	2088.6	0.2872	0.2815
55.95	548.87	2001.8	2001.7	0.4123	0.4041	2104.5	2104.4	0.1000	0.0980
65.95	646.97	2002.1	2002.1	0.2217	0.2173	2120.6	2120.7	0.2380	0.2333
75.95	745.07	2002.1	2002.1	0.2217	0.2173	2136.6	2136.7	0.4272	0.4186
85.95	843.17	2002.2	2002.2	0.4082	0.4001	2152.6	2152.7	0.6344	0.6217
90.95	892.22	2002.2	2002.2	0.2872	0.2815	2160.4	2160.5	0.5560	0.5449
95.95	941.27	2002.3	2002.3	0.2754	0.2699	2168.1	2168.2	0.7141	0.6998
100.95	990.32	2002.3	2002.4	0.5315	0.5209	2176.3	2176.6	0.6782	0.6647
105.95	1039.37	2002.0	2002.0	0.5560	0.5449	2184.1	2184.6	1.2193	1.1949
105.95	1039.37	2002.1	2002.1	0.6377	0.6249	2183.9	2184.6	1.7137	1.6794
100.95	990.32	2002.4	2002.4	0.4425	0.4337	2175.6	2176.1	1.6500	1.6170
95.95	941.27	2002.2	2002.3	0.4924	0.4826	2167.5	2168.3	1.9900	1.9501
90.95	892.22	2002.3	2002.3	0.1708	0.1674	2159.4	2160.2	1.6919	1.6580
85.95	843.17	2002.2	2002.2	0.4655	0.4562	2151.8	2152.4	1.8046	1.7685
75.95	745.07	2002.1	2002.2	0.3742	0.3667	2135.6	2136.3	1.9363	1.8975
65.95	646.97	2002.0	2002.0	0.1500	0.1470	2119.6	2120.3	1.9207	1.8823
55.95	548.87	2001.9	2001.9	0.3162	0.3099	2103.3	2103.8	1.5875	1.5557
45.95	450.77	2001.6	2001.5	0.2646	0.2593	2087.3	2088.0	1.6361	1.6033
36.88	361.79	2001.4	2001.4	0.1291	0.1265	2071.2	2072.1	1.9242	1.8857
27.81	272.82	2001.4	2001.4	0.3109	0.3047	2056.4	2057.0	1.7234	1.6889
18.74	183.84	2001.2	2001.2	0.2082	0.2040	2041.8	2042.8	2.2307	2.1860
9.67	94.86	2001.1	2001.1	0.2517	0.2466	2027.2	2028.2	2.2045	2.1604
0.60	5.89	2000.8	2000.8	0.1826	0.1789	2012.7	2013.6	2.4998	2.4498
0.00	0.00	2000.8	2000.9	0.1708	0.1674	1998.1	1999.0	2.4350	2.3862
		MEAN	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
		4			*INTERVALS*	*4*			*INTERVALS*
		tests			*LEVEL*	*tests*			*LEVEL*
Loading mass	Loading				*95%*				*95%*
kg	N	SFz				SMx			
0.00	0.00	2001.7	2002.0	1.7635	1.7282	2000.2	2000.4	0.5679	0.5565
0.60	5.89	2001.5	2001.8	1.7000	1.6660	1999.4	1999.5	0.8846	0.8669
9.67	94.86	2001.4	2001.5	1.3796	1.3520	1998.0	1998.1	1.0372	1.0165
18.74	183.84	2000.8	2000.9	1.9551	1.9160	1997.7	1998.1	1.2124	1.1882
27.81	272.82	2000.8	2001.0	2.0298	1.9891	1997.7	1997.7	2.5316	2.4810
36.88	361.79	2000.8	2001.0	1.8877	1.8499	1997.3	1998.2	2.6285	2.5759
45.95	450.77	2000.3	2000.5	2.0205	1.9801	1997.3	1998.4	2.6882	2.6344
55.95	548.87	2000.1	2000.2	1.8025	1.7665	1996.5	1997.6	2.7043	2.6502
65.95	646.97	2000.0	2000.4	2.2106	2.1663	1997.6	1998.9	4.5236	4.4331
75.95	745.07	1999.5	1999.8	2.3043	2.2582	1997.4	1999.0	4.8280	4.7313
85.95	843.17	1999.3	1999.4	2.0680	2.0266	1997.3	1998.1	4.0780	3.9964
90.95	892.22	1999.1	1999.1	1.9765	1.9370	1997.4	1998.1	3.5214	3.4509
95.95	941.27	1998.9	1999.1	2.1391	2.0963	1997.3	1997.7	3.4838	3.4140
100.95	990.32	1998.6	1998.8	1.9681	1.9287	1997.0	1997.3	2.9781	2.9185
105.95	1039.37	1998.5	1998.6	1.9485	1.9095	1997.8	1998.1	2.9263	2.8677
105.95	1039.37	1998.7	1999.1	2.2066	2.1624	1997.8	1998.1	2.9263	2.8677
100.95	990.32	1998.6	1998.9	2.1235	2.0810	1998.5	1998.9	2.9405	2.8817
95.95	941.27	1998.8	1999.0	2.1329	2.0902	1998.8	1999.0	2.6489	2.5959
90.95	892.22	1998.8	1999.1	2.2127	2.1684	1998.9	1998.8	2.4515	2.4025
85.95	843.17	1999.2	1999.4	1.9900	1.9501	1998.9	1998.9	2.2876	2.2419
75.95	745.07	1999.7	1999.9	2.1764	2.1328	1999.7	1999.6	1.7512	1.7161
65.95	646.97	2000.1	2000.0	2.0616	2.0203	1999.9	1999.9	1.2780	1.2524
55.95	548.87	2000.5	2000.6	2.3302	2.2836	1999.7	1999.8	1.0112	0.9909
45.95	450.77	2000.4	2000.4	2.4365	2.3877	2000.9	2000.5	1.8850	1.8473
36.88	361.79	2000.6	2000.6	2.4918	2.4419	2000.7	2000.5	1.7633	1.7280
27.81	272.82	2000.7	2000.7	2.1109	2.0686	2000.5	2000.2	1.0372	1.0165
18.74	183.84	2001.1	2001.1	2.1641	2.1208	2000.4	2000.0	0.8221	0.8056
9.67	94.86	2001.2	2001.5	2.1833	2.1396	2000.1	2000.1	0.1915	0.1877
0.60	5.89	2001.0	2001.0	2.0793	2.0376	2000.9	2001.0	0.6683	0.6550
0.00	0.00	2001.3	2001.1	2.1679	2.1245	2000.5	2000.5	0.1500	0.1470

Table VI.4a: Mean raw data (SFx, SFy main channel, SFz and SMx) from 4 tests, simultaneously recorded in the six channels when axial load Fy was applied, with descriptive statistics

11.VI.2 Calibration results in axial load Fy

The following table VI.4a (SFx, SFy main channel, SFz and SMx) and VI.4b (SMy and SMz) shows the mean results recorded from 4 calibration tests performed in axial load.

The set up to calibrate the axial load channels Fy was described in section 6.3.2. The device used for axial load calibration is shown in figures 6.4 and 6.5. The presented table VI.4 has the same arrangement as table 6.6 (shear force Fx positive).

The corresponding graph is shown in figure 6.12.

Axial Load				Main	Channel	Fy			
Load applied									
along Y axis									
		MEAN	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
		4			*INTERVALS*	*4*			*INTERVALS*
		tests			*LEVEL*	*tests*			*LEVEL*
Loading mass	Loading				*95%*				*95%*
kg	N	SMy				SMz			
0.00	0.00	2001.2	2001.2	0.1732	0.1697	2002.1	2002.2	0.2160	0.2117
0.60	5.89	2001.2	2001.1	0.2872	0.2815	2002.6	2002.5	0.1732	0.1697
9.67	94.86	2000.6	2000.4	1.0935	1.0716	2003.3	2003.3	0.4924	0.4826
18.74	183.84	2001.1	2001.0	0.4787	0.4691	2004.2	2004.3	0.5188	0.5084
27.81	272.82	2001.0	2000.9	0.6946	0.6807	2005.2	2005.3	0.9215	0.9031
36.88	361.79	2001.4	2001.4	0.4425	0.4337	2006.1	2006.2	0.9055	0.8874
45.95	450.77	2001.7	2001.7	0.2986	0.2926	2007.2	2007.3	1.1015	1.0795
55.95	548.87	2002.2	2002.3	0.2380	0.2333	2008.0	2008.1	1.1558	1.1326
65.95	646.97	2003.3	2003.1	0.9747	0.9552	2010.2	2010.5	2.4839	2.4342
75.95	745.07	2003.5	2003.2	0.9933	0.9734	2011.1	2011.5	2.4958	2.4459
85.95	843.17	2002.3	2002.6	1.3074	1.2812	2012.2	2012.5	2.2825	2.2368
90.95	892.22	2002.7	2002.9	1.3589	1.3317	2012.6	2013.0	2.3812	2.3335
95.95	941.27	2002.9	2003.1	1.1615	1.1383	2013.1	2013.6	2.3566	2.3094
100.95	990.32	2003.2	2003.3	0.9535	0.9344	2013.5	2014.1	2.3343	2.2876
105.95	1039.37	2002.8	2003.1	0.9394	0.9206	2013.8	2014.4	2.1762	2.1326
105.95	1039.37	2002.7	2003.1	0.8718	0.8543	2013.9	2014.4	2.1299	2.0873
100.95	990.32	2002.8	2002.8	0.4573	0.4482	2013.5	2013.8	2.1977	2.1537
95.95	941.27	2002.5	2002.6	0.6351	0.6224	2012.9	2013.3	1.9950	1.9551
90.95	892.22	2002.3	2002.6	0.5560	0.5449	2012.5	2012.9	1.6820	1.6483
85.95	843.17	2002.2	2002.2	0.7416	0.7268	2011.9	2012.4	1.7633	1.7280
75.95	745.07	2001.9	2002.0	0.4113	0.4031	2011.0	2011.3	1.7212	1.6867
65.95	646.97	2001.5	2001.5	0.5377	0.5270	2010.2	2010.5	1.5155	1.4851
55.95	548.87	2001.2	2001.3	0.3500	0.3430	2009.1	2009.6	1.6083	1.5761
45.95	450.77	2001.7	2001.7	0.5323	0.5216	2008.7	2009.2	1.7692	1.7338
36.88	361.79	2001.2	2001.2	0.5745	0.5630	2007.4	2007.9	1.4888	1.4590
27.81	272.82	2001.6	2001.6	0.2062	0.2020	2006.5	2006.9	1.4154	1.3871
18.74	183.84	2001.4	2001.3	0.3559	0.3488	2005.5	2005.9	0.8347	0.8180
9.67	94.86	2001.1	2001.1	0.2872	0.2815	2004.4	2004.5	0.6602	0.6470
0.60	5.89	2001.2	2001.2	0.0816	0.0800	2003.2	2003.2	0.3304	0.3238
0.00	0.00	2001.4	2001.4	0.2630	0.2577	2002.1	2002.1	0.1500	0 1470

Table VI.4b: Mean raw data (SMy and SMz) from 4 tests, simultaneously recorded in the six channels when axial load Fy was applied, with descriptive statistics.

Transverse	Torque			Main	Channel	My			
Load applied									
about Y axis		*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
Load applied		*4*			*INTERVALS*	*4*			*INTERVALS*
at 0.1 m from	Applied	*tests*			*LEVEL*	*tests*			*LEVEL*
Y axis	Torque				*95%*				*95%*
Loading	My = 0.1 L/2								
N	Nm	SFx				SFy			
0.0	0.0	2001.1	2001.1	0.2278	0.1996	2001.3	2001.1	1.0210	1.0006
1.8	0.1	1999.8	1999.8	0.1225	0.1074	1994.3	1994.4	0.7890	0.7732
116.0	5.8	2000.5	2000.5	0.2500	0.2191	1967.1	1967.2	0.3500	0.3430
214.1	10.7	2000.9	2001.1	0.4690	0.4111	1940.5	1940.5	0.5058	0.4957
214.1	10.7	2000.9	2001.1	0.4690	0.4111	1940.5	1940.5	0.5058	0.4957
116.0	5.8	2000.5	2000.5	0.1225	0.1074	1967.3	1967.0	0.8907	0.8729
1.8	0.1	2000.1	2000.1	0.1479	0.1296	1994.3	1994.0	0.9574	0.9383
0.0	0.0	2000.9	2000.9	0.1581	0.1386	2000.8	2000.7	0.5252	0.5147
		MEAN	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
	Applied	*4*			*INTERVALS*	*4*			*INTERVALS*
	Torque	*tests*			*LEVEL*	*tests*			*LEVEL*
Loading	My = 0.1 L/2				*95%*				*95%*
N	Nm	SFz				SMx			
0.0	0.0	2000.6	2000.6	0.3500	0.3430	1999.2	1999.2	1.1121	1.0898
1.8	0.1	2001.7	2001.7	0.1633	0.1600	2000.6	2001.0	1.1442	1.1213
116.0	5.8	2001.4	2001.4	0.4619	0.4526	2003.7	2003.4	3.4957	3.4257
214.1	10.7	2000.7	2000.7	0.5377	0.5270	2007.7	2005.0	7.4728	7.3232
214.1	10.7	2000.7	2000.7	0.5377	0.5270	2007.7	2005.0	7.4728	7.3232
116.0	5.8	2002.1	2002.1	0.2062	0.2020	2002.1	2001.3	3.8713	3.7938
1.8	0.1	2002.5	2002.5	0.2986	0.2926	1999.1	1999.5	1.2987	1.2727
0.0	0.0	2000.7	2000.7	0.4123	0.4041	1998.9	1999.1	1.5650	1.5337
		MEAN	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
	Applied	*4*			*INTERVALS*	*4*			*INTERVALS*
	Torque	*tests*			*LEVEL*	*tests*			*LEVEL*
Loading	My = 0.1 L/2				*95%*				*95%*
N	Nm	SMy				SMz			
0.0	0.0	2001.4	2001.4	0.8660	0.8487	2000.5	2000.3	0.5188	0.5084
1.8	0.1	2045.7	2046.9	2.6733	2.6198	1990.3	1990.6	0.8302	0.8135
116.0	5.8	2237.8	2237.6	1.3528	1.3257	1992.8	1992.9	1.0046	0.9845
214.1	10.7	2427.0	2426.8	1.8267	1.7901	1994.9	1995.2	1.5875	1.5557
214.1	10.7	2427.0	2426.8	1.8267	1.7901	1994.9	1995.2	1.5875	1.5557
116.0	5.8	2240.2	2240.2	0.7805	0.7649	1992.1	1992.7	1.4364	1.4077
1.8	0.1	2049.0	2048.9	0.4573	0.4482	1990.2	1990.4	0.8660	0.8487
0.0	0.0	2001.6	2001.7	0.9743	0.9547	2001.1	2001.2	0.1708	0.1674

Table VI.5: Mean raw data from 4 tests, simultaneously recorded in the six channels when positive transverse torque My was applied, with descriptive statistics.

11.VI.3 Calibration results in transverse torque My

The following tables VI.5, transverse torque SMy, main channel positive and VI.6, transverse torque SMy, main channel, negative, show the mean results recorded from 4 calibration tests performed in axial load. The set up to calibrate the torque channel My was described in section 6.3.3. The device used for torque calibration is shown in figures 6.6 and 6.7. The presented tables VI.5 and VI.6 have the same arrangement as table 6.6 (shear force Fx positive). The corresponding graph is shown in figure 6.15.

Transverse	Torque			Main	Channel	My			
Load applied									
about Y axis		*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
Load applied		*4*			*INTERVALS*	*4*			*INTERVALS*
at 0.1 m from	Applied	*tests*			*LEVEL*	*tests*			*LEVEL*
Y axis	Torque				*95%*				*95%*
Loading	My = 0.1 L/2								
N	Nm	SFx				SFy			
0.0	0.0	1998.9	1999.0	0.2160	0.2117	1998.8	1999.0	0.9430	0.9241
1.8	0.1	2000.2	2000.2	0.0500	0.0490	2005.7	2005.7	0.6702	0.6568
116.0	5.8	1999.4	1999.4	0.1291	0.1265	2031.8	2031.9	1.1091	1.0869
214.1	10.7	1998.4	1998.5	0.1708	0.1674	2058.0	2058.0	0.4546	0.4455
214.1	10.7	1998.4	1998.5	0.1708	0.1674	2058.0	2058.0	0.4546	0.4455
116.0	5.8	1999.4	1999.3	0.1915	0.1877	2031.8	2031.8	0.8266	0.8101
1.8	0.1	2000.3	2000.2	0.1732	0.1697	2005.0	2005.2	0.9215	0.9031
0.0	0.0	1999.0	1999.1	0.2500	0.2450	1997.8	1997.9	0.7848	0.7690
		MEAN	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
	Applied	*4*			*INTERVALS*	*4*			*INTERVALS*
	Torque	*tests*			*LEVEL*	*tests*			*LEVEL*
Loading	My = 0.1 L/2				*95%*				*95%*
N	Nm	SFz				SMx			
0.0	0.0	2001.8	2001.9	0.5852	0.5735	2002.6	2002.8	1.0966	1.0746
1.8	0.1	2000.9	2000.9	0.3162	0.3099	2001.8	2002.0	1.1916	1.1678
116.0	5.8	2001.3	2001.7	0.9215	0.9031	2001.2	2000.9	0.8995	0.8815
214.1	10.7	2001.6	2001.5	0.3109	0.3047	2001.3	2001.5	0.8461	0.8291
214.1	10.7	2001.6	2001.5	0.3109	0.3047	2001.3	2001.5	0.8461	0.8291
116.0	5.8	2000.6	2000.5	0.3775	0.3699	2003.4	2003.6	0.7746	0.7591
1.8	0.1	2000.3	2000.2	0.4899	0.4801	2003.8	2003.8	0.3873	0.3795
0.0	0.0	2002.0	2002.1	0.4573	0.4482	2002.9	2003.2	0.7047	0.6906
		MEAN	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
	Applied	*4*			*INTERVALS*	*4*			*INTERVALS*
	Torque	*tests*			*LEVEL*	*tests*			*LEVEL*
Loading	My = 0.1 L/2				*95%*				*95%*
N	Nm	SMy				SMz			
0.0	0.0	1999.5	1999.5	1.1902	1.1664	1999.4	1999.5	0.2380	0.2333
1.8	-0.1	1954.6	1954.7	1.1269	1.1044	2009.5	2009.5	0.3162	0.3099
116.0	-5.8	1764.3	1765.0	1.6419	1.6090	2008.0	2008.1	0.4856	0.4759
214.1	-10.7	1575.1	1575.1	0.4031	0.3950	2005.9	2006.1	0.7762	0.7607
214.1	-10.7	1575.1	1575.1	0.4031	0.3950	2005.9	2006.1	0.7762	0.7607
116.0	-5.8	1761.7	1761.7	0.3367	0.3299	2008.2	2008.3	0.4113	0.4031
1.8	-0.1	1952.2	1952.2	0.3775	0.3699	2009.6	2009.7	0.1708	0.1674
0.0	0.0	1999.1	1998.8	0.9465	0.9275	1999.2	1999.2	0.1500	0.1470

Table VI.6: Mean raw data from 4 tests, simultaneously recorded in the six channels when negative transverse torque My was applied, with descriptive statistics.

M/L Bending	Moment	Positive		Main	Channel	Mx				
about X axis										
Loading			*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
along Z axis			*4*			*INTERVALS*	*4*			*INTERVALS*
at 0.215 m			*tests*			*LEVEL*	*tests*			*LEVEL*
from ankle axis		Bending				*95%*				*95%*
Loading mass	Loading	moment								
kg	N	Nm	SFx				SFy			
0.0	0.0	0.0	2000.4	2000.4	0.2887	0.2829	2000.0	1999.9	0.6702	0.6568
0.8	7.6	1.6	1998.8	1998.8	0.2217	0.2173	1999.8	1999.7	0.5292	0.5186
9.8	96.6	20.8	1976.7	1976.8	0.2754	0.2699	2004.0	2003.7	0.5745	0.5630
18.9	185.5	39.9	1954.8	1954.8	0.1732	0.1697	2007.0	2006.8	0.8347	0.8180
28.0	274.5	59.0	1932.8	1932.8	0.2309	0.2263	2009.2	2009.0	0.6782	0.6647
37.1	363.5	78.2	1911.0	1911.1	0.3304	0.3238	2011.6	2011.3	0.7632	0.7479
42.1	412.5	88.7	1899.1	1899.1	0.4041	0.3961	2012.1	2011.8	0.9695	0.9501
42.1	412.5	88.7	1899.1	1899.1	0.4041	0.3961	2012.1	2011.8	0.9695	0.9501
37.1	363.5	78.2	1911.0	1911.1	0.3742	0.3667	2011.5	2011.5	0.7676	0.7522
28.0	274.5	59.0	1933.1	1933.1	0.4425	0.4337	2009.6	2009.3	0.7767	0.7612
18.9	185.5	39.9	1954.8	1954.8	0.0577	0.0566	2006.6	2006.7	0.6856	0.6718
9.8	96.6	20.8	1976.8	1976.8	0.1258	0.1233	2003.6	2003.7	0.8958	0.8779
0.8	7.6	1.6	1998.8	1998.8	0.2500	0.2450	1999.7	1999.7	0.8958	0.8779
0.0	0.0	0.0	2000.6	2000.6	0.2160	0.2117	1999.3	1999.4	0.7681	0.7527
			MEAN	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
			4			*INTERVALS*	*4*			*INTERVALS*
		Bending	*tests*			*LEVEL*	*tests*			*LEVEL*
Loading mass	Loading	moment				*95%*				*95%*
kg	N	Nm	SFz				SMx			
0.0	0.0	0.0	1999.7	1999.6	0.7234	0.7089	2000.3	2000.3	0.9327	0.9141
0.8	7.6	1.6	1998.4	1998.4	0.6801	0.6665	2034.7	2034.8	0.9592	0.9400
9.8	96.6	20.8	1984.9	1984.8	0.9674	0.9480	2439.8	2439.8	1.0456	1.0247
18.9	185.5	39.9	1971.6	1971.6	0.7228	0.7084	2843.8	2843.9	0.7974	0.7814
28.0	274.5	59.0	1958.3	1958.3	0.6131	0.6008	3247.8	3247.9	0.9979	0.9779
37.1	363.5	78.2	1945.2	1945.2	0.8165	0.8002	3650.5	3650.5	0.6481	0.6351
42.1	412.5	88.7	1937.9	1938.0	0.6850	0.6712	3873.1	3873.0	0.8180	0.8016
42.1	412.5	88.7	1937.9	1938.0	0.6850	0.6712	3873.1	3873.0	0.8180	0.8016
37.1	363.5	78.2	1945.3	1945.3	0.8185	0.8021	3650.1	3650.1	1.0308	1.0101
28.0	274.5	59.0	1958.3	1958.3	0.7805	0.7649	3247.1	3247.1	0.9983	0.9783
18.9	185.5	39.9	1971.8	1971.9	0.7681	0.7527	2843.1	2843.2	0.5737	0.5622
9.8	96.6	20.8	1984.9	1985.0	0.6292	0.6166	2439.4	2439.3	0.8699	0.8525
0.8	7.6	1.6	1998.4	1998.6	0.7632	0.7479	2034.2	2034.1	0.9674	0.9480
0.0	0.0	0.0	1999.5	1999.5	0.9309	0.9123	1999.9	1999.9	0.7274	0.7129
			MEAN	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
			4			*INTERVALS*	*4*			*INTERVALS*
		Bending	*tests*			*LEVEL*	*tests*			*LEVEL*
Loading mass	Loading	moment				*95%*				*95%*
kg	N	Nm	SMy				SMz			
0.0	0.0	0.0	1999.0	1999.0	0.3873	0.3795	1999.4	1999.5	0.6397	0.6269
0.8	7.6	1.6	1998.7	1998.8	0.5058	0.4957	1999.4	1999.4	0.6583	0.6451
9.8	96.6	20.8	1997.4	1997.2	1.7607	1.7254	1998.6	1998.6	0.6377	0.6249
18.9	185.5	39.9	1996.9	1995.8	2.9092	2.8509	1997.1	1997.1	0.4203	0.4119
28.0	274.5	59.0	1996.3	1995.3	3.7709	3.6954	1996.2	1996.2	0.3651	0.3578
37.1	363.5	78.2	1996.0	1994.9	4.7648	4.6694	1994.7	1994.8	0.3162	0.3099
42.1	412.5	88.7	1995.8	1994.9	5.5090	5.3987	1994.0	1994.0	0.3000	0.2940
42.1	412.5	88.7	1995.8	1994.9	5.5090	5.3987	1994.0	1994.0	0.3000	0.2940
37.1	363.5	78.2	1995.5	1994.8	5.7233	5.6087	1994.8	1994.7	0.2363	0.2316
28.0	274.5	59.0	1995.7	1995.0	4.9169	4.8185	1995.9	1995.9	0.3512	0.3442
18.9	185.5	39.9	1995.5	1995.5	1.6269	1.5943	1997.1	1997.2	0.6557	0.6426
9.8	96.6	20.8	1996.8	1996.9	0.6137	0.6014	1998.5	1998.5	0.5260	0.5155
0.8	7.6	1.6	1998.4	1998.4	0.3304	0.3238	1999.7	1999.7	0.8617	0.8444
0.0	0.0	0.0	1998.7	1998.8	0.2944	0.2885	1999.6	1999.5	0.7411	0.7262

Table VI.7a: Mean raw data from 4 tests, simultaneously recorded in the six channels when positive M/L bending moment Mx was applied (lever arm d = 0.215 m), with descriptive statistics.

11.VI.4 Calibration results in M/L (Mx) and A/P (Mz) bending moments

The following tables VI.7, VI.8, IV.9 and VI.10 show the mean results recorded from 4 calibration tests performed in M/L and A/P planes.

The set up to calibrate the bending moments channels Mx and Mz was described in section 6.3.4.The steel cable on which the loads were suspended was positioned with a lever arm d of 0.215 and 0.315 m from the ankle axis. The value of the applied bending moment was thus ± F.d.

Nevertheless, a pure shear force F was also recorded:

Fx when an A/P plane bending moment Mz was applied

Fz when a M/L plane bending moment Mx was applied.

The presented tables have the same arrangement as table 6.6 (shear force Fx positive, page 164A).

The schedule is the following:

table VI.7a: A/P Bending moment Mx positive with a lever arm d of 0.215 m

table VI.7b: A/P Bending moment Mx negative with a lever arm d of 0.215 m

table VI.8a: A/P Bending moment Mx positive with a lever arm d of 0.315 m

table VI.8b: A/P Bending moment Mx negative with a leyer arm d of 0.315 m

table VI.9a: M/L Bending moment Mz positive with a lever arm d of 0.215 m

table VI.9b: M/L Bending moment Mz negative with a lever arm d of 0.215 m

table VI.10a: M/L Bending moment Mz positive with a lever arm d of 0.315 m

table VI.10b: M/L Bending moment Mz negative with a lever arm d of 0.315 m

The corresponding graphs are shown in figure 6.14a and 6.14b for A/P bending moment Mx and 6.15a and 6.15b for M/L bending moment Mz.

M/L Bending	Moment	Negative			Main	Channel	Mx			
about X axis										
Loading			*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
along Z axis			*4*			*INTERVALS*	*4*			*INTERVALS*
at 0.215 m			*tests*			*LEVEL*	*tests*			*LEVEL*
from ankle axis		Bending				*95%*				*95%*
Loading mass	Loading	moment								
kg	N	Nm	SFx				SFy			
0.0	0.0	0.0	2000.8	2000.7	0.5260	0.5155	1999.5	1999.5	0.5795	0.5679
0.8	7.6	-1.6	2002.6	2002.6	0.6602	0.6470	1999.1	1999.0	0.4573	0.4482
9.8	96.6	-20.8	2024.4	2024.4	0.4573	0.4482	1994.6	1994.6	0.2160	0.2117
18.9	185.5	-39.9	2046.2	2046.2	0.7024	0.6883	1989.3	1989.5	0.2872	0.2815
28.0	274.5	-59.0	2067.9	2067.8	0.7047	0.6906	1984.0	1984.1	0.1708	0.1674
37.1	363.5	-78.2	2089.6	2089.7	0.8098	0.7936	1977.2	1977.2	0.4509	0.4419
42.1	412.5	-88.7	2101.5	2101.6	0.7789	0.7633	1973.5	1973.6	0.4243	0.4158
42.1	412.5	-88.7	2101.5	2101.6	0.7789	0.7633	1973.5	1973.6	0.4243	0.4158
37.1	363.5	-78.2	2089.6	2089.6	0.6976	0.6836	1976.8	1976.9	0.5802	0.5686
28.0	274.5	-59.0	2067.9	2067.9	0.6218	0.6094	1983.0	1982.8	0.3500	0.3430
18.9	185.5	-39.9	2046.3	2046.4	0.6652	0.6519	1988.6	1988.5	0.3559	0.3488
9.8	96.6	-20.8	2024.2	2024.2	0.9179	0.8995	1994.0	1994.0	0.2582	0.2530
0.8	7.6	-1.6	2002.5	2002.5	0.7024	0.6883	1998.5	1998.4	0.2646	0.2593
0.0	0.0	0.0	2000.6	2000.6	0.6076	0.5954	1999.0	1999.0	0.1258	0.1233
			MEAN	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
			4			*INTERVALS*	*4*			*INTERVALS*
		Bending	*tests*			*LEVEL*	*tests*			*LEVEL*
Loading mass	Loading	moment				*95%*				*95%*
kg	N	Nm	SFz				SMx			
0.0	0.0	0.0	2001.1	2001.1	0.7661	0.6715	1999.4	1999.6	0.5745	0.5630
0.8	7.6	-1.6	2002.1	2002.1	0.8814	0.7726	1965.1	1965.5	0.8000	0.7840
9.8	96.6	-20.8	2015.6	2015.6	0.9000	0.7889	1560.5	1560.6	0.5852	0.5735
18.9	185.5	-39.9	2029.0	2029.0	0.5050	0.4426	1157.0	1157.1	0.5033	0.4932
28.0	274.5	-59.0	2042.4	2042.4	0.5000	0.4383	753.4	753.2	0.6928	0.6790
37.1	363.5	-78.2	2055.7	2055.7	0.4265	0.3738	350.8	350.5	0.6898	0.6760
42.1	412.5	-88.7	2063.1	2063.1	0.5050	0.4426	128.1	127.7	0.9179	0.8995
42.1	412.5	-88.7	2063.1	2063.1	0.5050	0.4426	128.1	127.7	0.9179	0.8995
37.1	363.5	-78.2	2055.7	2055.7	0.4265	0.3738	350.9	350.6	0.7394	0.7246
28.0	274.5	-59.0	2042.5	2042.5	0.6260	0.5487	754.0	754.1	0.8246	0.8081
18.9	185.5	-39.9	2029.4	2029.4	0.6000	0.5259	1157.4	1157.5	0.7890	0.7732
9.8	96.6	-20.8	2016.0	2016.0	0.7462	0.6541	1560.6	1560.7	0.6758	0.6622
0.8	7.6	-1.6	2002.4	2002.4	0.7036	0.6167	1965.7	1965.9	0.7141	0.6998
0.0	0.0	0.0	2001.2	2001.2	0.8529	0.7476	1999.6	1999.8	0.5000	0.4900
			MEAN	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
			4			*INTERVALS*	*4*			*INTERVALS*
		Bending	*tests*			*LEVEL*	*tests*			*LEVEL*
Loading mass	Loading	moment				*95%*				*95%*
kg	N	Nm	SMy				SMz			
0.0	0.0	0.0	1998.5	1998.5	0.7365	0.7218	1999.4	1999.4	0.5500	0.5390
0.8	7.6	-1.6	1998.6	1998.5	0.8485	0.8315	1999.4	1999.4	0.6850	0.6712
9.8	96.6	-20.8	2002.1	2001.9	2.2286	2.1840	2000.5	2000.5	0.7528	0.7377
18.9	185.5	-39.9	2004.2	2004.4	2.6260	2.5734	2001.2	2001.3	0.9032	0.8852
28.0	274.5	-59.0	2006.6	2007.0	2.7215	2.6670	2002.1	2002.0	1.1955	1.1715
37.1	363.5	-78.2	2009.7	2010.1	3.7179	3.6434	2003.0	2002.9	1.6248	1.5923
42.1	412.5	-88.7	2010.8	2011.6	3.1042	3.0420	2003.3	2003.4	1.8547	1.8176
42.1	412.5	-88.7	2010.8	2011.6	3.1042	3.0420	2003.3	2003.4	1.8547	1.8176
37.1	363.5	-78.2	2009.1	2009.3	3.1095	3.0473	2003.1	2003.2	1.8786	1.8410
28.0	274.5	-59.0	2006.0	2006.7	1.8822	1.8445	2002.3	2002.3	1.4221	1.3937
18.9	185.5	-39.9	2003.1	2003.3	1.2767	1.2512	2001.3	2001.4	1.1518	1.1288
9.8	96.6	-20.8	2000.9	2001.1	0.6652	0.6519	2000.4	2000.4	0.8382	0.8214
0.8	7.6	-1.6	1998.9	1999.0	1.1045	1.0824	1999.5	1999.5	0.5260	0.5155
0.0	0.0	0.0	1998.5	1998.5	0.8500	0.8330	1999.6	1999.6	0.7805	0.7649

Table VI.7b: Mean raw data from 4 tests, simultaneously recorded in the six channels when negative M/L bending moment Mx was applied (lever arm d = 0.215 m), with descriptive statistics.

M/L Bending	Moment	Positive			Main	Channel	Mx			
about X axis										
Loading			*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
along Z axis			*4*			*INTERVALS*	*4*			*INTERVALS*
at 0.315 m			*tests*			*LEVEL*	*tests*			*LEVEL*
from ankle axis		Bending				*95%*				*95%*
Loading mass	Loading	moment								
kg	N	Nm	SFx				SFy			
0.0	0.0	0.0	2000.5	2000.6	0.1708	0.1674	1999.7	1999.2	1.7493	1.7143
0.8	7.6	1.6	1997.6	1997.6	0.2217	0.2173	2000.3	1999.8	1.9190	1.8806
9.8	96.6	20.8	1963.4	1963.5	0.2754	0.2699	2006.4	2006.0	1.6860	1.6522
18.9	185.5	39.9	1929.3	1929.3	0.3594	0.3522	2010.8	2010.6	1.7231	1.6886
23.9	234.6	73.9	1910.5	1910.4	0.3830	0.3753	2012.8	2012.3	2.0419	2.0010
28.9	283.6	89.3	1891.9	1891.8	0.2708	0.2654	2014.6	2014.0	2.2279	2.1833
28.9	283.6	89.3	1892.0	1892.0	0.2944	0.2885	2014.6	2014.0	2.3195	2.2730
23.9	234.6	73.9	1910.5	1910.5	0.3403	0.3335	2013.1	2012.5	2.3352	2.2885
18.9	185.5	39.9	1929.3	1929.2	0.2828	0.2772	2011.3	2010.8	1.8518	1.8147
9.8	96.6	20.8	1963.4	1963.4	0.1708	0.1674	2006.7	2006.3	2.1930	2.1491
0.8	7.6	1.6	1997.5	1997.5	0.2217	0.2173	2000.6	2000.3	2.0887	2.0468
0.0	0.0	0.0	2000.5	2000.6	0.3109	0.3047	2000.0	1999.6	1.8850	1.8473
			MEAN	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
			4			*INTERVALS*	*4*			*INTERVALS*
		Bending	*tests*			*LEVEL*	*tests*			*LEVEL*
Loading mass	Loading	moment				*95%*				*95%*
kg	N	Nm	SFz				SMx			
0.0	0.0	0.0	1999.7	1999.8	0.9678	0.9484	1999.9	1999.9	1.0308	1.0101
0.8	7.6	1.6	1998.6	1998.6	0.5888	0.5770	2052.3	2052.3	1.1030	1.0809
9.8	96.6	20.8	1985.2	1985.3	0.9469	0.9280	2670.3	2670.3	0.5560	0.5449
18.9	185.5	39.9	1972.0	1972.0	0.8185	0.8021	3286.9	3287.0	0.4041	0.3961
23.9	234.6	73.9	1964.6	1964.6	0.9899	0.9701	3626.4	3626.4	0.2062	0.2020
28.9	283.6	89.3	1957.6	1957.6	1.0145	0.9942	3965.3	3965.3	0.4272	0.4186
28.9	283.6	89.3	1957.6	1957.6	1.1030	1.0809	3965.3	3965.3	0.4272	0.4186
23.9	234.6	73.9	1964.8	1964.8	0.8185	0.8021	3625.9	3625.8	0.2986	0.2926
18.9	185.5	39.9	1971.8	1971.8	0.9570	0.9378	3286.2	3286.2	0.3651	0.3578
9.8	96.6	20.8	1985.1	1985.1	0.9535	0.9344	2670.2	2670.2	0.6028	0.5907
0.8	7.6	1.6	1998.4	1998.4	0.8679	0.8506	2051.6	2051.6	1.0112	0.9909
0.0	0.0	0.0	1999.5	1999.4	1.0520	1.0309	1999.5	1999.6	1.2473	1.2224
			MEAN	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
			4			*INTERVALS*	*4*			*INTERVALS*
		Bending	*tests*			*LEVEL*	*tests*			*LEVEL*
Loading mass	Loading	moment				*95%*				*95%*
kg	N	Nm	SMy				SMz			
0.0	0.0	0.0	1998.8	1998.8	0.4203	0.4119	1999.5	1999.5	0.6185	0.6061
0.8	7.6	1.6	1998.7	1998.7	0.1291	0.1265	1999.3	1999.4	0.6292	0.6166
9.8	96.6	20.8	1995.6	1995.3	1.7347	1.7000	1997.8	1997.8	0.3775	0.3699
18.9	185.5	39.9	1993.6	1992.9	2.8860	2.8283	1996.0	1995.9	0.3000	0.2940
23.9	234.6	73.9	1993.5	1993.2	2.1525	2.1094	1994.9	1994.9	0.2082	0.2040
28.9	283.6	89.3	1993.0	1992.3	2.6924	2.6385	1993.5	1993.6	0.2062	0.2020
28.9	283.6	89.3	1992.9	1992.1	2.7427	2.6878	1993.6	1993.6	0.1500	0.1470
23.9	234.6	73.9	1993.9	1993.2	2.8267	2.7701	1994.5	1994.5	0.1893	0.1855
18.9	185.5	39.9	1993.6	1993.1	2.6287	2.5761	1995.6	1995.6	0.4243	0.4158
9.8	96.6	20.8	1994.9	1994.5	1.2897	1.2639	1997.7	1997.7	0.4655	0.4562
0.8	7.6	1.6	1998.5	1998.7	0.4717	0.4623	1999.4	1999.4	0.4924	0.4826
0.0	0.0	0.0	1998.8	1998.8	0.2646	0.2593	1999.6	1999.6	0.9327	0.9141

Table VI.8a: Mean raw data from 4 tests, simultaneously recorded in the six channels when positive M/L bending moment Mx was applied (lever arm d = 0.315 m), with descriptive statistics.

M/L Bending	Moment	Negative			Main	Channel	Mx			
about X axis										
Loading			*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
along Z axis			*4*			*INTERVALS*	*4*			*INTERVALS*
at 0.315 m			*tests*			*LEVEL*	*tests*			*LEVEL*
from ankle axis		Bending				*95%*				*95%*
Loading mass	Loading	moment								
kg	N	Nm	SFx				SFy			
0.0	0.0	0.0	2000.7	2000.7	0.5058	0.4957	1998.8	1998.8	0.4425	0.4337
0.8	7.6	-1.6	2003.6	2003.6	0.6131	0.6008	1998.4	1998.6	0.3594	0.3522
9.8	96.6	-20.8	2037.6	2037.7	0.6557	0.6426	1990.9	1990.9	0.6272	0.6146
18.9	185.5	-39.9	2071.5	2071.5	0.8165	0.8002	1982.0	1981.8	0.4359	0.4272
23.9	234.6	-73.9	2090.1	2090.2	0.6752	0.6616	1976.1	1976.1	0.1291	0.1265
28.9	283.6	-89.3	2108.6	2108.7	0.7274	0.7129	1970.0	1969.9	0.5852	0.5735
28.9	283.6	-89.3	2108.6	2108.7	0.7274	0.7129	1970.0	1969.9	0.5852	0.5735
23.9	234.6	-73.9	2089.9	2089.9	0.7616	0.7463	1975.4	1975.6	0.4500	0.4410
18.9	185.5	-39.9	2071.3	2071.3	0.6377	0.6249	1980.9	1981.0	0.3464	0.3395
9.8	96.6	-20.8	2037.6	2037.6	0.6377	0.6249	1989.7	1989.6	0.5598	0.5486
0.8	7.6	-1.6	2003.4	2003.4	0.6481	0.6351	1997.5	1997.6	0.3500	0.3430
0.0	0.0	0.0	2000.8	2000.7	0.7047	0.6906	1998.2	1998.1	0.5802	0.5686
			MEAN	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
			4			*INTERVALS*	*4*			*INTERVALS*
		Bending	*tests*			*LEVEL*	*tests*			*LEVEL*
Loading mass	Loading	moment				*95%*				*95%*
kg	N	Nm	SFz				SMx			
0.0	0.0	0.0	2001.4	2001.4	1.3574	1.3302	1999.1	1999.2	0.4359	0.4272
0.8	7.6	-1.6	2002.5	2002.6	1.2010	1.1770	1946.6	1946.5	0.4435	0.4346
9.8	96.6	-20.8	2015.7	2015.7	1.0720	1.0505	1329.1	1329.0	0.8246	0.8081
18.9	185.5	-39.9	2029.0	2029.1	0.9469	0.9280	713.7	713.1	1.4592	1.4300
23.9	234.6	-73.9	2036.4	2036.4	0.8103	0.7941	374.5	374.3	1.3379	1.3111
28.9	283.6	-89.3	2043.9	2044.0	0.8421	0.8253	35.8	35.3	1.4888	1.4590
28.9	283.6	-89.3	2043.9	2044.0	0.8421	0.8253	35.8	35.3	1.4888	1.4590
23.9	234.6	-73.9	2036.4	2036.5	0.8756	0.8581	374.8	374.6	1.1236	1.1011
18.9	185.5	-39.9	2029.2	2029.2	0.6702	0.6568	714.7	714.5	1.4071	1.3790
9.8	96.6	-20.8	2016.0	2015.9	1.0813	1.0596	1329.9	1329.8	0.7326	0.7179
0.8	7.6	-1.6	2002.3	2002.3	1.0231	1.0026	1947.4	1947.4	0.3697	0.3623
0.0	0.0	0.0	2001.1	2001.1	0.9179	0.8995	1999.4	1999.4	0.3862	0.3785
			MEAN	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
			4			*INTERVALS*	*4*			*INTERVALS*
		Bending	*tests*			*LEVEL*	*tests*			*LEVEL*
Loading mass	Loading	moment				*95%*				*95%*
kg	N	Nm	SMy				SMz			
0.0	0.0	0.0	1999.1	1999.2	0.6455	0.6326	2000.2	2000.2	0.3697	0.3623
0.8	7.6	-1.6	1999.7	1999.6	0.2363	0.2316	1982.7	1982.7	0.3651	0.3578
9.8	96.6	-20.8	2003.0	2003.1	1.7076	1.6734	1779.7	1779.6	0.1732	0.1697
18.9	185.5	-39.9	2004.9	2004.9	1.2261	1.2016	1577.2	1577.3	0.2630	0.2577
23.9	234.6	-73.9	2004.9	2004.9	2.2677	2.2223	1465.5	1465.6	0.4193	0.4109
28.9	283.6	-89.3	2006.0	2005.8	2.2068	2.1626	1354.1	1354.2	0.4243	0.4158
28.9	283.6	-89.3	2006.0	2005.8	2.2068	2.1626	1354.1	1354.2	0.4243	0.4158
23.9	234.6	-73.9	2004.0	2004.2	1.4997	1.4697	1465.8	1465.9	0.1414	0.1386
18.9	185.5	-39.9	2003.5	2003.7	1.3865	1.3588	1577.3	1577.3	0.0500	0.0490
9.8	96.6	-20.8	2001.7	2001.7	0.7228	0.7084	1779.9	1779.9	0.0000	0.0000
0.8	7.6	-1.6	1999.8	2000.0	0.3862	0.3785	1982.8	1982.8	0.3948	0.3869
0.0	0.0	0.0	1999.5	1999.6	0.1893	0.1855	2000.2	2000.1	0.3367	0.3299

Table VI.8b: Mean raw data from 4 tests, simultaneously recorded in the six channels when negative M/L bending moment Mx was applied (lever arm d = 0.315 m), with descriptive statistics.

A/P Bending	Moment	Positive			Main	Channel	Mz			
about Z axis										
Loading			*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
along X axis			*4*			*INTERVALS*	*4*			*INTERVALS*
at 0.215 m			*tests*			*LEVEL*	*tests*			*LEVEL*
from ankle axis		Bending				*95%*				*95%*
Loading mass	Loading	moment								
kg	N	Nm	SFx				SFy			
0.0	0.0	0.0	2000.6	2000.7	0.5598	0.5486	1999.7	1999.6	0.3862	0.3785
0.8	7.6	1.6	2001.8	2001.9	0.3873	0.3795	1999.6	1999.7	0.0957	0.0938
9.8	96.6	20.8	2016.7	2016.8	0.4349	0.4262	1998.0	1997.9	0.5679	0.5565
18.9	185.5	39.9	2031.3	2031.3	0.2944	0.2885	1995.2	1995.1	0.2872	0.2815
28.0	274.5	59.0	2046.2	2046.2	0.4123	0.4041	1992.3	1992.2	0.4717	0.4623
37.1	363.5	78.2	2060.6	2060.6	0.1732	0.1697	1988.4	1988.3	0.6557	0.6426
42.1	412.5	88.7	2068.7	2068.8	0.3403	0.3335	1986.4	1986.2	0.5252	0.5147
42.1	412.5	88.7	2068.7	2068.8	0.3403	0.3335	1986.4	1986.2	0.5252	0.5147
37.1	363.5	78.2	2060.5	2060.6	0.3559	0.3488	1988.0	1988.0	0.2449	0.2400
28.0	274.5	59.0	2045.9	2046.0	0.2380	0.2333	1991.2	1991.2	0.6652	0.6519
18.9	185.5	39.9	2031.4	2031.3	0.4041	0.3961	1994.3	1994.3	0.8124	0.7961
9.8	96.6	20.8	2016.6	2016.6	0.3304	0.3238	1996.6	1996.5	0.5228	0.5123
0.8	7.6	1.6	2001.8	2001.7	0.2363	0.2316	1998.4	1998.4	0.3948	0.3869
0.0	0.0	0.0	2000.5	2000.4	0.2217	0.2173	1998.4	1998.4	1.1576	1.1344
			MEAN	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
			4			*INTERVALS*	*4*			*INTERVALS*
		Bending	*tests*			*LEVEL*	*tests*			*LEVEL*
Loading mass	Loading	moment				*95%*				*95%*
kg	N	Nm	SFz				SMx			
0.0	0.0	0.0	2000.5	2000.6	2.1172	2.0748	2000.5	2000.5	0.2217	0.2173
0.8	7.6	1.6	1998.5	1998.6	2.2000	2.1560	2000.3	2000.4	0.1708	0.1674
9.8	96.6	20.8	1976.1	1976.1	2.1747	2.1311	1999.8	1999.7	0.2646	0.2593
18.9	185.5	39.9	1953.8	1953.7	2.0825	2.0408	1999.6	1999.6	0.2630	0.2577
28.0	274.5	59.0	1931.4	1931.4	2.3101	2.2639	1999.2	1999.1	0.3000	0.2940
37.1	363.5	78.2	1908.9	1908.9	2.1954	2.1515	1998.7	1998.7	0.2449	0.2400
42.1	412.5	88.7	1896.9	1896.9	2.0793	2.0376	1998.5	1998.5	0.4349	0.4262
42.1	412.5	88.7	1896.9	1896.9	2.0793	2.0376	1998.5	1998.5	0.4349	0.4262
37.1	363.5	78.2	1908.9	1908.9	2.0825	2.0408	1998.9	1999.0	0.2630	0.2577
28.0	274.5	59.0	1931.3	1931.2	1.9740	1.9345	1999.2	1999.2	0.1500	0.1470
18.9	185.5	39.9	1953.7	1953.7	2.0347	1.9940	1999.5	1999.6	0.3202	0.3137
9.8	96.6	20.8	1976.0	1976.0	1.7907	1.7549	2000.1	2000.0	0.1500	0.1470
0.8	7.6	1.6	1998.8	1998.7	1.8839	1.8462	2000.4	2000.5	0.3162	0.3099
0.0	0.0	0.0	2000.9	2000.9	1.9088	1.8705	2000.6	2000.6	0.1915	0.1877
			MEAN	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
			4			*INTERVALS*	*4*			*INTERVALS*
		Bending	*tests*			*LEVEL*	*tests*			*LEVEL*
Loading mass	Loading	moment				*95%*				*95%*
kg	N	Nm	SMy				SMz			
0.0	0.0	0.0	1999.3	1999.4	0.2160	0.2117	2000.7	2000.7	0.2449	0.2400
0.8	7.6	1.6	1999.3	1999.3	0.0577	0.0566	2011.8	2011.8	0.2062	0.2020
9.8	96.6	20.8	1998.8	1999.1	1.3491	1.3221	2144.5	2144.4	0.2986	0.2926
18.9	185.5	39.9	1998.1	1998.3	2.0189	1.9785	2277.0	2276.9	0.3948	0.3869
28.0	274.5	59.0	1996.2	1996.4	1.6299	1.5973	2409.9	2409.9	0.6946	0.6807
37.1	363.5	78.2	1993.7	1993.8	1.8751	1.8375	2542.3	2542.2	0.9866	0.9668
42.1	412.5	88.7	1992.2	1992.4	1.8991	1.8611	2615.2	2615.0	1.1325	1.1098
42.1	412.5	88.7	1992.2	1992.4	1.8991	1.8611	2615.2	2615.0	1.1325	1.1098
37.1	363.5	78.2	1992.1	1992.3	2.2926	2.2467	2542.5	2542.5	0.8165	0.8002
28.0	274.5	59.0	1994.0	1994.0	2.1794	2.1358	2409.9	2409.8	0.7890	0.7732
18.9	185.5	39.9	1996.3	1996.4	1.5642	1.5329	2277.4	2277.3	0.5745	0.5630
9.8	96.6	20.8	1997.3	1997.5	0.8016	0.7855	2144.7	2144.7	0.2062	0.2020
0.8	7.6	1.6	1999.0	1999.0	0.4573	0.4482	2011.9	2011.9	0.1915	0.1877
0.0	0.0	0.0	1999.0	1999.0	0.1708	0.1674	2000.5	2000.4	0.1000	0.0980

Table VI.9a: Mean raw data from 4 tests, simultaneously recorded in the six channels when positive A/P bending moment Mz was applied (lever arm d = 0.215 m), with descriptive statistics.

A/P Bending	Moment	Negative			Main	Channel	Mz			
about Z axis										
Loading			*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
along X axis			*4*			*INTERVALS*	*4*			*INTERVALS*
at 0.215 m			*tests*			*LEVEL*	*tests*			*LEVEL*
from ankle axis		Bending				*95%*				*95%*
Loading mass	Loading	moment								
kg	N	Nm	SFx				SFy			
0.0	0.0	0.0	1999.6	1999.6	0.7228	0.7084	2000.0	1999.9	2.1016	2.0595
0.8	7.6	-1.6	1998.4	1998.5	0.6976	0.6836	1999.7	1999.9	1.9442	1.9053
9.8	96.6	-20.8	1984.3	1984.3	0.8995	0.8815	2000.5	2000.5	1.7944	1.7585
18.9	185.5	-39.9	1969.8	1969.9	0.6652	0.6519	2001.0	2001.0	1.6330	1.6003
28.0	274.5	-59.0	1955.6	1955.6	0.7365	0.7218	2000.8	2000.7	1.5086	1.4784
37.1	363.5	-78.2	1941.1	1941.3	0.8057	0.7896	2000.1	2000.1	1.6783	1.6447
42.1	412.5	-88.7	1933.4	1933.5	0.8617	0.8444	1999.7	1999.6	1.6939	1.6600
42.1	412.5	-88.7	1933.4	1933.5	0.8617	0.8444	1999.7	1999.6	1.6939	1.6600
37.1	363.5	-78.2	1941.3	1941.3	0.6238	0.6113	2000.1	2000.0	1.6299	1.5973
28.0	274.5	-59.0	1955.6	1955.6	0.8185	0.8021	2001.0	2001.1	1.6112	1.5789
18.9	185.5	-39.9	1969.9	1969.9	0.9570	0.9378	2001.0	2000.8	1.5945	1.5626
9.8	96.6	-20.8	1984.0	1984.0	0.7848	0.7690	2000.5	2000.4	1.5174	1.4870
0.8	7.6	-1.6	1998.5	1998.5	0.9309	0.9123	1999.1	1999.2	1.5130	1.4827
0.0	0.0	0.0	1999.7	1999.7	0.9639	0.9446	1999.0	1999.0	1.8998	1.8617
			MEAN	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
			4			*INTERVALS*	*4*			*INTERVALS*
		Bending	*tests*			*LEVEL*	*tests*			*LEVEL*
Loading mass	Loading	moment				*95%*				*95%*
kg	N	Nm	SFz				SMx			
0.0	0.0	0.0	2000.5	2000.6	0.4967	0.4867	1999.7	1999.7	1.0145	0.9942
0.8	7.6	-1.6	2002.1	2002.2	0.3096	0.3034	1999.8	1999.8	1.1147	1.0924
9.8	96.6	-20.8	2024.9	2024.9	0.4193	0.4109	1999.0	1999.0	0.8500	0.8330
18.9	185.5	-39.9	2047.4	2047.4	0.2062	0.2020	1998.6	1998.7	0.6976	0.6836
28.0	274.5	-59.0	2069.7	2069.7	0.1258	0.1233	1998.3	1998.2	0.5188	0.5084
37.1	363.5	-78.2	2092.1	2092.0	0.5560	0.5449	1998.0	1998.0	0.6076	0.5954
42.1	412.5	-88.7	2104.4	2104.4	0.2872	0.2815	1997.8	1997.8	0.8165	0.8002
42.1	412.5	-88.7	2104.4	2104.4	0.2872	0.2815	1997.8	1997.8	0.8165	0.8002
37.1	363.5	-78.2	2092.2	2092.2	0.2217	0.2173	1998.0	1998.0	0.9309	0.9123
28.0	274.5	-59.0	2069.6	2069.7	0.1414	0.1386	1998.2	1998.4	0.9129	0.8946
18.9	185.5	-39.9	2047.4	2047.5	0.1414	0.1386	1998.5	1998.5	1.0145	0.9942
9.8	96.6	-20.8	2025.0	2025.0	0.1708	0.1674	1998.8	1998.8	1.0996	1.0776
0.8	7.6	-1.6	2002.6	2002.6	0.1258	0.1233	1999.3	1999.4	1.1733	1.1498
0.0	0.0	0.0	2000.6	2000.6	0.1258	0.1233	1999.5	1999.6	1.5155	1.4851
			MEAN	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
			4			*INTERVALS*	*4*			*INTERVALS*
		Bending	*tests*			*LEVEL*	*tests*			*LEVEL*
Loading mass	Loading	moment				*95%*				*95%*
kg	N	Nm	SMy				SMz			
0.0	0.0	0.0	1999.3	1999.3	0.2944	0.2885	1996.2	1996.3	5.1994	5.0953
0.8	7.6	-1.6	1999.5	1999.4	0.2380	0.2333	1984.6	1984.7	4.9132	4.8149
9.8	96.6	-20.8	2002.7	2002.3	1.0966	1.0746	1851.4	1851.5	5.4002	5.2921
18.9	185.5	-39.9	2004.2	2004.4	0.7588	0.7436	1718.3	1718.4	5.6586	5.5453
28.0	274.5	-59.0	2005.4	2005.6	1.5042	1.4740	1585.5	1585.7	5.9908	5.8708
37.1	363.5	-78.2	2006.2	2006.2	1.5196	1.4892	1451.9	1451.6	5.6574	5.5442
42.1	412.5	-88.7	2006.8	2006.7	1.3647	1.3374	1379.4	1379.5	6.4099	6.2816
42.1	412.5	-88.7	2006.8	2006.7	1.3647	1.3374	1379.4	1379.5	6.4099	6.2816
37.1	363.5	-78.2	2006.1	2006.1	1.2659	1.2406	1452.6	1452.6	6.3535	6.2263
28.0	274.5	-59.0	2004.8	2004.6	1.3796	1.3520	1585.3	1585.5	5.8077	5.6914
18.9	185.5	-39.9	2002.9	2002.7	0.8583	0.8411	1718.5	1718.5	5.6329	5.5201
9.8	96.6	-20.8	2000.9	2001.0	0.3403	0.3335	1851.5	1851.5	5.3170	5.2105
0.8	7.6	-1.6	1999.8	1999.8	0.1708	0.1674	1984.9	1984.9	5.1117	5.0093
0.0	0.0	0.0	1999.7	1999.6	0.3862	0.3785	1996.1	1996.1	5.0520	4.9508

Table VI.9b: Mean raw data from 4 tests, simultaneously recorded in the six channels when negative A/P bending moment Mz was applied (lever arm d = 0.215 m), with descriptive statistics.

A/P Bending	Moment	Positive			Main	Channel	Mz			
about Z axis										
Loading			*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
along X axis			*4*			*INTERVALS*	*4*			*INTERVALS*
at 0.315 m			*tests*			*LEVEL*	*tests*			*LEVEL*
from ankle axis		Bending				*95%*				*95%*
Loading mass	Loading	moment								
kg	N	Nm	SFx				SFy			
0.0	0.0	0.0	2000.7	2000.7	0.2944	0.2885	2000.0	1999.8	0.6449	0.6319
0.8	7.6	2.4	2002.1	2002.1	0.4031	0.3950	1999.5	1999.4	0.6481	0.6351
9.8	96.6	30.4	2017.2	2017.2	0.3304	0.3238	1996.3	1996.4	0.4546	0.4455
18.9	185.5	58.4	2032.2	2032.1	0.4787	0.4691	1991.1	1991.1	0.8679	0.8506
23.9	234.6	73.9	2040.5	2040.6	0.7182	0.7038	1988.2	1988.0	0.8655	0.8482
28.9	283.6	89.3	2048.6	2048.8	0.4082	0.4001	1984.3	1984.0	0.8660	0.8487
28.9	283.6	89.3	2048.6	2048.8	0.4082	0.4001	1984.3	1984.0	0.8660	0.8487
23.9	234.6	73.9	2040.3	2040.4	0.4992	0.4892	1987.4	1987.4	1.1057	1.0835
18.9	185.5	58.4	2032.3	2032.2	0.5260	0.5155	1990.5	1990.5	0.8221	0.8056
9.8	96.6	30.4	2017.2	2017.2	0.2944	0.2885	1994.9	1995.2	0.9605	0.9412
0.8	7.6	2.4	2001.9	2001.8	0.4546	0.4455	1998.0	1998.3	1.0720	1.0505
0.0	0.0	0.0	2000.6	2000.6	0.2887	0.2829	1998.4	1998.5	0.8655	0.8482
			MEAN	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
			4			*INTERVALS*	*4*			*INTERVALS*
		Bending	*tests*			*LEVEL*	*tests*			*LEVEL*
Loading mass	Loading	moment				*95%*				*95%*
kg	N	Nm	SFz				SMx			
0.0	0.0	0.0	1999.7	1999.6	1.8833	1.8456	2000.4	2000.3	0.3775	0.3699
0.8	7.6	2.4	1996.8	1996.8	1.8797	1.8421	2000.3	2000.3	0.4573	0.4482
9.8	96.6	30.4	1961.9	1961.9	1.7935	1.7576	2000.2	2000.2	0.1258	0.1233
18.9	185.5	58.4	1927.0	1927.0	2.0516	2.0106	1999.6	1999.6	0.3000	0.2940
23.9	234.6	73.9	1907.9	1907.9	1.9397	1.9009	1999.0	1999.0	0.0500	0.0490
28.9	283.6	89.3	1889.0	1888.9	1.8520	1.8149	1998.8	1998.7	0.3559	0.3488
28.9	283.6	89.3	1889.0	1888.9	1.8520	1.8149	1998.8	1998.7	0.3559	0.3488
23.9	234.6	73.9	1908.0	1907.9	1.8083	1.7721	1999.2	1999.3	0.2630	0.2577
18.9	185.5	58.4	1927.3	1927.4	1.7896	1.7537	1999.3	1999.3	0.1000	0.0980
9.8	96.6	30.4	1961.9	1961.9	1.7251	1.6905	1999.8	1999.9	0.2986	0.2926
0.8	7.6	2.4	1997.1	1997.1	1.7462	1.7112	2000.3	2000.4	0.2630	0.2577
0.0	0.0	0.0	2000.0	1999.8	1.8457	1.8088	2000.7	2000.7	0.1258	0.1233
			MEAN	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
			4			*INTERVALS*	*4*			*INTERVALS*
		Bending	*tests*			*LEVEL*	*tests*			*LEVEL*
Loading mass	Loading	moment				*95%*				*95%*
kg	N	Nm	SMy				SMz			
0.0	0.0	0.0	1999.2	1999.2	0.3559	0.3488	2000.6	2000.7	0.1893	0.1855
0.8	7.6	2.4	1999.2	1999.3	0.3304	0.3238	2017.7	2017.7	0.0816	0.0800
9.8	96.6	30.4	1997.2	1997.0	1.0210	1.0006	2221.0	2221.0	0.1500	0.1470
18.9	185.5	58.4	1993.3	1993.5	1.6276	1.5950	2423.6	2423.6	0.3304	0.3238
23.9	234.6	73.9	1990.3	1990.1	1.0583	1.0371	2535.3	2535.3	0.2872	0.2815
28.9	283.6	89.3	1988.0	1987.7	0.9394	0.9206	2646.8	2646.7	0.2828	0.2772
28.9	283.6	89.3	1988.0	1987.7	0.9394	0.9206	2646.8	2646.7	0.2828	0.2772
23.9	234.6	73.9	1989.3	1989.2	0.7141	0.6998	2535.5	2535.5	0.1258	0.1233
18.9	185.5	58.4	1991.5	1991.4	0.9327	0.9141	2423.6	2423.6	0.2160	0.2117
9.8	96.6	30.4	1996.3	1996.4	0.5058	0.4957	2221.0	2220.9	0.2708	0.2654
0.8	7.6	2.4	1999.2	1999.2	0.2754	0.2699	2017.8	2017.8	0.2517	0.2466
0.0	0.0	0.0	1999.3	1999.3	0.4967	0.4867	2000.6	2000.6	0.3109	0.3047

Table VI.10a: Mean raw data from 4 tests, simultaneously recorded in the six channels when positive A/P bending moment Mz was applied (lever arm d = 0.315 m), with descriptive statistics.

A/P Bending	Moment	Negative			Main	Channel	Mz			
about Z axis										
Loading			*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
along X axis			*4*			*INTERVALS*	*4*			*INTERVALS*
at 0.315 m			*tests*			*LEVEL*	*tests*			*LEVEL*
from ankle axis		Bending				*95%*				*95%*
Loading mass	Loading	moment								
kg	N	Nm	SFx				SFy			
0.0	0.0	0.0	1999.7	1999.8	0.8907	0.8729	1999.1	1999.1	0.4082	0.4001
0.8	7.6	-2.4	1998.5	1998.5	0.8103	0.7941	1999.3	1999.3	0.2887	0.2829
9.8	96.6	-30.4	1984.4	1984.7	0.6351	0.6224	2000.7	2000.8	0.2449	0.2400
18.9	185.5	-58.4	1969.6	1969.6	0.7848	0.7690	2000.5	2000.5	0.1708	0.1674
23.9	234.6	-73.9	1961.6	1961.6	0.4690	0.4597	2000.2	2000.2	0.1732	0.1697
28.9	283.6	-89.3	1953.7	1953.7	0.7848	0.7690	1999.2	1999.2	0.2500	0.2450
28.9	283.6	-89.3	1953.7	1953.7	0.7848	0.7690	1999.2	1999.2	0.2500	0.2450
23.9	234.6	-73.9	1961.9	1962.2	0.8042	0.7881	2000.1	2000.1	0.1500	0.1470
18.9	185.5	-58.4	1969.9	1970.2	0.6733	0.6598	2000.8	2000.6	0.3697	0.3623
9.8	96.6	-30.4	1984.4	1984.7	0.6500	0.6370	2000.7	2001.0	0.4856	0.4759
0.8	7.6	-2.4	1998.9	1999.3	0.8500	0.8330	1999.1	1999.1	0.5260	0.5155
0.0	0.0	0.0	1999.9	2000.3	0.6850	0.6712	1998.6	1998.7	0.5033	0.4932
			MEAN	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
			4			*INTERVALS*	*4*	-		*INTERVALS*
		Bending	*tests*			*LEVEL*	*tests*			*LEVEL*
Loading mass	Loading	moment				*95%*				*95%*
kg	N	Nm	SFz				SMx			
0.0	0.0	0.0	2001.1	2001.1	0.2160	0.2117	1999.8	2000.2	1.2527	1.2276
0.8	7.6	-2.4	2003.9	2003.9	0.3686	0.3612	1999.6	1999.9	1.1758	1.1523
9.8	96.6	-30.4	2038.6	2038.5	0.2708	0.2654	1998.4	1998.4	0.9815	0.9618
18.9	185.5	-58.4	2073.5	2073.5	0.2062	0.2020	1998.2	1998.4	0.5909	0.5791
23.9	234.6	-73.9	2092.5	2092.6	0.3202	0.3137	1997.7	1998.0	0.6946	0.6807
28.9	283.6	-89.3	2111.6	2111.6	0.2582	0.2530	1997.5	1997.8	0.7616	0.7463
28.9	283.6	-89.3	2111.6	2111.6	0.2582	0.2530	1997.5	1997.8	0.7616	0.7463
23.9	234.6	-73.9	2092.5	2092.5	0.1633	0.1600	1997.2	1997.2	0.7228	0.7084
18.9	185.5	-58.4	2073.2	2073.2	0.0500	0.0490	1997.7	1997.6	0.8699	0.8525
9.8	96.6	-30.4	2038.5	2038.5	0.1732	0.1697	1998.1	1998.0	1.2010	1.1770
0.8	7.6	-2.4	2003.7	2003.6	0.1915	0.1877	1999.3	1999.0	1.1413	1.1184
0.0	0.0	0.0	2000.7	2000.7	0.2449	0.2400	1999.0	1998.8	1.1587	1.1355
			MEAN	*MEDIAN*	*1/2 SD*	*CONFIDENCE*	*MEAN*	*MEDIAN*	*1/2 SD*	*CONFIDENCE*
			4			*INTERVALS*	*4*			*INTERVALS*
		Bending	*tests*			*LEVEL*	*tests*			*LEVEL*
Loading mass	Loading	moment				*95%*				*95%*
kg	N	Nm	SMy				SMz			
0.0	0.0	0.0	1998.9	1998.9	0.7000	0.7921	2000.2	2000.2	0.3697	0.3623
0.8	7.6	-2.4	1999.7	1999.5	0.2887	0.3267	1982.7	1982.7	0.3651	0.3578
9.8	96.6	-30.4	2003.6	2004.5	1.6166	1.8293	1779.7	1779.6	0.1732	0.1697
18.9	185.5	-58.4	2005.1	2005.8	1.3317	1.5069	1577.2	1577.3	0.2630	0.2577
23.9	234.6	-73.9	2005.7	2006.0	1.8148	2.0535	1465.5	1465.6	0.4193	0.4109
28.9	283.6	-89.3	2006.7	2006.6	1.9035	2.1540	1354.1	1354.2	0.4243	0.4158
28.9	283.6	-89.3	2006.7	2006.6	1.9035	2.1540	1354.1	1354.2	0.4243	0.4158
23.9	234.6	-73.9	2004.6	2005.3	1.2702	1.4373	1465.8	1465.9	0.1414	0.1386
18.9	185.5	-58.4	2003.8	2004.7	1.5588	1.7640	1577.3	1577.3	0.0500	0.0490
9.8	96.6	-30.4	2001.9	2002.3	0.7506	0.8493	1779.9	1779.9	0.0000	0.0000
0.8	7.6	-2.4	1999.7	2000.0	0.4619	0.5227	1982.8	1982.8	0.3948	0.3869
0.0	0.0	0.0	1999.5	1999.6	0.2309	0.2613	2000.2	2000.1	0.3367	0.3299

Table VI.10 b: Mean raw data from 4 tests, simultaneously recorded in the six channels when negative A/P bending moment Mz was applied (lever arm d = 0.315 m), with descriptive statistics.

11.VII COMPLETE RESULTS OF THE VALIDATION TESTS PERFORMED WITH THE NEW VILLIERS PYLON TRANSDUCER

11.VII.1 Combined loads in dorsiflexion or plantarflexion

Tables VII.1 and VII.2 show the static tests performed using a special validation rig designed by Magnissalis (1992). The complete comments are shown in section 7.2.1. In this configuration, there were no rotations about the longitudinal Y axis, it was thus a configuration similar as the calibration set-up (see chapter 6). Only one test was performed in each position of the VPT (sampling frequency of 16 Hz). The difference (predicted - applied) loads are very small in A/P shear force Fx. The values of the different lever arms for A/P bending moment Mz were so small that the results of such a channel must not be considered. This is why no statistical results nor graph are shown in such a channel.

Table VII.1 represents the following position of the Villiers Pylon Transducer:

Θz was 22°25 and 40°, it was thus a dorsiflexion.

Table VII.2 represents the following position:

Θz was - 19°87 and - 40°, it was thus a plantarflexion.

The two angles were not equal because of the size of the VPT with its flanges into the validation rig (see section 7.2.1). Table VII.3 also provides the statistical analysis of the two channels tested in such a configuration: A/P shear force Fx and axial load Fy. The graphs of these two channels are shown in figures VII.1a and b.

	Fx	Dorsi	flexion					
Loading	Theta Z =	22°25			Theta Z =	40°		
Weight	Applied	Predicted	difference	difference	Applied	Predicted	difference	difference
in N	in N	in N	in N	in %	in N	in N	in N	in %
7.84	3.0	3.3	0.3	11.2	5.0	7.1	2.1	40.9
96.82	36.7	39.8	3.1	8.6	62.2	64.7	2.5	4.0
185.8	70.4	72.2	1.8	2.6	119.4	121.1	1.7	1.4
274.77	104.1	104	-0.1	-0.1	176.6	178.3	1.7	1.0
372.87	141.2	139	-2.2	-1.6	239.7	240.1	0.4	0.2
274.77	104.1	104	-0.1	-0.1	176.6	178.1	1.5	0.8
185.8	70.4	71.5	1.1	1.6	119.4	121.9	2.5	2.1
96.82	36.7	39.7	3.0	8.3	62.2	63.7	1.5	2.4
7.84	3.0	3.3	0.3	11.2	5.0	6.9	1.9	36.9
			mean %	2.8			mean %	1.7
	Fy	Dorsi	flexion					
Loading								
Weight	Applied	Predicted	difference	difference	Applied	Predicted	difference	difference
in N	in N	in N	in N	in %	in N	in N	in N	in %
7.84	7.3	3.2	-4.1	-55.9	6.0	0.2	-5.8	-96.7
96.82	89.6	90.4	0.8	0.9	74.2	74.8	0.6	0.9
185.8	172.0	177.8	5.8	3.4	142.3	150.7	8.4	5.9
274.77	254.3	265.4	11.1	4.4	210.5	227.7	17.2	8.2
372.87	345.1	360.4	15.3	4.4	285.6	310.4	24.8	8.7
274.77	254.3	264.6	10.3	4.0	210.5	226.9	16.4	7.8
185.8	172.0	177.9	5.9	3.5	142.3	151.4	9.1	6.4
96.82	89.6	92.5	2.9	3.2	74.2	74.9	0.7	1.0
7.84	7.3	4.9	-2.4	-32.5	6.0	-0.8	-6.8	-113.3
			mean %	3.4			mean %	5.5
	Fz	Dorsi	flexion					
Loading								
Weight	Applied	Predicted	difference		Applied	Predicted	difference	
in N	in N	in N	in N		in N	in N	in N	
7.84	0.00	-0.16	-0.16		0.00	0.10	0.10	
96.82	0.00	0.59	0.59		0.00	0.22	0.22	
185.8	0.00	0.22	0.22		0.00	0.94	0.94	
274.77	0.00	-0.68	-0.68		0.00	0.78	0.78	
372.87	0.00	-0.23	-0.23		0.00	1.56	1.56	
274.77	0.00	-0.03	-0.03		0.00	1.25	1.25	
185.8	0.00	0.34	0.34		0.00	-0.06	-0.06	
96.82	0.00	0.43	0.43		0.00	0.37	0.37	
7.84	0.00	0.16	0.16		0.00	-0.37	-0.37	

Table VII.1a: The three forces in dorsiflexion (Θz = 22°25 and 40°). There was no rotation about the Y axis, therefore, the applied loads were only Fx, Fy and Mz (with a lever arm = 0.024 m or 0.042 m).

	Mx	Dorsi	flexion					
Loading								
Weight	Applied	Predicted	difference		Applied	Predicted	difference	
in N	in Nm	in Nm	in Nm		in Nm	in Nm	in N	
7.84	0.00	0.07	0.07		0.00	0.04	0.04	
96.82	0.00	0.02	0.02		0.00	0.08	0.08	
185.8	0.00	-0.02	-0.02		0.00	0.05	0.05	
274.77	0.00	-0.01	-0.01		0.00	0.02	0.02	
372.87	0.00	-0.09	-0.09		0.00	-0.05	-0.05	
274.77	0.00	-0.01	-0.01		0.00	-0.03	-0.03	
185.8	0.00	0.02	0.02		0.00	0.04	0.04	
96.82	0.00	0.02	0.02		0.00	0.08	0.08	
7.84	0.00	0.06	0.06		0.00	0.04	0.04	
	My	Dorsi	flexion					
Loading								
Weight	Applied	Predicted	difference		Applied	Predicted	difference	
in N	in Nm	in Nm	in Nm		in Nm	in Nm	in N	
7.84	0.00	0.08	0.08		0.00	0.08	0.08	
96.82	0.00	0.05	0.05		0.00	0.05	0.05	
185.8	0.00	0.02	0.02		0.00	0.03	0.03	
274.77	0.00	0.00	0.00		0.00	-0.03	-0.03	
372.87	0.00	-0.03	-0.03		0.00	-0.05	-0.05	
274.77	0.00	0.01	0.01		0.00	-0.01	-0.01	
185.8	0.00	0.02	0.02		0.00	0.00	0.00	
96.82	0.00	0.05	0.05		0.00	0.05	0.05	
7.84	0.00	0.08	0.08		0.00	0.08	0.08	
	Mz	Dorsi	flexion					
Loading	l = 24 mm				l = 42 mm			
Weight	Applied	Predicted	difference	difference	Applied	Predicted	difference	difference
in N	in Nm	in Nm	in Nm	in %	in Nm	in Nm	in N	in %
7.84	0.14	-0.08	-0.22	-155.50	0.25	0.34	0.1	34.8
96.82	1.78	1.72	-0.06	-3.37	3.12	3.60	0.5	15.6
185.8	3.42	3.63	0.21	6.27	5.98	6.88	0.9	15.1
274.77	5.05	5.66	0.61	12.04	8.84	10.02	1.2	13.3
372.87	6.86	7.76	0.90	13.20	12.00	13.70	1.7	14.2
274.77	5.05	5.67	0.62	12.24	8.84	10.14	1.3	14.7
185.8	3.42	3.75	0.33	9.78	5.98	6.87	0.9	14.9
96.82	1.78	1.83	0.05	2.81	3.12	3.61	0.5	15.9
7.84	0.14	-0.08	-0.22	-155.50	0.25	0.45	0.2	78.4
			mean %	7.6			mean %	14.8

Table VII.1b: The three moments in dorsiflexion (Θz = 22°25 and 40°). There was no rotation about the Y axis, therefore, the applied loads were only Fx, Fy and Mz (with a lever arm = 0.024 m or 0.042 m).

Fx	**Plantar**	**flexion**					
Theta Z = -	**19°87**			**Theta Z = -**	**40°**		
Applied in N	Predicted in N	difference in N	difference in %	Applied in N	Predicted in N	difference in N	difference in %
2.7	4.1	1.4	53.9	5.0	10.8	5.8	114.3
32.9	34.6	1.7	5.1	62.2	64.5	2.3	3.6
63.2	63.8	0.6	1.0	119.4	119.2	-0.2	-0.2
93.4	93.5	0.1	0.1	176.6	173.9	-2.7	-1.5
126.7	126.9	0.2	0.1	239.7	233.9	-5.8	-2.4
93.4	94.9	1.5	1.6	176.6	175.1	-1.5	-0.9
63.2	64.5	1.3	2.1	119.4	120.7	1.3	1.1
32.9	36.8	3.9	11.8	62.2	66.0	3.8	6.1
2.7	5.1	2.4	91.4	5.0	11.0	6.0	118.3
		mean %	**3.1**			**mean %**	**0.8**
Fy	**Plantar**	**flexion**					
Applied in N	Predicted in N	difference in N	difference in %	Applied in N	Predicted in N	difference - in N	difference in %
7.4	5.1	-2.27	-30.83	6.0	1.1	-4.9	-81.7
91.1	87.4	-3.66	-4.02	74.2	69.0	-5.2	-7.0
174.7	173.6	-1.14	-0.65	142.3	139.9	-2.4	-1.7
258.4	258.7	0.29	0.11	210.5	210.6	0.1	0.1
350.7	349.0	-1.67	-0.48	285.6	285.9	0.3	0.1
258.4	256.6	-1.81	-0.70	210.5	210.2	-0.3	-0.1
174.7	172.5	-2.24	-1.28	142.3	140.9	-1.4	-1.0
91.1	90.4	-0.66	-0.72	74.2	71.1	-3.1	-4.1
7.4	6.8	-0.57	-7.77	6.0	1.4	-4.6	-76.7
		mean %	**-1.1**			**mean %**	**-2.0**
Fz	**Plantar**	**flexion**					
Applied in N	Predicted in N	difference in N		Applied in N	Predicted in N	difference in N	
0.00	-0.89	-0.89		0.00	-1.13	-1.13	
0.00	0.01	0.01		0.00	0.55	0.55	
0.00	0.62	0.62		0.00	1.37	1.37	
0.00	0.91	0.91		0.00	0.89	0.89	
0.00	1.22	1.22		0.00	1.48	1.48	
0.00	0.40	0.40		0.00	0.86	0.86	
0.00	-0.33	-0.33		0.00	-0.11	-0.11	
0.00	-0.32	-0.32		0.00	-0.29	-0.29	
0.00	-0.95	-0.95		0.00	-1.45	-1.45	

Table VII.2a: The three forces in plantarflexion (Θz = - 19°87 and - 40°). There was no rotation about the Y axis, therefore, the applied loads were only Fx, Fy and Mz (with a lever arm = 0.004 m or 0.012 m).

Mx	**Plantar**	**flexion**					
Applied in N.m	Predicted in N.m	difference in N		Applied in N.m	Predicted in N.m	difference in N.m	
0.00	0.06	0.06		0.00	0.06	0.06	
0.00	0.09	0.09		0.00	0.08	0.08	
0.00	0.16	0.16		0.00	0.10	0.10	
0.00	0.15	0.15		0.00	0.14	0.14	
0.00	0.01	0.01		0.00	0.08	0.08	
0.00	0.07	0.07		0.00	0.10	0.10	
0.00	0.04	0.04		0.00	0.03	0.03	
0.00	0.05	0.05		0.00	0.01	0.01	
0.00	0.06	0.06		0.00	0.03	0.03	
My	**Plantar**	**flexion**					
Applied in N.m	Predicted in N.m	difference in N		Applied in N.m	Predicted in N.m	difference in N.m	
0.00	0.09	0.09		0.00	0.08	0.08	
0.00	0.08	0.08		0.00	0.05	0.05	
0.00	0.07	0.07		0.00	0.04	0.04	
0.00	0.03	0.03		0.00	0.02	0.02	
0.00	0.06	0.06		0.00	0.03	0.03	
0.00	0.06	0.06		0.00	0.01	0.01	
0.00	0.08	0.08		0.00	0.06	0.06	
0.00	0.09	0.09		0.00	0.08	0.08	
0.00	0.09	0.09		0.00	0.08	0.08	
Mz	**Plantar**	**flexion**					
l = 4 mm				**l = 12mm**			
Applied in N.m	Predicted in N.m	difference in N	difference in %	Applied in N.m	Predicted in N.m	difference in N.m	difference in %
-0.03	-0.83	-0.80	2714.23	-0.07	-3.20	-3.1	4340.2
-0.36	-0.99	-0.63	171.81	-0.89	-3.27	-2.4	267.4
-0.70	-1.14	-0.44	63.10	-1.71	-3.46	-1.8	102.6
-1.03	-1.29	-0.26	24.80	-2.53	-3.65	-1.1	44.5
-1.40	-1.37	0.03	-2.33	-3.43	-3.89	-0.5	13.5
-1.03	-1.19	-0.16	15.13	-2.53	-3.66	-1.1	44.9
-0.70	-1.24	-0.54	77.41	-1.71	-3.59	-1.9	110.2
-0.36	-0.99	-0.63	171.81	-0.89	-3.40	-2.5	282.0
-0.03	-0.83	-0.80	2714.23	-0.07	-3.20	-3.1	4340.2
		mean %	**74.5**			**mean %**	**123.6**

Table VII.2b: The three moments in plantarflexion (Θz = - 19°87 and - 40°). There was no rotation about the Y axis, therefore, the applied loads were only Fx, Fy and Mz (with a lever arm = 0.004 m or 0.012 m).

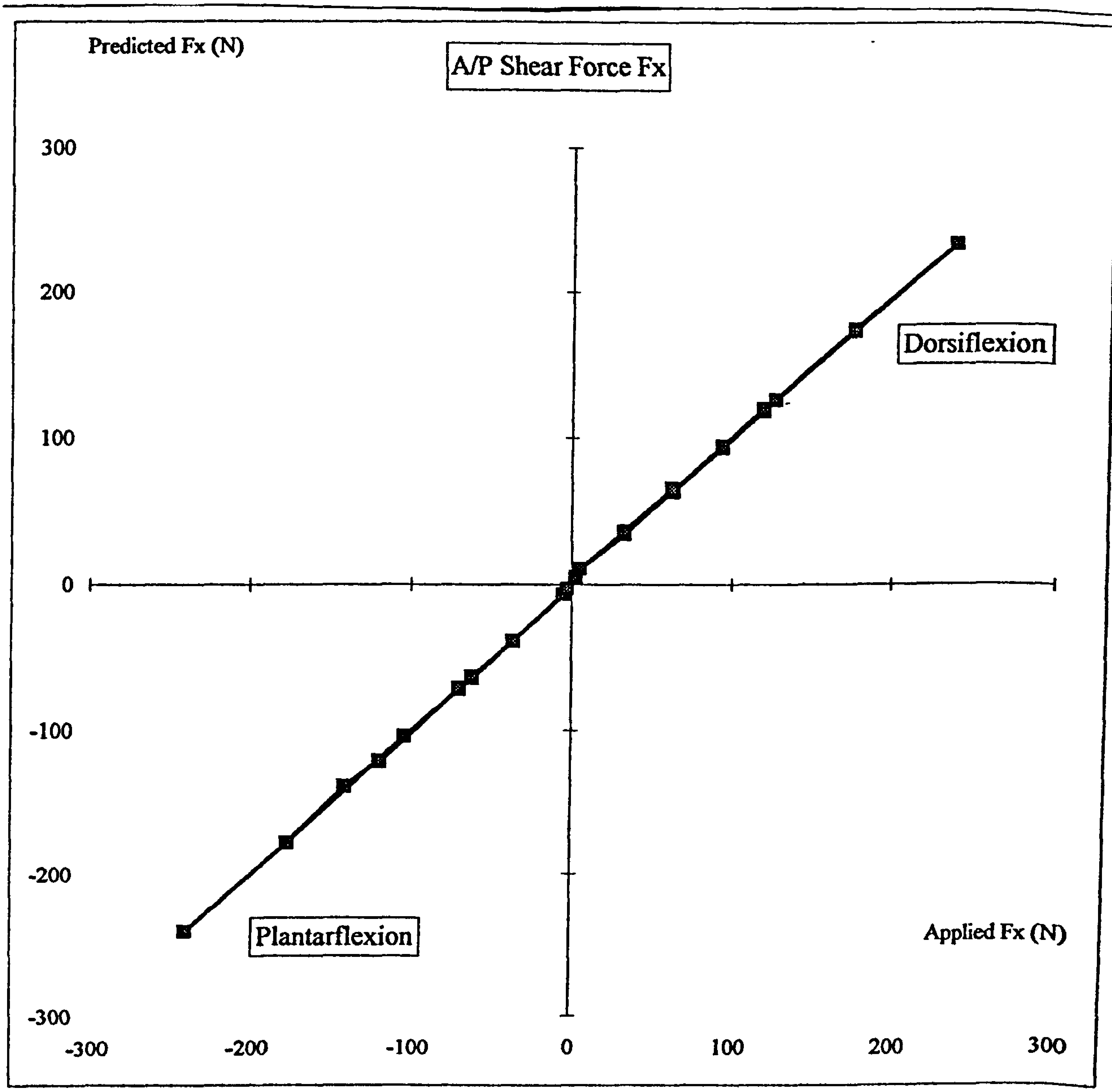


Figure VII.1a: Predicted versus Applied A/P shear force Fx with no rotation about the longitudinal Y axis. One test in plantar and one in dorsiflexion.

Fx		Regression Statistics			
Applied	Predicted				
-3	-3	Multiple R	0.999730508		
-5	-7	R Square	0.999461089		
-37	-40	Adjusted R Square	0.999445238		
-62	-65	Standard Error	2.552987124		
-70	-72	Observations	36		
-104	-104				
-119	-121	*Analysis of Variance*			
-141	-139		*df*	*Sum of Squares*	*Mean Square*
-177	-178	Regression	1	410983.7467	410983.7467
-240	-240	Residual	34	221.6032708	6.517743257
-177	-178	Total	35	411205.35	
-104	-104				
-119	-122			*F*	*Significance F*
-70	-72			63056.14236	3.70608E-57
-62	-64				
-37	-40		*Coefficients*	*Standard Error*	*t Statistic*
-5	-7				
-3	-3	Intercept	-0.027842709	0.425546889	-0.065428064
3	4	x1	1.001100639	0.003986704	251.1098213
5	11				
33	35		*P-value*	*Lower 95%*	*Upper 95%*
62	65				
63	64		0.948205476	-0.892657469	0.836972051
93	94		1.40819E-58	0.992998686	1.009202591
119	119				
127	127				
177	174				
240	234				
177	175				
119	121				
93	95				
63	65				
62	66				
33	37				
5	11				
3	5				

Table VII.3a: The regression statistical analysis of the channel Fx in dorsi and plantarflexion. Intercept is ≈ zero, the slope x1 is ≈ one and the r - square is ≈ one.

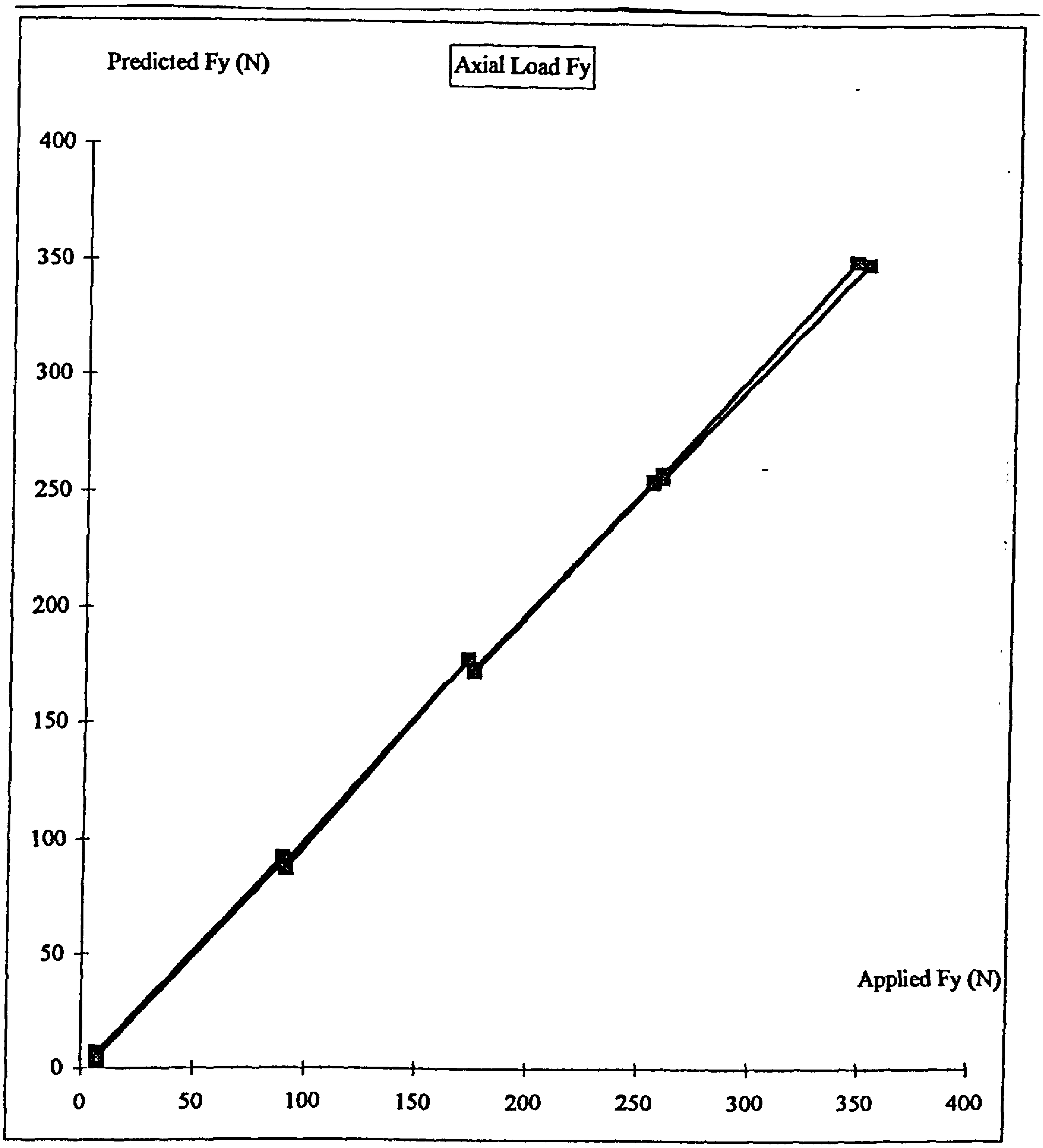


Figure VII.1b: Predicted versus Applied axial load Fy with no rotation about the longitudinal Y axis. One test in plantar and one in dorsiflexion.

Fy		Regression Statistics			
Applied	Predicted				
7	3	Multiple R	0.999203237		
7	5	R Square	0.998407109		
90	90	Adjusted R Square	0.998307554		
91	87	Standard Error	4.821470028		
172	178	Observations	18		
175	174				
254	255	*Analysis of Variance*			
258	259		*df*	*Sum of Squares*	*Mean Square*
345	350	Regression	1	233131.3059	233131.3059
351	349	Residual	16	371.9451717	23.24657323
258	257	Total	17	233503.2511	
254	255				
175	173			*F*	*Significance F*
172	178			10028.63104	8.14506E-24
91	90				
90	93		*Coefficients*	*Standard Error*	*t Statistic*
7	7				
7	5	Intercept	-2.495980182	1.961616869	-1.272409624
		x1	1.02741448	0.010259468	100.1430529
			P-value	*Lower 95%*	*Upper 95%*
			0.22035662	-6.654421238	1.662460875
			5.28045E-25	1.005665384	1.049163577

Table VII.3b: The regression statistical analysis of the channel Fy in plantar and dorsiflexion. The exhibited results show a sufficient linearity: intercept ≈ zero, slope x1 ≈ one and the r - square ≈ one

	Fx						
Loading	**Dorsi**	**flexion**	**Internal**				
Weight	Applied	Predicted	Predicted	Mean	Standard	difference	difference
in N	in N	in N	in N		Deviation	in N	in %
7.84	-2.3	-1.0	-0.2	-0.6	0.566	1.7	-73.7
96.82	-28.3	-31.3	-30.0	-30.7	0.919	-2.4	8.5
185.8	-54.2	-56.1	-55.0	-55.6	0.778	-1.3	2.5
274.77	-80.2	-82.0	-81.2	-81.6	0.566	-1.4	1.8
372.87	-108.8	-115.4	-114.2	-114.8	0.849	-6.0	5.5
274.77	-80.2	-83.1	-82.1	-82.6	0.707	-2.4	3.0
185.8	-54.2	-57.8	-55.4	-56.6	1.697	-2.4	4.4
96.82	-28.3	-30.4	-30.6	-30.5	0.141	-2.2	7.8
7.84	-2.3	-1.1	-0.1	-0.6	0.707	1.7	-73.9
						mean %	**4.8**
	Fy						
Loading	**Dorsi**	**flexion**	**Internal**				
Weight	Applied	Predicted	Predicted	Mean	Standard	difference	difference
in N	in N	in N	in N		Deviation	in N	in %
7.84	7.42	6.2	7	6.6	0.566	-0.8	-11.1
96.82	91.7	89.9	86.4	88.15	2.475	-3.6	-3.9
185.8	175.9	180.9	180.5	180.7	0.283	4.8	2.7
274.77	260.1	271.4	266.4	268.9	3.536	8.8	3.4
372.87	352.9	370.1	367.2	368.65	2.051	15.8	4.5
274.77	260.1	271.6	267.7	269.65	2.758	9.5	3.7
185.8	175.9	181.6	177.7	179.65	2.758	3.7	2.1
96.82	91.7	91.7	86.8	89.25	3.465	-2.5	-2.7
7.84	7.42	6.7	7.8	7.25	0.778	-0.2	-2.3
						mean %	**1.4**
	Fz						
Loading	**Dorsi**	**flexion**	**Internal**				
Weight	Applied	Predicted	Predicted	Mean	Standard	difference	difference
in N	in N	in N	in N		Deviation	in N	in %
7.84	1.32	0.71	0.69	0.7	0.014	-0.6	-47.0
96.82	16.32	12.70	10.98	11.84	1.216	-4.5	-27.4
185.8	31.32	23.26	20.90	22.08	1.669	-9.2	-29.5
274.77	46.31	34.14	31.33	32.735	1.987	-13.6	-29.3
372.87	62.85	46.16	42.68	44.42	2.461	-18.4	-29.3
274.77	46.31	33.81	31.15	32.48	1.881	-13.8	-29.9
185.8	31.32	23.37	21.05	22.21	1.640	-9.1	-29.1
96.82	16.32	12.02	10.28	11.15	1.230	-5.2	-31.7
7.84	1.32	1.46	0.37	0.915	0.771	-0.4	-30.8
						mean %	**-29.5**

Table VII.4a : The three forces in dorsiflexion ($\Theta z = 18°.80$) and internal rotation ($\Theta y = 30°$). The table shows the results of two tests with columns for mean and standard deviation.

11.VII.2 Combined loads in dorsiflexion or plantarflexion with internal or external rotation of the transducer

Tables VII.4, VII.5, VII.6 and VII.7 show the static tests performed when the validation rig was used with rotational angles about the longitudinal Y axis (see section 7.2.3)

Table VII.4 represents the following positions of the Villiers Pylon Transducer:

Θz was 18.80 degrees ; it was positive, it was thus a dorsiflexion about the Z axis

Θy was 30 degrees ; it was positive, it was thus an internal rotation about the Y axis

Table VII.5 represents the following positions:

Θz was 18.80 degrees ; it was positive, it was thus a dorsiflexion about the Z axis

Θy was - 30 degrees ; it was positive, it was thus an external rotation about the Y axis

Table VII.6 represents the following positions:

Θz was - 18.80 degrees ; it was negative, it was thus a plantarflexion about the Z axis

Θy was - 30 degrees ; it was negative, it was thus an external rotation about the Y axis

Table VII.7 represents the following position:

Θz was - 18.80 degrees ; it was negative, it was thus a plantarflexion about the Z axis

Θy was 30 degrees ; it was positive, it was thus an internal rotation about the Y axis

All these tables are organised as follows:

First column: Applied Loads in N or Bending Moments in N.m

Second column: Predicted Loads in N or Predicted Bending Moments in N.m of the test N°1 (the six channels of the VPT, two sticks with a sampling frequency of 64 Hz)

Third column: Predicted Loads in N or Predicted Bending Moments in N.m of the test N°2 if it has been performed (the six channels of the VPT with a sampling frequency of 16 Hz)

Fourth column: The arithmetic mean value of two tests

Fifth column: The standard deviation of the mean

Sixth column: The difference in N or N.m between the two tests

Seventh column: The difference in percentage between the two tests for each loading cases and the mean percentage in which the first and the last rows were not considered. The weight of the load - carrier (2.3 N) was found too small to express any accurate result.

There are no statistical differences between the two tests in each configuration despite the difference in the equipment and the sampling frequency.

In both configurations, the lever arms concerning the A/P bending moments Mz about the Z axis are so small that the results of such a channel should not be considered. Both applied and predicted values are too far from what it is expected in practice.

The statistical analysis of such tables are shown in the following tables: table VII.8a, the Fx channel ; VII.8b, Fy ; VII.8c, Fz ; VII.8d, Mx. The My channel was not recorded in such a set-up. The channel Mz was not considered because of the low recorded values due to the small lever arm.

The graphs of these channels are shown in figures VII.2a, Fx; VII.2b, Fy ; VII.2c, Fz and VII.2d, Mx..

	Mx						
Loading	**Dorsi**	**flexion**	**Internal**				
Weight	Applied	Predicted	Predicted	Mean	Standard	difference	difference
in N	in N.m	in N.m	in N.m		Deviation	in N.m	in %
7.84	0.09	0.01	0.01	0.01	0.000	-0.1	-88.4
96.82	1.07	1.11	0.99	1.05	0.085	0.0	-1.4
185.8	2.04	2.31	1.99	2.15	0.226	0.1	5.2
274.77	3.02	3.33	2.99	3.16	0.240	0.1	4.6
372.87	4.10	4.56	4.26	4.41	0.212	0.3	7.5
274.77	3.02	3.46	3.15	3.31	0.219	0.3	9.3
185.8	2.04	2.35	2.07	2.21	0.198	0.2	8.1
96.82	1.07	1.24	1.04	1.14	0.141	0.1	7.0
7.84	0.09	0.12	0.04	0.08	0.057	0.0	-7.2
						mean %	**5.8**
	My						
Loading	**Dorsi**	**flexion**	**Internal**				
Weight	Applied	Predicted	Predicted	Mean	Standard	difference	difference
in N	in N.m	in N.m	in N.m		Deviation	in N.m	in %
7.84	0	0.01	0.03	0.02	0.014	0.02	
96.82	0	0.01	0.01	0.01	0.000	0.01	
185.8	0	0.05	0.02	0.04	0.021	0.04	
274.77	0	0.06	0.03	0.05	0.021	0.05	
372.87	0	0.08	0.05	0.07	0.021	0.07	
274.77	0	0.07	0.05	0.06	0.014	0.06	
185.8	0	0.05	0.03	0.04	0.014	0.04	
96.82	0	0.04	0.01	0.03	0.021	0.03	
7.84	0	0.01	0.03	0.02	0.014	0.02	
	Mz						
Loading	**Dorsi**	**flexion**	**Internal**				
Weight	Applied	Predicted	Predicted	Mean	Standard	difference	difference
in N	in N.m	in N.m	in N.m		Deviation	in N.m	in %
7.84	0.15	0.11	0.18	0.15	0.049	0.0	-2.9
96.82	1.84	1.59	1.77	1.68	0.127	-0.2	-8.9
185.8	3.54	3.19	3.35	3.27	0.113	-0.3	-7.6
274.77	5.23	4.77	5.06	4.92	0.205	-0.3	-6.1
372.87	7.10	6.56	6.84	6.70	0.198	-0.4	-5.7
274.77	5.23	4.78	5.06	4.92	0.198	-0.3	-6.0
185.8	3.54	3.30	3.47	3.39	0.120	-0.2	-4.4
96.82	1.84	1.59	1.77	1.68	0.127	-0.2	-8.9
7.84	0.15	0.00	0.18	0.09	0.127	-0.1	-39.7
						mean %	**-6.0**

Table VII.4b : The three moments in dorsiflexion ($\Theta z = 18°.80$) and internal rotation ($\Theta y = 30°$). No transverse bending moments My were applied. The table shows the results of two tests with columns for mean and standard deviation.

	Fx						
Loading	**Dorsi**	**flexion**	**External**				
Weight	Applied	Predicted	Predicted	Mean	Standard	difference	difference
in N	in N	in N	in N		Deviation	in N	in %
7.84	-2.3	-1.2	0	-0.6	0.849	1.7	-73.9
96.82	-28.4	-29.1	-27.8	-28.5	0.919	-0.1	0.2
185.8	-54.5	-55.4	-54.6	-55.0	0.566	-0.5	0.9
274.77	-80.7	-83.7	-82.1	-82.9	1.131	-2.2	2.7
372.87	-109.4	-113.3	-110.8	-112.1	1.768	-2.6	2.4
274.77	-80.7	-83.9	-81.4	-82.7	1.768	-2.0	2.4
185.8	-54.5	-56.1	-55.6	-55.9	0.354	-1.4	2.5
96.82	-28.4	-29.3	-27.8	-28.6	1.061	-0.2	0.5
7.84	-2.3	-1.2	-0.9	-1.1	0.212	1.3	-54.3
						mean %	**1.7**
	Fy						
Loading	**Dorsi**	**flexion**	**External**				
Weight	Applied	Predicted	Predicted	Mean	Standard	difference	difference
in N	in N	in N	in N		Deviation	in N	in %
7.84	7.37	6.3	8	7.2	1.202	-0.2	-3.0
96.82	91.1	88.8	90.2	89.5	0.990	-1.6	-1.8
185.8	174.8	172.4	172.9	172.7	0.354	-2.2	-1.2
274.77	258.5	253.1	255.9	254.5	1.980	-4.0	-1.5
372.87	350.9	345.7	347.4	346.6	1.202	-4.4	-1.2
274.77	258.5	254.2	256.3	255.3	1.485	-3.3	-1.3
185.8	174.8	172.6	175.7	174.2	2.192	-0.7	-0.4
96.82	91.1	88.8	102.1	95.5	9.405	4.3	4.8
7.84	7.37	6.6	8.8	7.7	1.556	0.3	4.5
						mean %	**-0.4**
	Fz						
Loading	**Dorsi**	**flexion**	**External**				
Weight	Applied	Predicted	Predicted	Mean	Standard	difference	difference
in N	in N	in N	in N		Deviation	in N	in %
7.84	-1.33	-1.12	-1.00	-1.06	0.085	0.3	-20.3
96.82	-16.41	-11.08	-12.08	-11.58	0.707	4.8	-29.4
185.8	-31.49	-20.82	-21.52	-21.17	0.495	10.3	-32.8
274.77	-46.57	-31.12	-31.30	-31.21	0.127	15.4	-33.0
372.87	-63.20	-41.87	-42.51	-42.19	0.453	21.0	-33.2
274.77	-46.57	-30.59	-31.44	-31.02	0.601	15.6	-33.4
185.8	-31.49	-20.69	-20.75	-20.72	0.042	10.8	-34.2
96.82	-16.41	-10.92	-11.77	-11.35	0.601	5.1	-30.9
7.84	-1.33	-0.69	-1.37	-1.03	0.481	0.3	-22.6
						mean %	**-32.4**

Table VII.5a: The three forces in dorsiflexion (Θz = 18°.80) and external rotation (Θy = -30°). The table shows the results of two tests with columns for mean and standard deviation.

	Mx						
Loading	Dorsi	flexion	External				
Weight	Applied	Predicted	Predicted	Mean	Standard	difference	difference
in N	in N.m	in N.m	in N.m		Deviation	in N.m	in %
7.84	-0.09	-0.81	0.00	-0.41	0.573	-0.3	350.0
96.82	-1.11	-1.81	-0.99	-1.40	0.580	-0.3	26.1
185.8	-2.14	-2.81	-2.00	-2.41	0.573	-0.3	12.4
274.77	-3.16	-3.81	-2.96	-3.39	0.601	-0.2	7.1
372.87	-4.29	-4.97	-4.11	-4.54	0.608	-0.3	5.8
274.77	-3.16	-3.86	-3.00	-3.43	0.608	-0.3	8.5
185.8	-2.14	-2.85	-2.01	-2.43	0.594	-0.3	13.6
96.82	-1.11	-1.85	-1.00	-1.43	0.601	-0.3	28.4
7.84	-0.09	-0.81	-0.01	-0.41	0.566	-0.3	355.6
						mean %	**14.6**
	My						
Loading	**Dorsi**	**flexion**	**External**				
Weight	Applied	Predicted	Predicted	Mean	Standard	difference	difference
in N	in N.m	in N.m	in N.m		Deviation	in N.m	in %
7.84	0	0.05	0.00	0.03	0.035	0.03	
96.82	0	0.04	0.01	0.03	0.021	0.03	
185.8	0	0.01	0.03	0.02	0.014	0.02	
274.77	0	0.00	0.06	0.03	0.042	0.03	
372.87	0	0.01	0.06	0.04	0.035	0.04	
274.77	0	0.00	0.04	0.02	0.028	0.02	
185.8	0	0.02	0.04	0.03	0.014	0.03	
96.82	0	0.03	0.02	0.03	0.007	0.03	
7.84	0	0.05	0.01	0.03	0.028	0.03	
	Mz						
Loading	**Dorsi**	**flexion**	**External**				
Weight	Applied	Predicted	Predicted	Mean	Standard	difference	difference
in N	in N.m	in N.m	in N.m		Deviation	in N.m	in %
7.84	0.16	0.01	0	0.01	0.007	-0.2	-96.8
96.82	1.93	1.75	1.62	1.69	0.092	-0.2	-12.6
185.8	3.70	3.6	3.48	3.54	0.085	-0.2	-4.3
274.77	5.47	5.34	5.34	5.34	0.000	-0.1	-2.4
372.87	7.43	7.4	7.29	7.35	0.078	-0.1	-1.1
274.77	5.47	5.34	5.23	5.29	0.078	-0.2	-3.4
185.8	3.70	3.6	3.58	3.59	0.014	-0.1	-3.0
96.82	1.93	1.86	1.74	1.80	0.085	-0.1	-6.7
7.84	0.16	0.12	0.01	0.07	0.078	-0.1	-58.4
						mean %	**-2.9**

Table VII.5b : The three moments in dorsiflexion (Θz = 19°.82) and external rotation (Θy = - 30°). No transverse bending moments My were applied. The table shows the results of two tests with columns for mean and standard deviation.

	Fx						
Loading	**Plantar**	**Flexion**	**Internal**				
Weight	Applied	Predicted	Predicted	Mean	Standard	difference	difference
in N	in N	in N	in N		Deviation	in N	in %
7.84	2.4	5.8	6.5	6.2	0.495	3.7	152.8
96.82	30.0	30.8	31.6	31.2	0.566	1.2	3.8
185.8	57.7	55.6	57.3	56.5	1.202	-1.2	-2.1
274.77	85.3	81.3	83.1	82.2	1.273	-3.1	-3.6
372.87	115.7	108.4	111.2	109.8	1.980	-5.9	-5.1
274.77	85.3	82.3	82.6	82.5	0.212	-2.8	-3.3
185.8	57.7	54.3	57.6	56.0	2.333	-1.7	-3.0
96.82	30.0	31.6	32.3	32.0	0.495	1.9	6.3
7.84	2.4	6.8	6.5	6.7	0.212	4.2	173.3
						mean %	**-1.0**
	Fy						
Loading	**Plantar**	**Flexion**	**Internal**				
Weight	Applied	Predicted	Predicted	Mean	Standard	difference	difference
in N	in N	in N	in N		Deviation	in N	in %
7.84	7.3	5.0	5.8	5.4	0.566	-1.9	-26.2
96.82	90.4	85.5	87.9	86.7	1.697	-3.7	-4.1
185.8	173.5	169.5	170.2	169.9	0.495	-3.6	-2.1
274.77	256.5	254.1	252.7	253.4	0.990	-3.1	-1.2
372.87	348.1	344.7	343.4	344.1	0.919	-4.1	-1.2
274.77	256.5	252.0	252.6	252.3	0.424	-4.2	-1.6
185.8	173.5	171.7	169.8	170.8	1.344	-2.7	-1.6
96.82	90.4	89.4	87.6	88.5	1.273	-1.9	-2.1
7.84	7.3	6.3	4.1	5.2	1.556	-2.1	-29.0
						mean %	**-2.0**
	Fz						
Loading	**Plantar**	**Flexion**	**Internal**				
Weight	Applied	Predicted	Predicted	Mean	Standard	difference	difference
in N	in N	in N	in N		Deviation	in N	in %
7.84	-1.40	-2.22	-2.36	-2.3	0.099	-0.9	63.0
96.82	-17.35	-11.52	-12.01	-11.8	0.346	5.6	-32.2
185.8	-33.29	-22.35	-22.81	-22.6	0.325	10.7	-32.2
274.77	-49.23	-32.48	-33.93	-33.2	1.025	16.0	-32.6
372.87	-66.81	-44.49	-45.72	-45.1	0.870	21.7	-32.5
274.77	-49.23	-33.10	-34.29	-33.7	0.841	15.5	-31.6
185.8	33.29	-22.62	-23.13	-22.9	0.361	-56.2	-168.7
96.82	-17.35	12.09	-12.28	-0.1	17.232	17.3	-99.5
7.84	-1.40	-1.06	-2.03	-1.5	0.686	-0.1	10.0
						mean %	**-61.3**

Table VII.6a: The three forces in plantarflexion (Θz = - 19°.82) and internal rotation (Θy = 30°). The table shows the results of two tests with columns for mean and standard deviation

	Mx						
Loading	Plantar	Flexion	Internal				
Weight	Applied	Predicted	Predicted	Mean	Standard	difference	difference
in N	in N.m	in N.m	in N.m		Deviation	in N.m	in %
7.84	0.01	0.50	0.09	0.30	0.290	0.3	2524.9
96.82	0.14	0.47	0.05	0.26	0.297	0.1	87.3
185.8	0.27	0.47	0.06	0.27	0.290	0.0	-0.5
274.77	0.39	0.48	0.05	0.27	0.304	-0.1	-32.7
372.87	0.53	0.43	0.00	0.22	0.304	-0.3	-59.8
274.77	0.39	0.47	-0.03	0.22	0.354	-0.2	-44.1
185.8	0.27	0.51	0.09	0.26	0.297	0.0	-2.4
96.82	0.14	0.50	0.01	0.29	0.346	0.2	109.0
7.84	0.01	0.50	0.08	0.50	0.297	0.5	4349.0
						mean %	**8.1**
	My						
Loading	**Plantar**	**Flexion**	**Internal**				
Weight	Applied	Predicted	Predicted	Mean	Standard	difference	difference
in N	in N.m	in N.m	in N.m		Deviation	in N.m	in %
7.84	0	0.06	0.08	0.07	0.014	0.1	
96.82	0	0.06	0.06	0.06	0.000	0.1	
185.8	0	0.04	0.04	0.04	0.000	0.0	
274.77	0	0.00	0.05	0.03	0.035	0.0	
372.87	0	0.02	0.01	0.02	0.007	0.0	
274.77	0	0.05	0.04	0.05	0.007	0.0	
185.8	0	0.03	0.06	0.05	0.021	0.0	
96.82	0	0.04	0.06	0.05	0.014	0.1	
7.84	0	0.07	0.08	0.08	0.007	0.1	
	Mz						
Loading	**Plantar**	**Flexion**	**Internal**				
Weight	Applied	Predicted	Predicted	Mean	Standard	difference	difference
in N	in N.m	in N.m	in N.m		Deviation	in N.m	in %
7.84	-0.03	-0.26	-0.27	-0.27	0.007	-0.2	805.1
96.82	-0.36	-0.48	-0.49	-0.49	0.007	-0.1	34.1
185.8	-0.69	-0.58	-0.61	-0.60	0.021	0.1	-14.2
274.77	-1.03	-0.69	-0.72	-0.71	0.021	0.3	-31.3
372.87	-1.39	-1.12	-0.97	-1.05	0.106	0.3	-25.0
274.77	-1.03	-0.71	-0.74	-0.73	0.021	0.3	-29.3
185.8	-0.69	-0.59	-0.61	-0.60	0.014	0.1	-13.5
96.82	-0.36	-0.49	-0.5	-0.50	0.007	-0.1	36.9
7.84	-0.03	-0.38	-0.27	-0.33	0.078	-0.3	1010.1
						mean %	**-22.7**

Table VII.6b : The three moments in plantarflexion ($\Theta z = -18°.80$) and internal rotation ($\Theta y = 30°$). No transverse bending moments My were applied. The table shows the results of two tests with columns for mean and standard deviation.

	Fx						
Loading	**Plantar**	**Flexion**	**External**				
Weight	Applied	Predicted	Predicted	Mean	Standard	difference	difference
in N	in N	in N	in N		Deviation	in N	in %
7.84	2.3	0.7	-2.1	-0.7	1.980	-3.0	-130.6
96.82	28.3	28.5	26.0	27.3	1.768	-1.0	-3.6
185.8	54.2	57.5	54.0	55.8	2.475	1.5	2.8
274.77	80.2	85.7	83.0	84.4	1.909	4.1	5.2
372.87	108.8	117.5	113.1	115.3	3.111	6.5	5.9
274.77	80.2	86.5	82.8	84.7	2.616	4.4	5.5
185.8	54.2	58.8	55.3	57.1	2.475	2.8	5.2
96.82	28.3	29.3	26.9	28.1	1.697	-0.2	-0.6
7.84	2.3	1.6	0.8	1.2	0.566	-1.1	-47.6
						mean %	**2.9**
	Fy						
Loading	**Plantar**	**Flexion**	**External**				
Weight	Applied	Predicted	Predicted	Mean	Standard	difference	difference
in N	in N	in N	in N		Deviation	in N	in %
7.84	7.4	7.6	7.8	7.7	0.141	0.3	4.3
96.82	91.2	91.6	92.6	92.1	0.707	0.9	1.0
185.8	174.9	176.2	176.1	176.2	0.071	1.2	0.7
274.77	258.7	262.0	260.4	261.2	1.131	2.5	1.0
372.87	351.0	352.8	352.8	352.8	0.000	1.8	0.5
274.77	258.7	259.8	251.4	255.6	5.940	-3.1	-1.2
185.8	174.9	176.6	176.6	176.6	0.000	1.7	1.0
96.82	91.2	91.2	93.6	92.4	1.697	1.2	1.4
7.84	7.4	8.6	8.4	8.5	0.141	1.1	15.2
						mean %	**0.6**
	Fz						
Loading	**Plantar**	**Flexion**	**External**				
Weight	Applied	Predicted	Predicted	Mean	Standard	difference	difference
in N	in N	in N	in N		Deviation	in N	in %
7.84	1.32	1.36	1.65	1.5	0.205	0.2	13.9
96.82	16.32	10.40	10.67	10.5	0.191	-5.8	-35.4
185.8	31.32	20.21	20.31	20.3	0.071	-11.1	-35.3
274.77	46.31	29.23	29.36	29.3	0.092	-17.0	-36.7
372.87	62.85	40.20	40.36	40.3	0.113	-22.6	-35.9
274.77	46.31	29.58	30.75	30.2	0.827	-16.1	-34.9
185.8	31.32	19.93	20.02	20.0	0.064	-11.3	-36.2
96.82	16.32	10.88	13.71	12.3	2.001	-4.0	-24.7
7.84	1.32	1.40	1.20	1.3	0.141	0.0	-1.6
						mean %	**-34.2**

Table VII.7a: The three forces in plantarflexion (Θz = - 18°.80) and external rotation (Θy = - 30°). The table shows the results of two tests with columns for mean and standard deviation.

	Mx						
Loading	**Plantar**	**Flexion**	**External**				
Weight	Applied	Predicted	Predicted	Mean	Standard	difference	difference
in N	in N.m	in N.m	in N.m		Deviation	in N.m	in %
7.84	-0.02	-0.23	-0.25	-0.2	0.014	-0.2	1430.6
96.82	-0.19	-0.36	-0.34	-0.4	0.014	-0.2	80.7
185.8	-0.37	-0.46	-0.44	-0.5	0.014	-0.1	21.1
274.77	-0.55	-0.55	-0.53	-0.5	0.014	0.0	-1.7
372.87	-0.75	-0.66	-0.47	-0.6	0.134	0.2	-24.2
274.77	-0.55	-0.55	-0.46	-0.5	0.064	0.0	-8.1
185.8	-0.37	-0.41	-0.39	-0.4	0.014	0.0	7.6
96.82	-0.19	-0.37	-0.34	-0.4	0.021	-0.2	83.3
7.84	0.02	-0.23	-0.27	-0.3	0.028	-0.3	-1694.4
						mean %	**22.7**
	My						
Loading	**Plantar**	**Flexion**	**External**				
Weight	Applied	Predicted	Predicted	Mean	Standard	difference	difference
in N	in N.m	in N.m	in N.m		Deviation	in N.m	in %
7.84	0	0.06	0.05	0.06	0.007	0.1	
96.82	0	0.06	0.03	0.05	0.021	0.0	
185.8	0	0.05	0.04	0.05	0.007	0.0	
274.77	0	0.01	0.04	0.03	0.021	0.0	
372.87	0	0.04	0.04	0.04	0.000	0.0	
274.77	0	0.06	0.04	0.05	0.014	0.1	
185.8	0	0.05	0.04	0.05	0.007	0.0	
96.82	0	0.07	0.05	0.06	0.014	0.1	
7.84	0	0.07	0.40	0.24	0.233	0.2	
	Mz						
Loading	**Plantar**	**Flexion**	**External**				
Weight	Applied	Predicted	Predicted	Mean	Standard	difference	difference
in N	in N.m	in N.m	in N.m		Deviation	in N.m	in %
7.84	-0.03	-0.50	-0.82	-0.66	0.226	-0.6	2135.4
96.82	-0.36	-0.64	-0.95	-0.80	0.219	-0.4	118.0
185.8	-0.70	-0.95	-1.09	-1.02	0.099	-0.3	45.8
274.77	-1.03	-1.03	-1.24	-1.14	0.148	-0.1	9.7
372.87	-1.40	-1.32	-1.39	-1.36	0.049	0.0	-3.5
274.77	-1.03	-1.04	-1.35	-1.20	0.219	-0.2	15.5
185.8	-0.70	-0.91	-1.10	-1.01	0.134	-0.3	43.6
96.82	-0.36	-0.76	-0.96	-0.86	0.141	-0.5	135.9
7.84	-0.03	-0.51	-0.88	-0.70	0.262	-0.7	2254.0
						mean %	**22.2**

Table VII.7b: The three moments in plantarflexion ($\Theta z = -18°.80$) and external rotation ($\Theta y = -30°$). No transverse bending moments My were applied. The table shows the results of two tests with columns for mean and standard deviation.

Fx		*Regression Statistics*			
Applied	**Predicted**				
-2	-0.6	Multiple R	0.999704691		
-3	-3.0	R Square	0.99940947		
-5	-7.0	Adjusted R Square	0.999397659		
-28	-29.6	Standard Error	2.349555561		
-37	-40.0	Observations	52		
-55	-55.3				
-62	-65.0	*Analysis of Variance*			
-70	-72.0		*df*	*Sum of Squares*	*Mean Square*
-81	-82.3	Regression	1	467135.5312	467135.5312
-104	-104.0	Residual	50	276.0205667	5.520411334
-119	-121.0	Total	51	467411.5517	
-141	-139.0				
-177	-178.0			*F*	*Significance F*
-240	-240.0			84619.69641	2.14515E-82
-177	-178.0				
-119	-121.5		*Coefficients*	*Standard Error*	*t Statistic*
-109	-113.4				
-104	-104.0	Intercept	0.487693421	0.325948001	1.496230748
-81	-82.6	x1	0.997024305	0.003427441	290.8946483
-70	-72.0				
-62	-64.0		*P-value*	*Lower 95%*	*Upper 95%*
-55	-56.2			-	
-28	-29.5		0.140756764	-0.166992673	1.142379515
-5	-7.0		8.5506E-84	0.990140084	1.003908526
-2	-0.8				
2	2.7				
5	4.0				
28	27.5				
30	32.7				
54	56.0				
62	64.5				
80	84.5				
85	82.0				
119	119.0				
177	174.0				
240	234.0				
177	175.0				
119	121.5				
116	109.5				
109	115.5				
85	85.0				
80	82.5				
62	64.5				
58	57.0				
54	56.0				
30	32.0				
28	28.0				
5	5.0				
2	3.9				

Table VII.8a: The regression statistical analysis of the channel Fx in dorsi and plantarflexion combined with external and internal rotation about the longitudinal Y axis. The results show a good linearity: intercept ≈ zero (0.48), slope x1 ≈ one (0.99) and the r - square ≈ one (0.99).

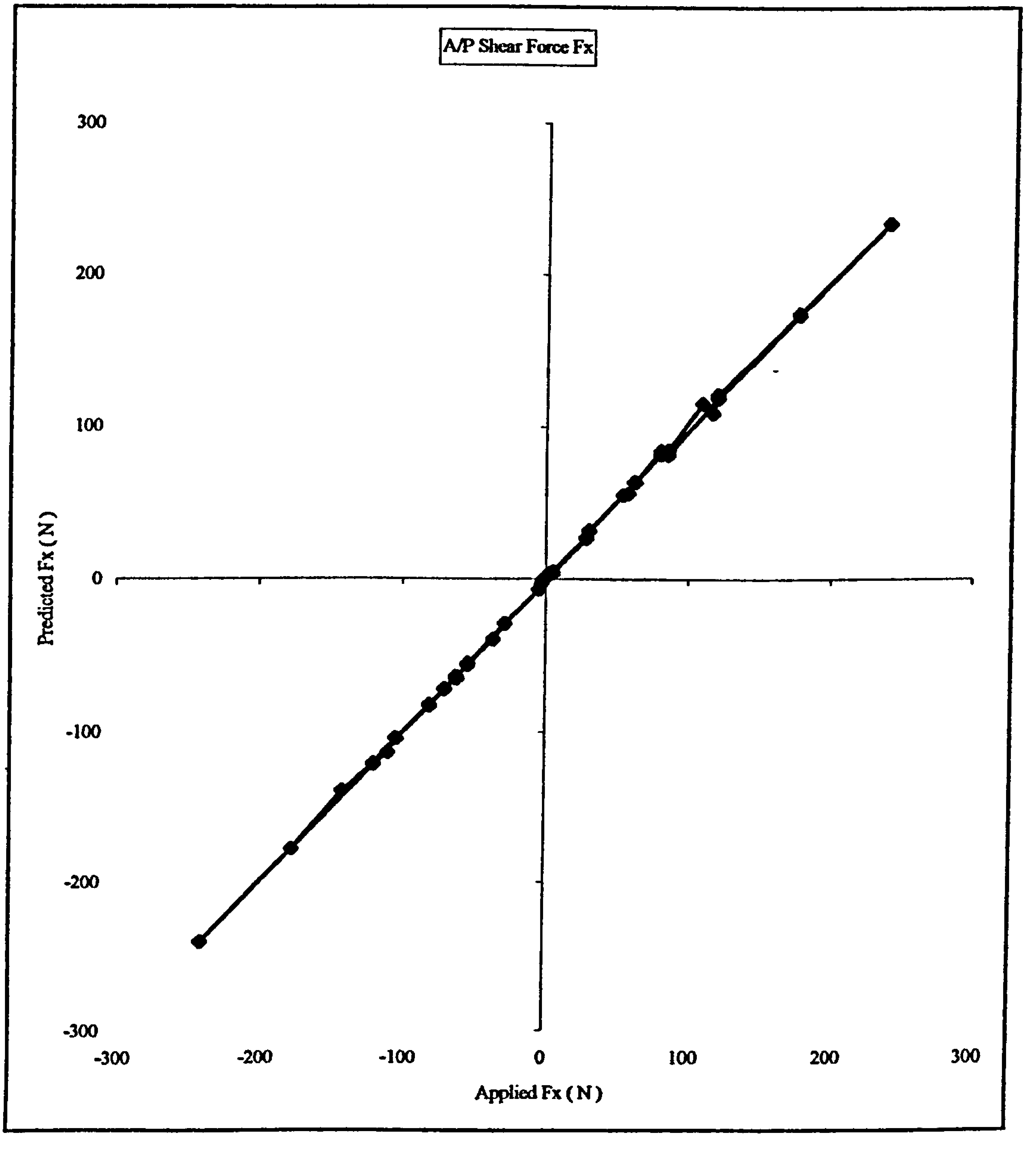


Figure VII.2a: Predicted versus Applied A/P shear force Fx with internal or external rotations about the longitudinal Y axis (from table VII.8a). Averaging two tests in plantar and dorsiflexion.

Fy		*Regression Statistics*			
Applied	Predicted				
6.0	0.65	Multiple R	0.993298362		
7.3	4.7	R Square	0.986641637		
7.4	6.8	Adjusted R Square	0.986338037		
7.4	6.6	Standard Error	12.72755631		
7.8	6.8	Observations	46		
74.2	73.6				
89.6	86.7	*Analysis of Variance*			
90.4	91.5		*df*	*Sum of Squares*	*Mean Square*
91.2	90.5	Regression	1	526440.0408	526440.0408
91.7	88.2	Residual	44	7127.590346	161.9906897
96.8	95.0	Total	45	533567.6311	
142.3	150.7				
172.0	167.8			*F*	*Significance F*
173.5	169.9			3249.816652	7.03251E-43
174.9	175.3				
175.9	180.7		*Coefficients*	*Standard Error*	*t Statistic*
185.8	183.6				
210.5	216.3	Intercept	-4.399475746	3.312482976	-1.328150447
254.3	265.0	x1	1.005181302	0.017632544	57.00716316
256.5	262.3				
258.7	260.4		*P-value*	*Lower 95%*	*Upper 95%*
260.1	268.9				
274.8	275.8		0.190825634	-11.07534628	2.276394788
351.0	351.5		1.32391E-43	0.969645246	1.040717357
352.9	368.7				
372.9	362.3				
348.1	344.1				
274.8	276.4				
260.1	269.7				
258.7	256.5				
256.5	254.5				
210.5	218.6				
185.8	173.7				
175.9	179.1				
174.9	175.2				
173.5	170.8				
142.3	144.1				
96.8	90.0				
91.7	89.3				
91.2	91.7				
90.4	88.5				
74.2	65.3				
7.8	6.3				
7.4	4.9				
7.4	8.5				
7.3	3.2				
6.0	1.3				

Table VII.8b: The regression statistical analysis of the channel Fy in combined dorsi and plantarflexion with external and internal rotation about the longitudinal Y axis. The results show a good linearity: intercept close to zero (-4.39), slope x1 ≈ one (1.005) and the r - square ≈ one (0.98).

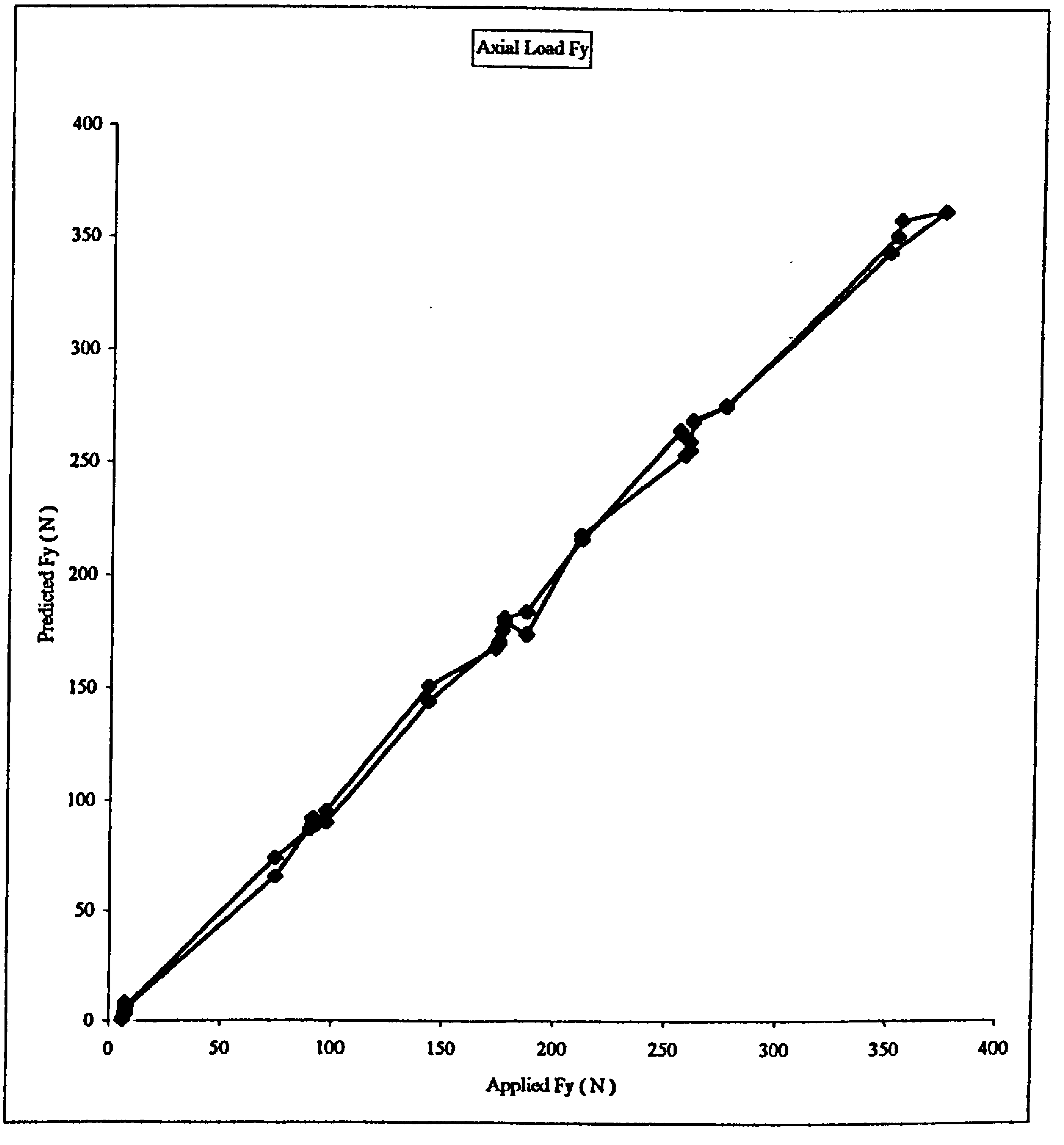


Figure VII.2b: Predicted versus Applied Axial Load Fy with internal or external rotations about the longitudinal Y axis (from table VII.8b). Averaging two tests in plantar and dorsiflexion. Probably due to the set up, the linearity was not so perfect as it could be expected and as it was found in other validation tests (see appendix 11.7)

Fz		*Regression Statistics*			
Applied	**Predicted**				
1.32	1.5	Multiple R	0.999443938		
1.33	1.06	R Square	0.998888185		
1.40	2.3	Adjusted R Square	0.998861714		
16.32	10.5	Standard Error	0.807992376		
16.41	11.58	Observations	44		
31.32	20.3				
33.29	22.6	*Analysis of Variance*			
46.31	29.3		*df*	*Sum of Squares*	*Mean Square*
46.57	31.21	Regression	1	24634.76026	24634.76026
62.85	40.3	Residual	42	27.41977056	0.65285168
63.20	42.19	Total	43	24662.18003	
49.23	33.7				
46.57	31.02			*F*	*Significance F*
46.31	30.2			37734.08419	1.13407E-63
33.29	22.9				
31.49	20.72				
31.32	20.0		*Coefficients*	*Standard Error*	*t Statistic*
17.35	12.2				
16.41	11.35	Intercept	-0.216383137	0.121830741	-1.776096366
16.32	12.3	x1	0.673484942	0.003467057	194.2526298
1.40	1.5				
1.33	1.03		*P-value*	*Lower 95%*	*Upper 95%*
1.32	1.3				
-1.32	-0.7		0.082793463	-0.462247604	0.029481331
-1.33	-1.06		6.19552E-65	0.666488135	0.680481748
-16.32	-11.84				
-16.41	-11.58				
-17.35	-11.8				
-31.32	-22.08				
-31.49	-21.17				
-46.31	-32.735				
-46.57	-31.21				
-62.85	-44.42				
-66.81	-45.1				
-63.2	-42.19				
-49.23	-33.2				
-46.57	-31.015				
-46.31	-32.48				
-31.49	-20.72				
-31.32	-22.21				
-16.41	-11.345				
-16.32	-11.15				
-1.33	-1.03				
-1.32	-0.915				

Table VII.8c: The regression statistical analysis of the channel Fz in combined dorsi and plantarflexion with external and internal rotation about the longitudinal Y axis. The results show a good linearity: intercept close to zero (-0.21), slope x1 far from one (0.67) and the r - square ≈ one (0.99). The 0.67 slope shows the bad ability of this particular channel to predict accurate values. This is why a correcting factor (see section 7.8.1) will be necessary.

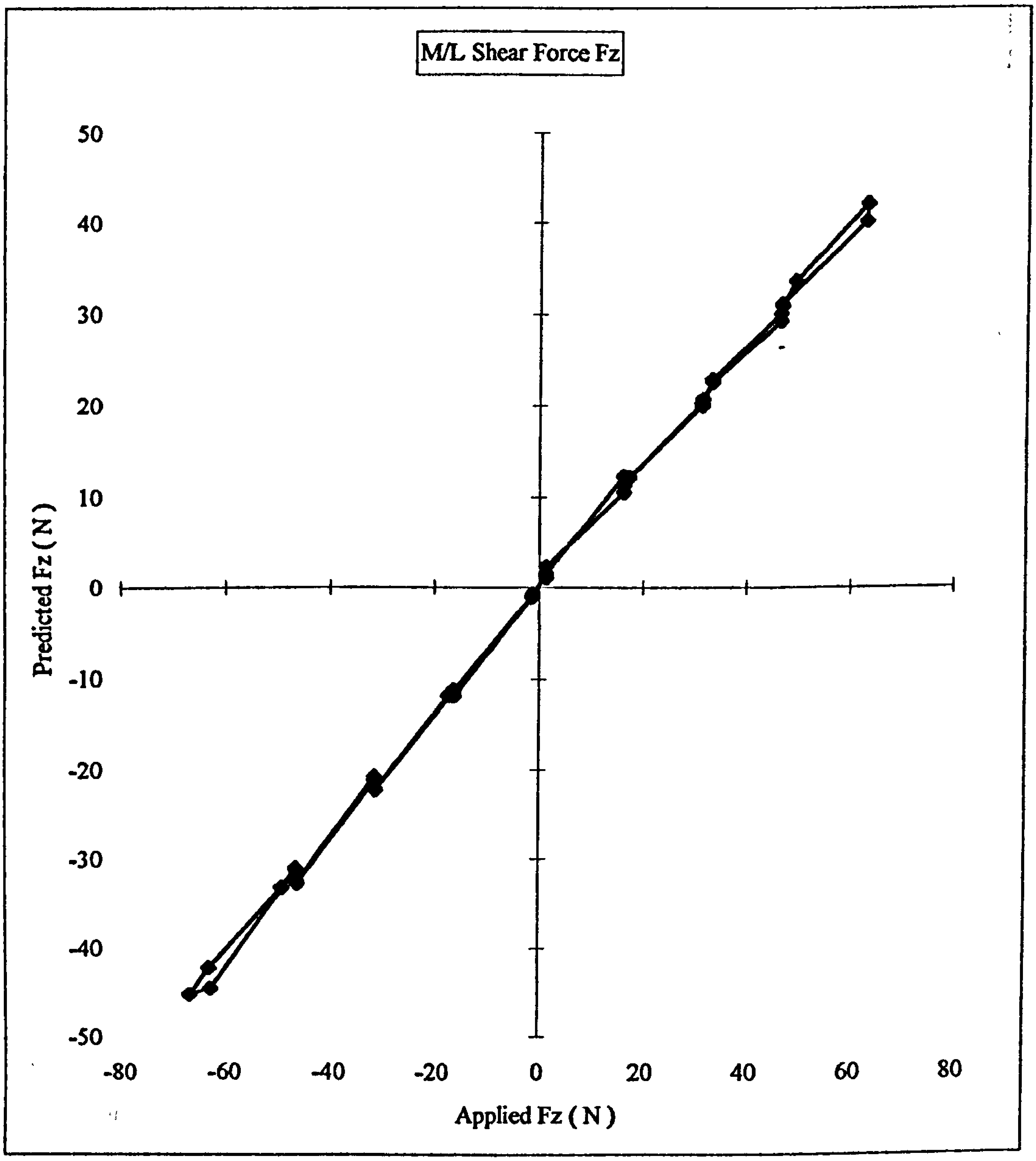


Figure VII.2c: Predicted versus Applied M/L shear force Fz with internal or external rotations about the longitudinal Y axis (from table VII.8c). Averaging two tests in plantar and dorsiflexion. The linearity is good but not the ability to predict the correct value.

Mx		Regression Statistics			
Applied	Predicted				
0.02	0.2	Multiple R	0.995450079		
0.09	0.41	R Square	0.990920859		
0.19	0.4	Adjusted R Square	0.990653825		
0.37	0.5	Standard Error	0.174617823		
0.55	0.5	Observations	36		
0.75	0.6				
1.11	1.40	*Analysis of Variance*			
2.14	2.41		*df*	*Sum of Squares*	*Mean Square*
3.16	3.39	Regression	1	113.1488818	113.1488818
4.29	4.54	Residual	34	1.036707063	0.030491384
3.16	3.43	Total	35	114.1855889	
2.14	2.43				
1.11	1.43			*F*	*Significance F*
0.55	0.5			3710.847664	2.64021E-36
0.37	0.4				
0.19	0.4		*Coefficients*	*Standard Error*	*t Statistic*
0.09	0.41				
0.02	0.3	Intercept	0.046528499	0.029113598	1.59817066
-0.01	-0.30	x1	1.074717485	0.017642404	60.91672729
-0.09	-0.01				
-0.14	-0.26		*P-value*	*Lower 95%*	*Upper 95%*
-0.27	-0.27				
-0.39	-0.27		0.118995141	-0.012637413	0.10569441
-0.53	-0.22		4.10011E-37	1.038863831	1.11057114
-1.07	-1.05				
-2.04	-2.15				
-3.02	-3.16				
-4.10	-4.41				
-3.02	-3.31				
-2.04	-2.21				
-1.07	-1.14				
-0.39	-0.22				
-0.27	-0.26				
-0.14	-0.29				
-0.09	-0.08				
-0.01	-0.50				

Table VII.8d: The regression statistical analysis of the channel Mx in dorsi and plantarflexion combined with external and internal rotation about the longitudinal Y axis. The results show a good linearity: intercept close to zero (0.02), slope x1 ≈ one (1.07) and the r - square ≈ one (0.99).

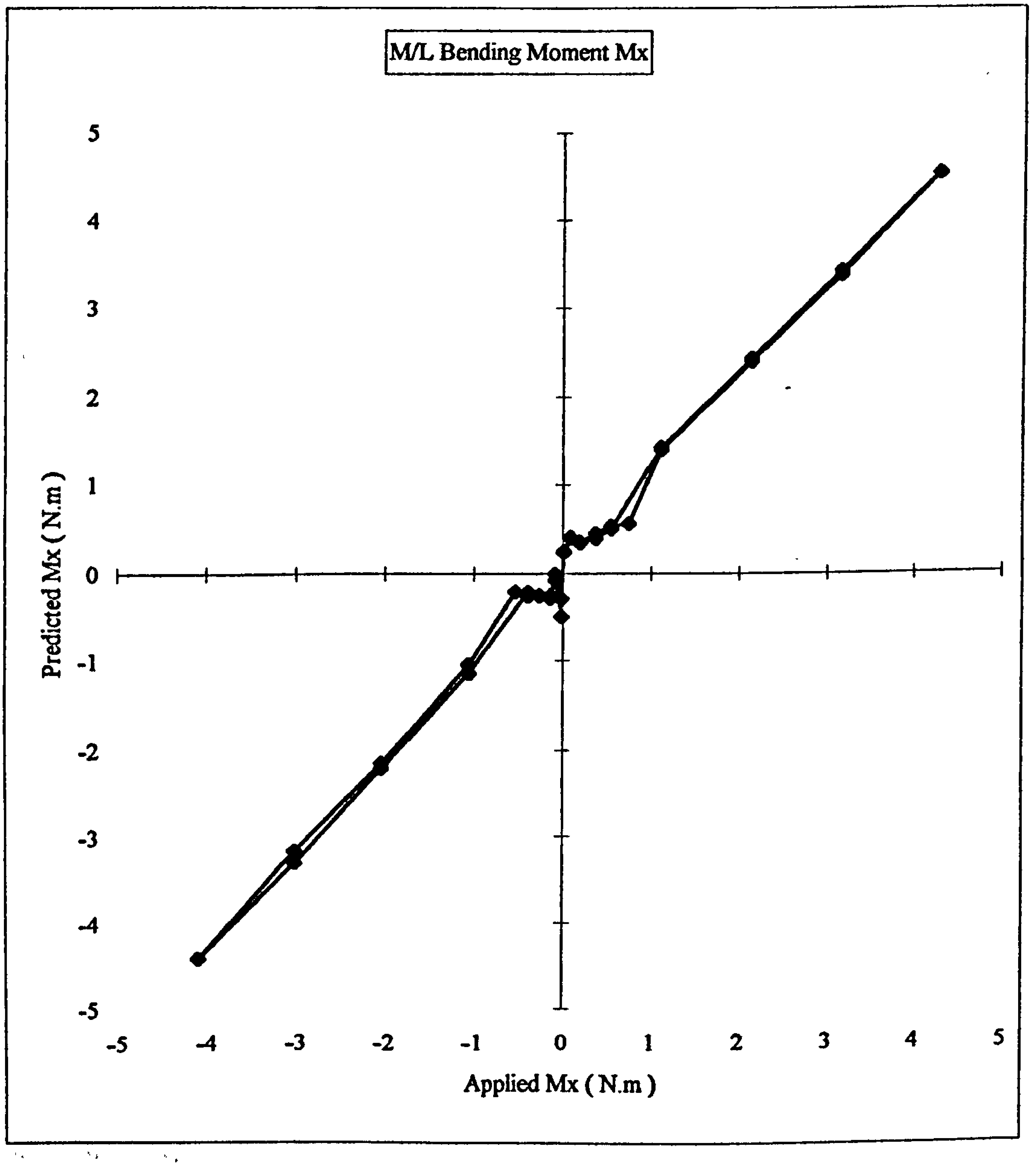


Figure VII.2d: Predicted versus Applied M/L bending moment Mx with internal or external rotations about the longitudinal Y axis (from table VII.8d). Averaging two tests in plantar and dorsiflexion. The linearity is good and it seems logic to have an inflexion of the trace when very low values are applied. In this range, the results must not be considered.

11.VII.3 Combined loads using the bench table with the Villiers Pylon Transducer used alone

Tables VII.9 and VII.10 show the static tests performed using the bench table described in section 7.4.1. The Villiers Pylon Transducer was used alone. It was a cantilever configuration.

Table VII.9 represents a dorsiflexion set up with the following position of the VPT:

$\Theta y = 42°$, it was an internal rotation about the longitudinal Y axis ; then the angle $\Theta y = -44°$, it was an external rotation about the same axis.

Because of the set up, the axial load channel Fy must not be considered.

Table VII.10 represents a plantarflexion set up with the same position of the VPT:

The columns are arranged as follows (from left to right): the loading weights, the applied loads in N or N.m, the predicted loads in N or N.m, the difference in N or N.m, the difference in percentage for each loading cases and a mean difference between applied and predicted in percentage for all the loading cases of the test. Two tests (internal and external rotations) are shown side by side.

The statistical analysis are shown in tables VII.11a (Fx), VII.11b (Fz), VII.11c (Mx and VII.11d (Mz). The graphs of the corresponding tables are shown in figures VII.3a (Fx), VII.3b (Fz), VII.3c (Mx) and VII.3d (Mz).

	Fx				Fx			
		Theta	Y = 42°	l = 0.337 m		Theta	Y = - 44°	l = 0.337 m
Loading	Dorsi	flexion	Internal	Rotation	Dorsi	flexion	External	Rotation
Weight	Applied	Predicted	difference	difference	Applied	Predicted	difference	difference
in N	in N	in N	in N	in %	in N	in N	in N	in %
0	0.0	-0.8	-0.8	n.s.	0.0	-0.9	-0.9	n.s.
9.32	-6.9	-6.8	0.1	-1.8	-6.7	-6.6	0.1	-1.6
58.37	-43.4	-36.4	7.0	-16.1	-42.0	-36.1	5.9	-14.0
107.42	-79.8	-58.8	21.0	-26.3	-77.3	-59.4	17.9	-23.1
156.47	-116.3	-82.2	34.1	-29.3	-112.6	-84.2	28.4	-25.2
205.52	-152.7	-106.4	46.3	-30.3	-147.8	-107.2	40.6	-27.5
156.47	-116.3	-78.8	37.5	-32.2	-112.6	-82.4	30.2	-26.8
107.42	-79.8	-53.2	26.6	-33.4	-77.3	-52.6	24.7	-31.9
58.37	-43.4	-29.2	14.2	-32.7	-42.0	-28.6	13.4	-32.0
9.32	-6.9	-5.2	1.7	-24.9	-6.7	-6.4	0.3	-4.5
0	0.0	-1.3	-1.3	n.s.	0.0	-1.1	-1.1	n.s.
			mean %	-25.2			mean %	-20.7
	Fy				Fy			
Loading	Dorsi	flexion	Internal	Rotation	Dorsi	flexion	External	Rotation
Weight	Applied	Predicted	difference	difference	Applied	Predicted	difference	difference
in N	in N	in N	in N	in %	in N	in N	in N	in %
			mean %	0.0			mean %	0.0
	Fz				Fz			
Loading	Dorsi	flexion	Internal	Rotation	Dorsi	flexion	External	Rotation
Weight	Applied	Predicted	difference	difference	Applied	Predicted	difference	difference
in N	in N	in N	in N	in %	in N	in N	in N	in %
0	0.00	0.03	0.0	n.s.	0.00	-0.02	0.0	n.s.
9.32	6.22	4.10	-2.1	-34.0	-6.47	-4.80	1.7	-25.9
58.37	38.93	29.70	-9.2	-23.7	-40.55	-31.50	9.0	-22.3
107.42	71.64	55.30	-16.3	-22.8	-74.62	-58.30	16.3	-21.9
156.47	104.35	83.46	-20.9	-20.0	-108.69	-84.90	23.8	-21.9
205.52	137.06	113.90	-23.2	-16.9	-142.77	-114.30	28.5	-19.9
156.47	104.35	83.10	-21.3	-20.4	-108.69	-84.10	24.6	-22.6
107.42	71.64	53.07	-18.6	-25.9	-74.62	-56.20	18.4	-24.7
58.37	38.93	24.59	-14.3	-36.8	-40.55	-27.80	12.7	-31.4
9.32	6.22	4.70	-1.5	-24.4	-6.47	-5.24	1.2	-19.1
0	0.00	0.06	0.1	n.s.	0.00	-0.12	-0.1	n.s.
			mean %	-25.0			mean %	-23.3

Table VII.9a : The three forces recorded during a static test using the bench table in dorsiflexion (cantilever set-up) with internal (Θy = 42°) then external position (Θy = -44°) of the VPT about its longitudinal Y axis. Fy is working in tension and thus it must not be considered.

	Mx				Mx			
Loading	Dorsi	flexion	Internal	Rotation	Dorsi	flexion	External	Rotation
Weight	Applied	Predicted	difference	difference	Applied	Predicted	difference	difference
in N	in N.m	in N.m	in N.m	in %	in N.m	in N.m	in N.m	in %
0	0.00	0.11	0.1	n.s.	0.00	-0.20	-0.2	n.s.
9.32	2.10	2.03	-0.1	-3.4	-2.18	-2.15	0.0	-1.5
58.37	13.16	12.78	-0.4	-2.9	-13.66	-13.22	0.4	-3.3
107.42	24.22	23.61	-0.6	-2.5	-25.15	-24.97	0.2	-0.7
156.47	35.28	34.29	-1.0	-2.8	-36.63	-35.12	1.5	-4.1
205.52	46.34	44.96	-1.4	-3.0	-48.11	-47.09	1.0	-2.1
156.47	35.28	34.37	-0.9	-2.6	-36.63	-35.26	1.4	-3.7
107.42	24.22	23.67	-0.6	-2.3	-25.15	-25.08	0.1	-0.3
58.37	13.16	12.87	-0.3	-2.2	-13.66	-13.41	0.3	-1.9
9.32	2.10	2.05	-0.1	-2.5	-2.18	-2.17	0.0	-0.5
0	0.00	0.28	0.3	n.s.	0.00	0.11	0.1	n.s.
			mean %	**-2.7**			**mean %**	**-2.0**
	My				**My**			
Loading	**Dorsi**	**flexion**	**Internal**	**Rotation**	**Dorsi**	**flexion**	**External**	**Rotation**
Weight	Applied	Predicted	difference	difference	Applied	Predicted	difference	difference
in N	in N.m	in N.m	in N.m	in %	in N.m	in N.m	in N.m	in %
0	0.0	0.04	0.04		0.0	0.02	0.02	
9.32	0.0	0.02	0.02		0.0	0.06	0.06	
58.37	0.0	-0.08	-0.08		0.0	0.04	0.04	
107.42	0.0	-0.24	-0.24		0.0	0.05	0.05	
156.47	0.0	-0.32	-0.32		0.0	-0.01	-0.01	
205.52	0.0	-0.50	-0.50		0.0	-0.06	-0.06	
156.47	0.0	-0.40	-0.40		0.0	0.00	0.00	
107.42	0.0	-0.37	-0.37		0.0	0.03	0.03	
58.37	0.0	-0.09	-0.09		0.0	-0.07	-0.07	
9.32	0.0	-0.01	-0.01		0.0	-0.08	-0.08	
0	0.0	0.04	0.04		0.0	0.02	0.02	
	Mz				**Mz**			
Loading	**Dorsi**	**flexion**	**Internal**	**Rotation**	**Dorsi**	**flexion**	**External**	**Rotation**
Weight	Applied	Predicted	difference	difference	Applied	Predicted	difference	difference
in N	in N.m	in N.m	in N.m	in %	in N.m	in N.m	in N.m	in %
0	0.00	0.23	0.2	n.s.	0.00	0.21	0.2	n.s.
9.32	2.33	2.34	0.0	0.3	2.26	2.11	-0.1	-6.6
58.37	14.62	14.20	-0.4	-2.9	14.15	13.88	-0.3	-1.9
107.42	26.90	26.12	-0.8	-2.9	26.04	25.11	-0.9	-3.6
156.47	39.19	38.04	-1.1	-2.9	37.93	37.06	-0.9	-2.3
205.52	51.47	50.08	-1.4	-2.7	49.82	48.98	-0.8	-1.7
156.47	39.19	38.20	-1.0	-2.5	37.93	37.23	-0.7	-1.8
107.42	26.90	26.29	-0.6	-2.3	26.04	25.49	-0.6	-2.1
58.37	14.62	14.50	-0.1	-0.8	14.15	13.97	-0.2	-1.3
9.32	2.33	2.38	0.0	2.0	2.26	2.19	-0.1	-3.1
0	0.00	0.29	0.3	n.s.	0.00	0.27	0.3	n.s.
			mean %	**-1.6**			**mean %**	**-2.7**

Table VII.9b: The three moments recorded during a static test using the bench table in dorsiflexion (cantilever set-up) with internal ($\Theta y = 42°$) then external position ($\Theta y = - 44°$) of the VPT about its longitudinal Y axis.

	Fx				Fx			
		Theta	Y = 42°	l = 0.271 m		Theta	Y = - 44°	l = 0.271 m
Loading	Plantar	flexion	Internal	Rotation	Plantar	flexion	External	Rotation
Weight	Applied	Predicted	difference	difference	Applied	Predicted	difference	difference
in N	in N	in N	in N	in %	in N	in N	in N	in %
0	0.0	0.3	0.3	n.s.	0.0	0.7	0.7	n.s.
9.32	6.9	6	-0.9	-13.4	6.7	13.8	7.1	-105.8
58.37	43.4	39.2	-4.2	-9.6	42.0	83.1	41.1	-97.9
107.42	79.8	72.7	-7.1	-8.9	77.3	154.5	77.2	-99.9
156.47	116.3	107.1	-9.2	-7.9	112.6	227.1	114.5	-101.8
205.52	152.7	139.1	-13.6	-8.9	147.8	301.6	153.8	-104.0
156.47	116.3	103.7	-12.6	-10.8	112.6	223.2	110.6	-98.3
107.42	79.8	67.3	-12.5	-15.7	77.3	148.5	71.2	-92.2
58.37	43.4	33.4	-10.0	-23.0	42.0	79.4	37.4	-89.1
9.32	6.9	6.2	-0.7	-10.5	6.7	10.4	3.7	-55.1
0	0.0	0.5	0.5	n.s.	0.0	0.9	0.9	n.s.
			mean %	-12.1			mean %	-93.8
	Fy				Fy			
Loading	Plantar	flexion	Internal	Rotation	Plantar	flexion	External	Rotation
Weight	Applied	Predicted	difference	difference	Applied	Predicted	difference	difference
in N	in N	in N	in N	in %	in N	in N -	in N	in %
0								
9.32								
58.37								
107.42								
156.47								
205.52								
156.47								
107.42								
58.37								
9.32								
0								
			mean %	0.0			mean %	0.0
	Fz				Fz			
Loading	Plantar	flexion	Internal	Rotation	Plantar	flexion	External	Rotation
Weight	Applied	Predicted	difference	difference	Applied	Predicted	difference	difference
in N	in N	in N	in N	in %	in N	in N	in N	in %
0	0.00	0.36	0.4	n.s.	0.00	0.24	0.2	n.s.
9.32	-6.24	-4.45	-1.8	-28.6	6.47	4.85	-1.6	-25.1
58.37	-39.06	-27.56	-11.5	-29.4	40.55	33.50	-7.0	-17.4
107.42	-71.88	-50.78	-21.1	-29.4	74.62	62.43	-12.2	-16.3
156.47	-104.70	-72.29	-32.4	-31.0	108.69	91.34	-17.4	-16.0
205.52	-137.52	-93.49	-44.0	-32.0	142.77	122.44	-20.3	-14.2
156.47	-104.70	-71.40	-33.3	-31.8	108.69	90.18	-18.5	-17.0
107.42	-71.88	-48.76	-23.1	-32.2	74.62	59.55	-15.1	-20.2
58.37	-39.06	-25.99	-13.1	-33.5	40.55	30.88	-9.7	-23.8
9.32	-6.24	-5.02	-1.2	-19.5	6.47	3.38	-3.1	-47.8
0	0.00	0.02	0.0	n.s.	0.00	0.52	0.5	n.s.
			mean %	-29.7			mean %	-22.0

Table VII.10a : The three forces recorded during a static test using the bench table in plantarflexion (cantilever set-up) with internal ($\Theta y = 42°$) then external position ($\Theta y = - 44°$) of the VPT about its longitudinal Y axis. Fy is working in tension and thus it must not be considered.

	Mx				**Mx**			
Loading	**Plantar**	**flexion**	**Internal**	**Rotation**	**Plantar**	**flexion**	**External**	**Rotation**
Weight	Applied	Predicted	difference	difference	Applied	Predicted	difference	difference
in N	in N.m	in N.m	in N.m	in %	in N.m	in N.m	in N.m	in %
0	0.00	0.1	-0.1	n.s.	0.00	-0.08	-0.1	n.s.
9.32	1.69	1.45	0.2	-14.2	-1.75	-1.67	0.1	-4.8
58.37	10.58	10.39	0.2	-1.8	-10.99	-10.58	0.4	-3.7
107.42	19.48	19.24	0.2	-1.2	-20.22	-19.61	0.6	-3.0
156.47	28.37	28.07	0.3	-1.1	-29.46	-28.46	1.0	-3.4
205.52	37.27	36.85	0.4	-1.1	-38.69	-37.32	1.4	-3.5
156.47	28.37	28.17	0.2	-0.7	-29.46	-28.47	1.0	-3.3
107.42	19.48	19.3	0.2	-0.9	-20.22	-19.64	0.6	-2.9
58.37	10.58	10.4	0.2	-1.7	-10.99	-10.69	0.3	-2.7
9.32	1.69	0.75	0.9	-55.6	-1.75	-1.61	0.1	-8.2
0	0.00	0.84	-0.8	n.s.	0.00	-0.09	-0.1	n.s.
			mean %	**-8.7**			**mean %**	**-4.0**
	My				**My**			
Loading	**Plantar**	**flexion**	**Internal**	**Rotation**	**Plantar**	**flexion**	**External**	**Rotation**
Weight	Applied	Predicted	difference	difference	Applied	Predicted	difference	difference
in N	in N.m	in N.m	in N.m	in %	in N.m	in N.m	in N.m	in %
0	0.0	0.04	0.04		0.0	0.03	0.03	
9.32	0.0	0.05	0.05		0.0	0.05	0.05	
58.37	0.0	0.03	0.03		0.0	0.06	0.06	
107.42	0.0	0.10	0.10		0.0	0.15	0.15	
156.47	0.0	0.12	0.12		0.0	0.31	0.31	
205.52	0.0	0.24	0.24		0.0	0.32	0.32	
156.47	0.0	0.19	0.19		0.0	0.17	0.17	
107.42	0.0	0.06	0.06		0.0	0.11	0.11	
58.37	0.0	0.07	0.07		0.0	0.10	0.10	
9.32	0.0	0.05	0.05		0.0	0.03	0.03	
0	0.0	0.02	0.02		0.0	0.02	0.02	
	Mz				**Mz**			
Loading	**Plantar**	**flexion**	**Internal**	**Rotation**	**Plantar**	**flexion**	**External**	**Rotation**
Weight	Applied	Predicted	difference	difference	Applied	Predicted	difference	difference
in N	in N.m	in N.m	in N.m	in %	in N.m	in N.m	in N.m	in %
0	0.00	-0.08	0.1	n.s.	0.00	-0.06	-0.06	n.s.
9.32	-1.88	-1.74	-0.1	-7.3	-1.82	-1.52	0.30	-16.34
58.37	-11.76	-11.27	-0.5	-4.1	-11.38	-10.41	0.97	-8.51
107.42	-21.63	-20.67	-1.0	-4.5	-20.94	-19.27	1.67	-7.98
156.47	-31.51	-30.17	-1.3	-4.3	-30.50	-28.12	2.38	-7.81
205.52	-41.39	-39.58	-1.8	-4.4	-40.06	-36.95	3.11	-7.77
156.47	-31.51	-30.32	-1.2	-3.8	-30.50	-28.16	2.34	-7.68
107.42	-21.63	-20.84	-0.8	-3.7	-20.94	-19.45	1.49	-7.12
58.37	-11.76	-11.33	-0.4	-3.6	-11.38	-10.56	0.82	-7.20
9.32	-1.88	-1.92	0.0	2.3	-1.82	-1.56	0.26	-14.14
0	0.00	-0.11	0.1	n.s.	0.00	-0.09	-0.09	n.s.
			mean %	**-3.70**			**mean %**	**-9.39**

Table VII.10b: The three moments recorded during a static test using the bench table in plantarflexion (cantilever set-up) with internal ($\Theta y = 42°$) then external position ($\Theta y = -44°$) of the VPT about its longitudinal Y axis.

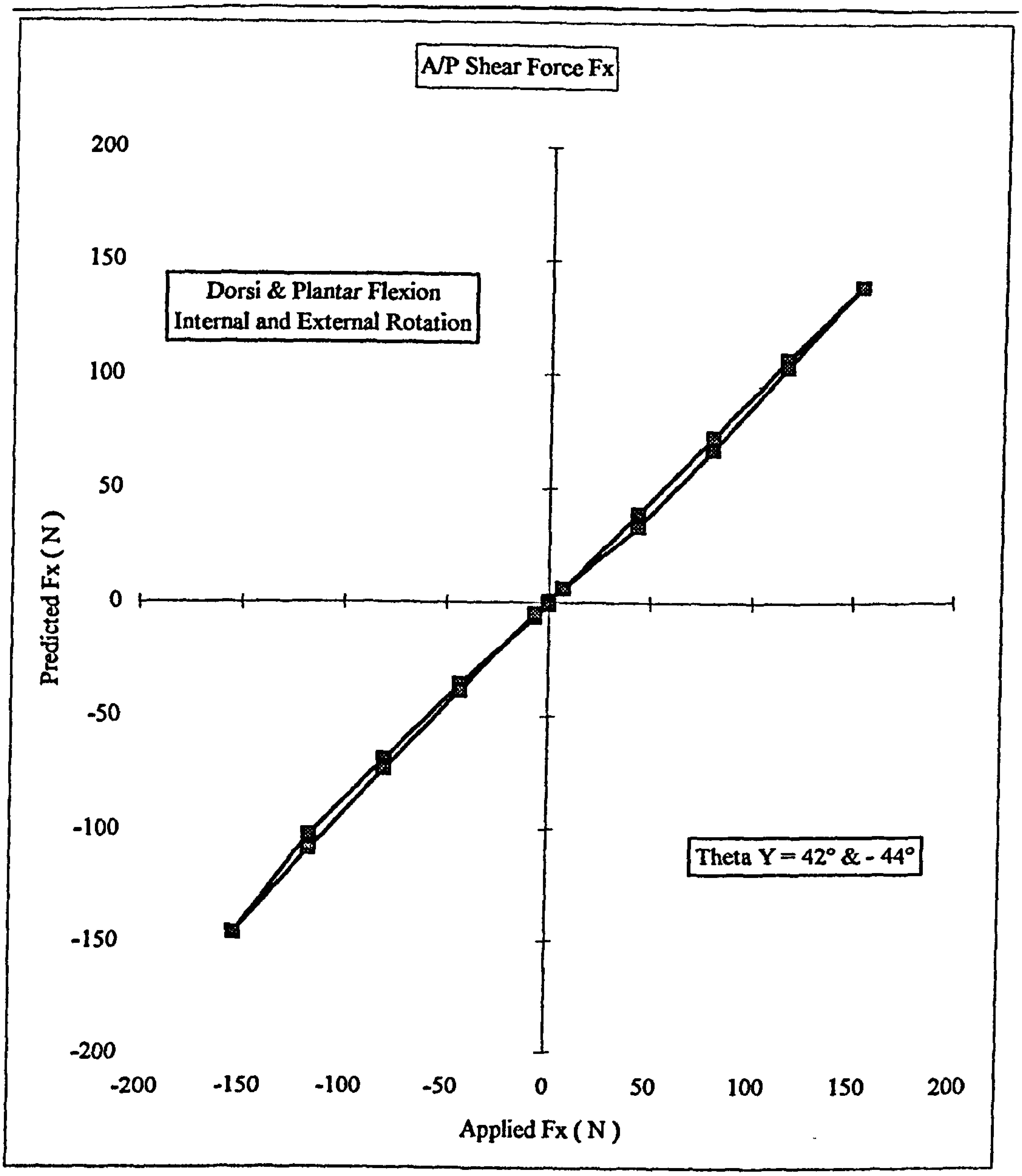


Figure VII.3a: Predicted versus Applied A/P shear force Fx with internal or external rotations about the longitudinal Y axis (from table VII.11a). One test in plantar and dorsiflexion. The linearity is good and it seems logic to have an inflexion of the trace when very low values are applied. In this range, the results must not be considered.

Fx		Dorsi & Plantarflexion		Internal	Rotation
Applied	Predicted			External	Rotation
0	0	*Regression Statistics*			
7	6				
43	39	Multiple R	0.99923778		
80	73	R Square	0.99847614		
116	107	Adjusted R Square	0.99839995		
153	139	Standard Error	3.19464919		
116	104	Observations	22		
80	67				
43	33	*Analysis of Variance*			
7	6		*df*	*Sum of Squares*	*Mean Square*
0	1	Regression	1	133742.2095	133742.2095
0	-1	Residual	20	204.1156689	10.20578344
-7	-7	Total	21	133946.3252	
-43	-36				
-80	-69			*F*	*Significance F*
-116	-102			13104.55099	1.19057E-29
-153	-146				
-116	-109		*Coefficients*	*Standard Error*	*t Statistic*
-80	-73				
-43	-39	Intercept	0.6790195	0.681127324	0.996905393
-7	-5	x1	1.0984139	0.00959522	114.4751108
0	-1				
			P-value	*Lower 95%*	*Upper 95%*
			0.3301596	-0.741786538	2.099825543
			7.5692E-31	1.078398632	1.118429171

Table VII.11a: The regression statistical analysis of the channel Fx in dorsi and plantarflexion combined with internal and external rotation about the longitudinal Y axis. The results show a good linearity: intercept close to zero (0.6), slope x1 ≈ one (1.09) and the r - square ≈ one (0.99).

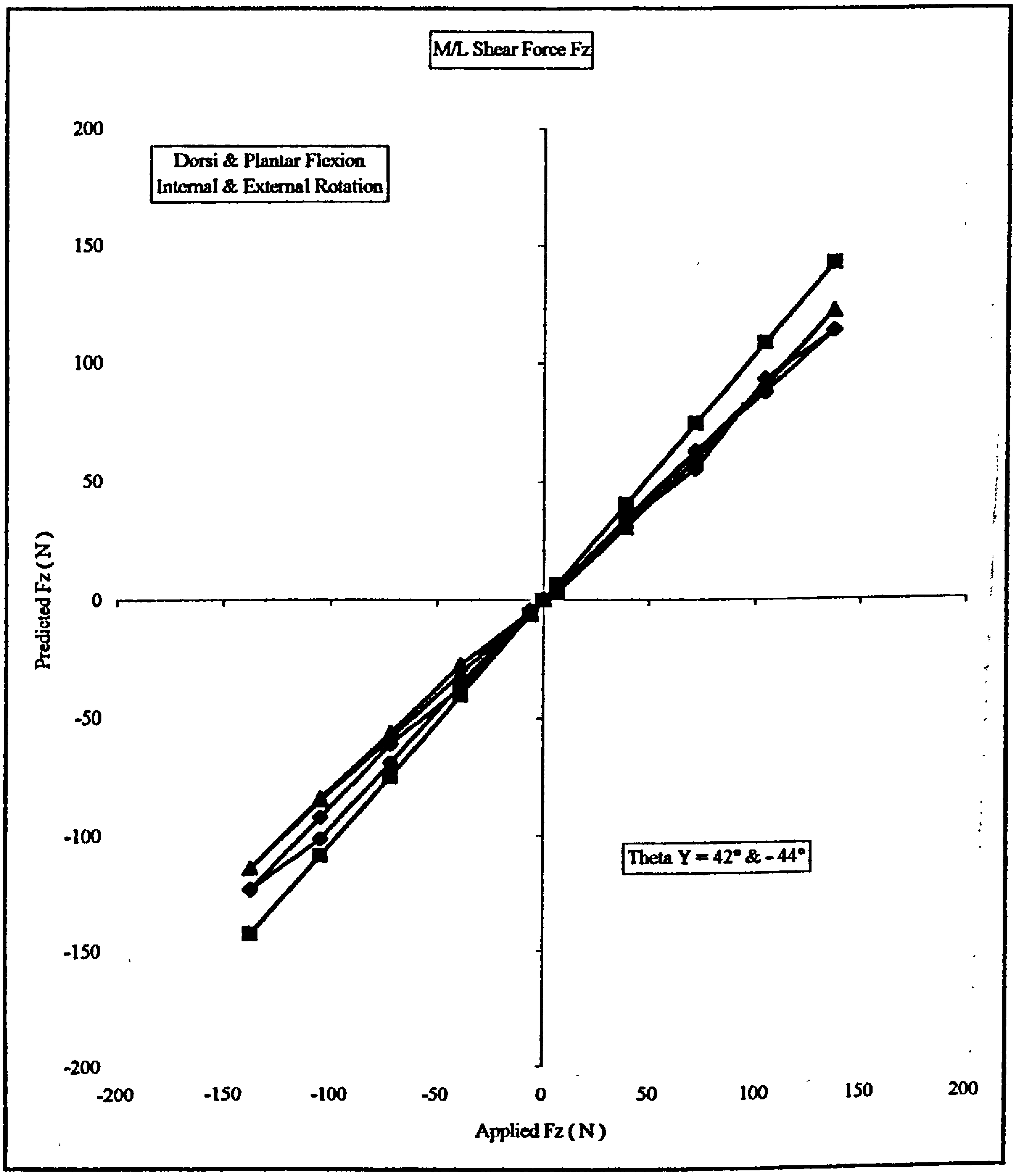


Figure VII.3b: Predicted versus Applied M/L shear force Fz with internal or external rotations about the longitudinal Y axis (from table VII.11b). Three tests in plantar and dorsiflexion. The linearity is good but the ability of this particular channel to predict accurate values is not as it could be expected. Therefore, applying a correcting factor will be necessary.

Fz		Dorsi & Plantarflexion		Internal	Rotation
Applied	Predicted			External	Rotation
0	0	*Regression Statistics*			
-6	-4				
-39	-38	Multiple R	0.99877292		
-72	-61	R Square	0.99754735		
-105	-92	Adjusted R Square	0.99742472		
-138	-123	Standard Error	3.64322047		
-105	-101	Observations	22		
-72	-69				
-39	-36	*Analysis of Variance*			
-6	-5		*df*	*Sum of Squares*	*Mean Square*
0	0	Regression	1	107969.0404	107969.0404
0	0	Residual	20	265.4611075	13.27305537
6	4	Total	21	108234.5015	
39	34				
72	55			*F*	*Significance F*
104	93			8134.452642	1.38943E-27
137	114				
104	88		*Coefficients*	*Standard Error*	*t Statistic*
72	63				
39	35	Intercept	1.88835942	0.777046115	2.430176773
6	5	x1	1.13351355	0.012567895	90.19120047
0	0				
			P-value	*Lower 95%*	*Upper 95%*
			0.02414301	0.26747038	3.50924846
			1.1201E-28	1.107297391	1.159729706

Table VII.11b: The regression statistical analysis of the channel Fz in dorsi and plantarflexion combined with internal and external rotation about the longitudinal Y axis. The results show a good linearity: intercept with a small value (1.88), slope x1 far from one (1.13) and the r - square ≈ one (0.99).

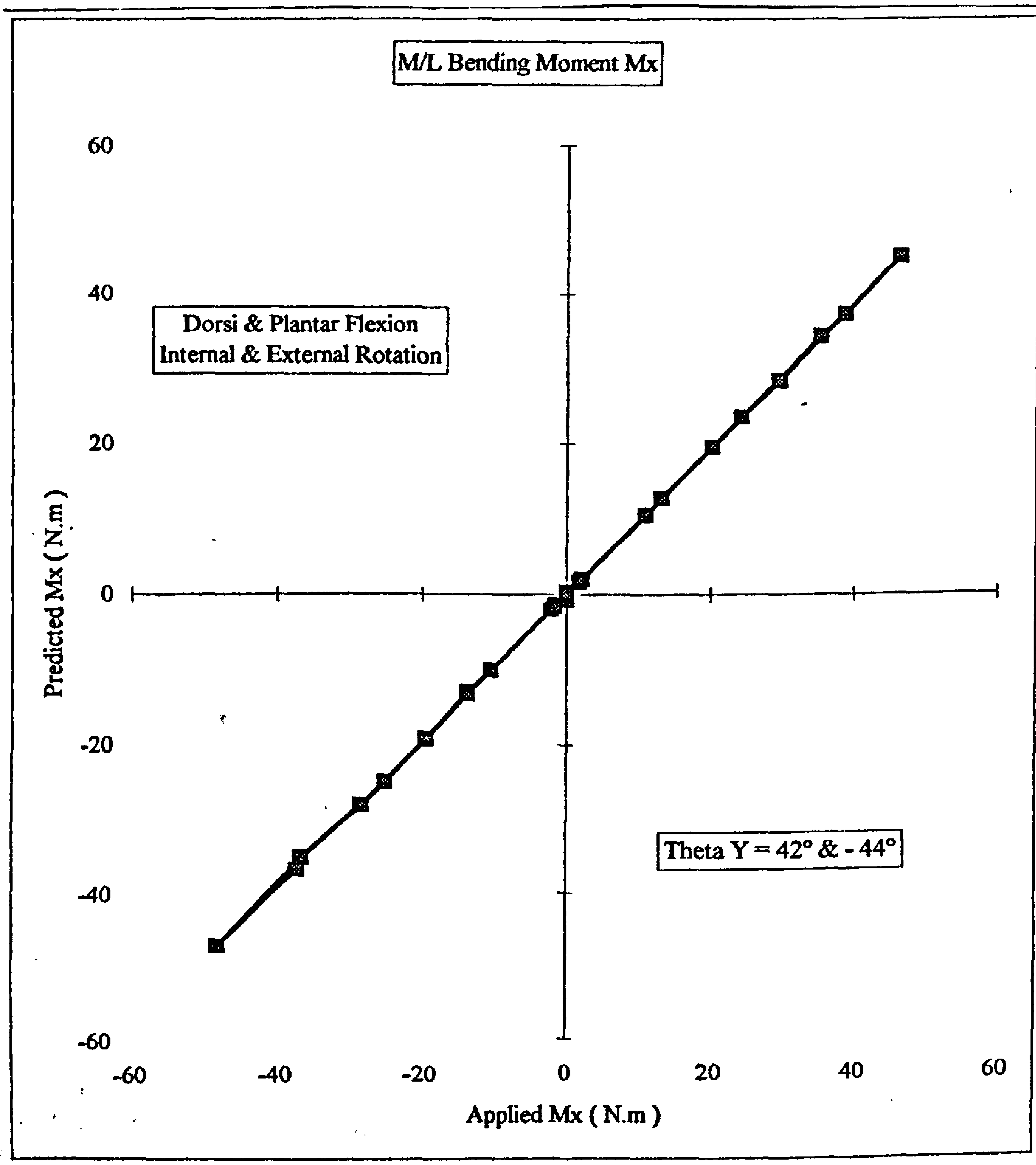


Figure VII.3c: Predicted versus Applied M/L bending moment Mx with internal or external rotations about the longitudinal Y axis (from table VII.11c). One test in plantar and dorsiflexion. The linearity is good and the ability of this particular channel to predict accurate values is as it could be expected. Therefore, applying a correcting factor close to the unity will be sufficient.

Mx		Dorsi & Plantarflexion	Internal		
Applied	**Predicted**		**External**	**Rotation**	
0	0	*Regression Statistics*			
0	0				
-2	-1	Multiple R	0.999927591		
-2	-2	R Square	0.999855188		
-11	-10	Adjusted R Square	0.99985174		
-14	-13	Standard Error	0.26		
-19	-19	Observations	44		
-25	-25				
-28	-28	*Analysis of Variance*			
-37	-35		*df*	*Sum of Squares*	*Mean Square*
-37	-37	Regression	1	20059.82284	20059.82284
-48	-47	Residual	42.00	2.91	0.069174477
-37	-35	Total	43.00	20062.73	
-28	-28				
-25	-25			*F*	*Significance F*
-19	-19			289988.789	2.91521E-82
-14	-13				
-11	-10		*Coefficients*	*Standard Error*	*t Statistic*
-2	-2				
-2	-2	Intercept	-0.096656178	0.039650357	-2.437712669
0	-1	x1	0.9750939	0.001810739	538.5060715
0	0				
0	0		*P-value*	*Lower 95%*	*Upper 95%*
0	0				
2	2		0.01898947	-0.176673864	-0.016638492
2	2		5.75047E-84	0.97143968	0.97874812
11	11				
13	13				
20	20				
24	24				
29	28				
35	34				
39	37				
46	45				
29	28				
35	34				
24	24				
20	20				
13	13				
11	11				
2	2				
2	2				
0	0				
0	0				

Table VII.11c: The regression statistical analysis of the channel Mx in dorsi and plantarflexion combined with internal and external rotation about the longitudinal Y axis. The results show a good linearity: intercept close to zero (-0.09), slope x1 close to one (0.97) and the r - square ≈ one (0.999).

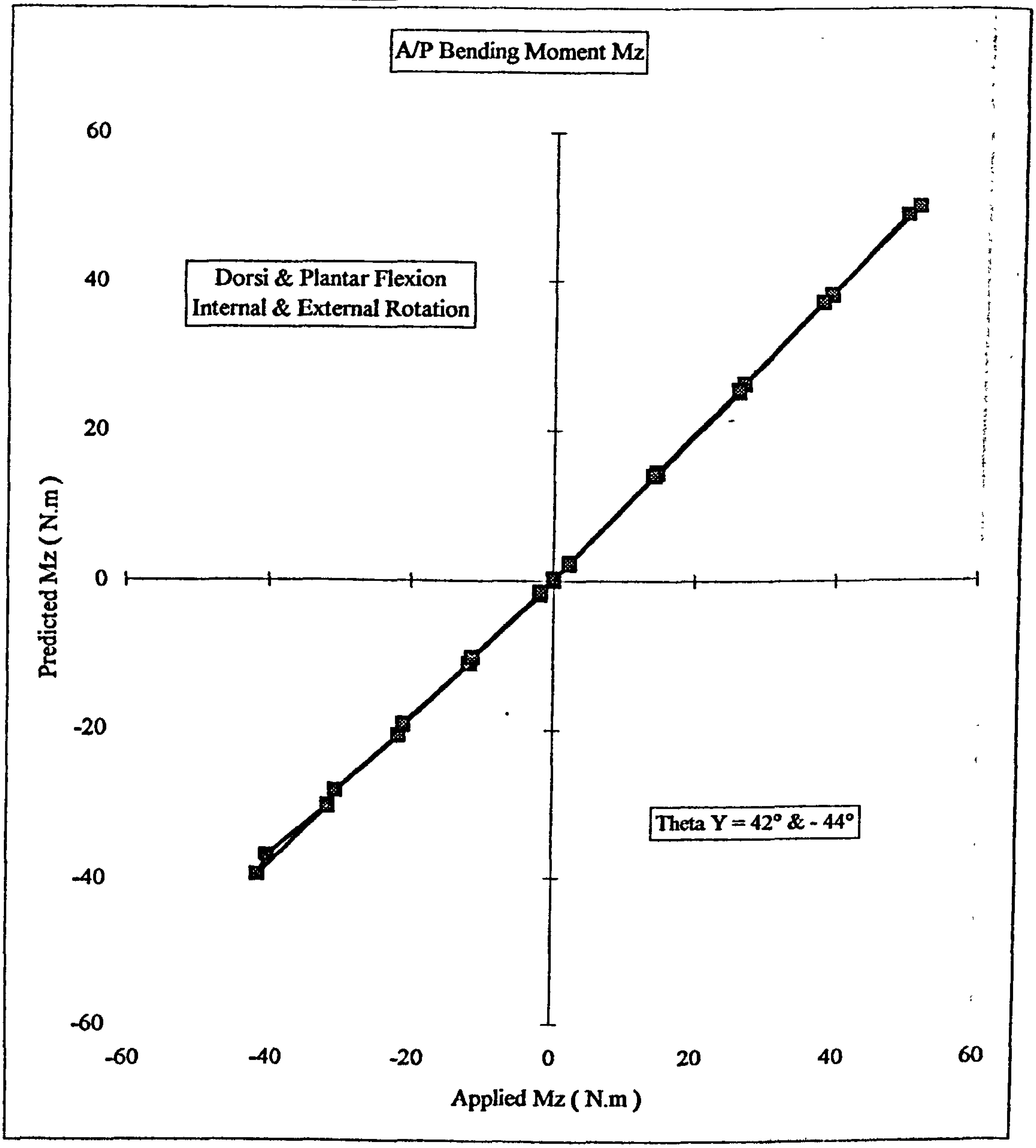


Figure VII.3d: Predicted versus Applied A/P bending moment Mz with internal or external rotations about the longitudinal Y axis (from table VII.11d). One test in plantar and dorsiflexion. The linearity is good and the ability of this particular channel to predict accurate values is as it could be expected. Therefore, applying a correcting factor close to the unity will be sufficient.

Mz		Dorsi & Plantarflexion	Internal		
Applied	Predicted		External	Rotation	
0.00	-0.06	*Regression Statistics*			
0.00	-0.08				
-1.82	-1.52	Multiple R	0.999854948		
-1.88	-1.74	R Square	0.999709917		
-11.38	-10.41	Adjusted R Square	0.99970301		
-11.76	-11.27	Standard Error	0.392320948		
-20.94	-19.27	Observations	44		
-21.63	-20.67				
-30.50	-28.12	*Analysis of Variance*			
-31.51	-30.17		*df*	*Sum of Squares*	*Mean Square*
-40.06	-36.95	Regression	1	22278.39998	22278.39998
-41.39	-39.58	Residual	42	6.464460489	0.153915726
-31.51	-30.32	Total	43	22284.86444	
-30.50	-28.16				
-21.63	-20.84			*F*	*Significance F*
-20.94	-19.45			144744.1439	6.32061E-76
-11.76	-11.33				
-11.38	-10.56		*Coefficients*	*Standard Error*	*t Statistic*
-1.88	-1.92				
-1.82	-1.56	Intercept	0.326649828	0.059340352	5.504683014
0.00	-0.11	x1	0.961465624	0.002527163	380.4525515
0.00	-0.09				
0.00	0.21		*P-value*	*Lower 95%*	*Upper 95%*
0.00	0.23				
2.26	2.11		1.91141E-06	0.206896111	0.446403544
2.33	2.34		1.76449E-77	0.956365601	0.966565647
14.15	13.88				
14.62	14.20				
26.04	25.11				
26.90	26.12				
37.93	37.06				
39.19	38.04				
49.82	48.98				
51.47	50.08				
39.19	38.20				
37.93	37.23				
26.90	26.29				
26.04	25.49				
14.62	14.50				
14.15	13.97				
2.33	2.38				
2.26	2.19				
0.00	0.29				
0.00	0.27				

Table VII.11d: The regression statistical analysis of the channel Mz in dorsi and plantarflexion combined with internal and external rotation about the longitudinal Y axis. The results show a good linearity: intercept close to zero (0.32), slope x1 close to one (0.96) and the r - square ≈ one (0.999).

		Torque	Negative			Torque	Positive	
				l = 0.1 m				l = 0.1 m
Loading	Fx				Fx			
Weight	Applied	Predicted	difference	difference	Applied	Predicted	difference	difference
in N	in N	in N	in N	in %	in N	in N	in N	in %
0.0	0.0	0.0	0.0	n.s.	0.0	-0.1	-0.1	n.s.
17.7	0.0	0.0	0.0	n.s.	0.0	1.7	1.7	n.s.
116.0	0.0	-0.6	-0.6	n.s.	0.0	0	0.0	n.s.
214.1	0.0	-0.6	-0.6	n.s.	0.0	-0.5	-0.5	n.s.
116.0	0.0	0.3	0.3	n.s.	0.0	2.5	2.5	n.s.
17.7	0.0	-1.4	-1.4	n.s.	0.0	1.4	1.4	n.s.
0.0	0.0	0.0	0.0	n.s.	0.0	0.1	0.1	n.s.
		mean	**-0.31**			**mean**	**0.73**	
	Fy				Fy			
Loading		Torque	Negative			Torque	Positive	
Weight	Applied	Predicted	difference	difference	Applied	Predicted	difference	difference
in N	in N	in N	in N	in %	in N	in N	in N	in %
0.0	0.0	0	0.0	n.s.	0.0	0.6	0.6	n.s.
17.7	0.0	29.8	29.8	n.s.	0.0	-27.9	-27.9	n.s.
116.0	0.0	211.49	211.5	n.s.	0.0	-208.3	-208.3	n.s.
214.1	0.0	388.96	389.0	n.s.	0.0	-387.5	-387.5	n.s.
116.0	0.0	214.82	214.8	n.s.	0.0	-212.7	-212.7	n.s.
17.7	0.0	34.82	34.8	n.s.	0.0	-35.7	-35.7	n.s.
0.0	0.0	5.95	6.0	n.s.	0.0	-3.1	-3.1	n.s.
		mean	**126.55**			**mean**	**-124.94**	
	Fz				Fz			
Loading		Torque	Negative			Torque	Positive	
Weight	Applied	Predicted	difference	difference	Applied	Predicted	difference	difference
in N	in N	in N	in N	in %	in N	in N	in N	in %
0.0	0.0	-0.01	0.0	n.s.	0.0	0.4	0.4	n.s.
17.7	0.0	-0.85	-0.9	n.s.	0.0	0.65	0.7	n.s.
116.0	0.0	-2.98	-3.0	n.s.	0.0	3.96	4.0	n.s.
214.1	0.0	-6.97	-7.0	n.s.	0.0	7.04	7.0	n.s.
116.0	0.0	-2.93	-2.9	n.s.	0.0	4.7	4.7	n.s.
17.7	0.0	-0.34	-0.3	n.s.	0.0	1.64	1.6	n.s.
0.0	0.0	-0.03	0.0	n.s.	0.0	0.39	0.4	n.s.
		mean	**-2.02**			**mean**	**2.68**	

Table VII.12a : The three forces in torque study using the bench table and the Villiers Pylon Transducer alone. Considering the set-up, the applied forces were zero. Except in Fy (see explanations in section 7.3.4), the results were as expected.

11.VII.4 Transverse torque study using the bench table

Table VII.12 shows the static test performed in torque using the bench table as described in section 7.3.4. The Villiers Pylon Transducer was used alone. Table VII.13 also shows the statistical analysis of such a test: r-square = 0.99956, intercept = 0.03714 and the slope is 0.93517 (the best being respectively, 1, 0 and 1).

When the applied loads are equal to zero a mean difference in N or N.m between predicted-applied is shown in table VII.12.

See section 7.3.4.1 for more explanations concerning torque and axial compression interaction – effects.

		Torque	**Negative**			**Torque**	**Positive**	
				l = 0.1 m			-	**l = 0.1 m**
	Mx				**Mx**			
Loading								
Weight	Applied	Predicted	difference	difference	Applied	Predicted	difference	difference
in N	in Nm	in Nm	in Nm	in %	in Nm	in Nm	in Nm	in %
0.0	0.0	0.00	0.0	n.s.	0.0	-0.05	-0.1	n.s.
17.7	0.0	-0.01	0.0	n.s.	0.0	-0.03	0.0	n.s.
116.0	0.0	-0.14	-0.1	n.s.	0.0	0.17	0.2	n.s.
214.1	0.0	-0.21	-0.2	n.s.	0.0	0.16	0.2	n.s.
116.0	0.0	0.02	0.0	n.s.	0.0	0.08	0.1	n.s.
17.7	0.0	0.11	0.1	n.s.	0.0	0	0.0	n.s.
0.0	0.0	0.00	0.0	n.s.	0.0	-0.1	-0.1	n.s.
		mean	**-0.03**			**mean**	**0.03**	
	My				**My**			
Loading		**Torque**	**Negative**			**Torque**	**Positive**	
Weight	Applied	Predicted	difference	difference	Applied	Predicted	difference	difference
in N	in Nm	in Nm	in Nm	in %	in Nm	in Nm	in Nm	in %
0.0	0.00	0.05	0.1	n.s.	0.00	-0.03	0.0	n.s.
17.7	-0.88	-0.61	0.3	-30.9	0.88	0.71	-0.2	-19.5
116.0	-5.80	-5.40	0.4	-6.9	5.80	5.40	-0.4	-6.9
214.1	-10.71	-10.01	0.7	-6.5	10.71	10.00	-0.7	-6.6
116.0	-5.80	-5.41	0.4	-6.7	5.80	5.62	-0.2	-3.1
17.7	-0.88	-0.61	0.3	-30.9	0.88	0.74	-0.1	-16.1
0.0	0.00	0.07	0.1	n.s.	0.00	0.00	0.0	n.s.
			mean %	**-6.70**			**mean %**	**-5.53**
	Mz				**Mz**			
Loading		**Torque**	**Negative**			**Torque**	**Positive**	
Weight	Applied	Predicted	difference	difference	Applied	Predicted	difference	difference
in N	in Nm	in Nm	in Nm	in %	in Nm	in Nm	in Nm	in %
0.0	0.0	0.00	0.0	n.s.	0.0	-0.32	-0.3	n.s.
17.7	0.0	1.51	1.5	n.s.	0.0	-1.07	-1.1	n.s.
116.0	0.0	0.17	0.2	n.s.	0.0	-0.5	-0.5	n.s.
214.1	0.0	0.40	0.4	n.s.	0.0	-0.73	-0.7	n.s.
116.0	0.0	0.30	0.3	n.s.	0.0	-0.39	-0.4	n.s.
17.7	0.0	1.29	1.3	n.s.	0.0	-1.07	-1.1	n.s.
0.0	0.0	0.00	0.0	n.s.	0.0	-0.32	-0.3	n.s.
		mean	**0.52**			**mean**	**-0.63**	

Table VII.12b : The three bending moments in torque study using the bench table and the Villiers Pylon Transducer alone. Considering the set-up, the applied moments in A/P and M/L planes were zero. The results were as expected.

		Positive & Negative	**Torque**		
My		*Regression Statistics*			
Applied	**Predicted**				
0.00	0.05	Multiple R	0.999783004		
-0.88	-0.61	R Square	0.999566056		
-5.80	-5.40	Adjusted R Square	0.999529894		
-10.71	-10.01	Standard Error	0.107766916		
-5.80	-5.41	Observations	14		
-0.88	-0.61				
0.00	0.07	*Analysis of Variance*			
0.00	-0.03		*df*	*Sum of Squares*	*Mean Square*
0.88	0.71	Regression	1	321.0181212	321.0181212
5.80	5.40	Residual	12	0.139364499	0.011613708
10.71	10.00	Total	13	321.1574857	
5.80	5.62				
0.88	0.74			*F*	*Significance F*
0.00	0.00			27641.31102	1.5066E-21
			Coefficients	*Standard Error*	*t Statistic*
		Intercept	0.037142857	0.02880192	1.289596573
		x1	0.935174838	0.005624883	166.2567623
			P-value	*Lower 95%*	*Upper 95%*
			0.219662253	-0.025611134	0.099896849
			5.08027E-23	0.922919271	0.947430405

Table VII.13: The regression statistical analysis of the torque channel My. The results show a good linearity: intercept close to zero (0.03), slope x1 close to one (0.93) and the r - square ≈ one (0.999).

	Dorsi	flexion	External	Theta	Yext= - 42°
	VPT		SPT		
Loading	Fx		Fx		
Weight	Applied	Predicted	Applied	Predicted	difference
in N	in N	in N	in N	in N	in N
0	0.0	-1.7	0.0	-4.9	3.2
9.32	-6.9	-7.1	-6.9	-6.9	-0.2
58.37	-43.4	-36.7	-43.4	-42.4	5.7
107.42	-79.8	-69.2	-79.8	-80.5	11.3
156.47	-116.3	-93.6	-116.3	-115.8	22.2
205.52	-152.7	-121.5	-152.7	-151.4	29.9
156.47	-116.3	-90.1	-116.3	-115.8	25.7
107.42	-79.8	-64.7	-79.8	-80.3	15.6
58.37	-43.4	-29.3	-43.4	-42.3	13.0
9.32	-6.9	-6.8	-6.9	-6.8	0.0
0	0.0	-1.2	0.0	0.1	-1.3
	mean diff %	**-20.4**	**mean diff %**	**-0.7**	
Loading	Fz		Fz		
Weight	Applied	Predicted	Applied	Predicted	difference
in N	in N	in N	in N	in N	in N
0	0.00	-0.25	0.00	5.55	5.8
9.32	6.24	5.16	6.24	12.37	-7.2
58.37	39.06	29.05	39.06	47.63	-18.6
107.42	71.88	55.75	71.88	74.79	-19.0
156.47	104.70	83.23	104.70	101.89	-18.7
205.52	137.52	117.24	137.52	126.93	-9.7
156.47	104.70	81.59	104.70	102.01	-20.4
107.42	71.88	53.12	71.88	72.14	-19.0
58.37	39.06	24.88	39.06	42.11	-17.2
9.32	6.24	5.89	6.24	14.77	-8.9
0	0.00	0.15	0.00	5.21	5.1
	mean diff %	**-24.0**	**mean diff %**	**3.0**	

Table VII.14a : The two shear forces (Fx (A/P) and Fz (M/L) — axial load Fy was not considered — in dorsiflexion and external rotation (Θy = - 42°) using the bench table and recording simultaneously two pylon transducers (VPT and SPT).. Table VII.14a also shows the difference of the results between the two transducers which should the smallest as possible.

11.VII.5 Combined load using the bench table and recording simultaneous data from two transducers: the new Villiers Pylon Transducer (VPT) and the Strathclyde Pylon Transducer (SPT)

Tables VII.14 and VII.15 show the static tests performed using the bench table and two pylon transducers simultaneously recorded: the Villiers Pylon Transducer (VPT) and the Strathclyde Pylon Transducer (SPT). The set-up was described in section 7.4.1.

The different positions were as follows:

Table VII.14: dorsiflexion ; external rotation with $\Theta y = -42°$ then internal rotation with $\Theta y = 30°$. The difference in the rotational angle about the Y axis was due to the possibility of the set-up. The set-up is a cantilever configuration and thus there is a tension about the longitudinal Y axis. Therefore, the Fy channel was not considered (see section 7.4.3). No transverse torque My was applied.

Table VII.15: plantarflexion ; external rotation with $\Theta y = -34°$ then internal rotation with $\Theta y = 33°$. Regarding the angles, the axial load Fy and the transverse torque My, the same comments as those expressed for dorsiflexion can be made.

Table VII.16 shows the bridge voltages, gain settings and the calibration matrix used to convert the raw data coming from the Strathclyde Pylon transducer into processed data.

Figures VII.4a and b show the A/P shear force Fx in dorsi and plantarflexion with both external and internal rotations about the longitudinal Y axis. The two traces are linear with two different slopes: the VPT is less accurate than the SPT in this particular channel with some uncertainties due to the set-up.

Figures VII.5a and b show the M/L shear force Fz in dorsi and plantarflexion with both external and internal rotations about the longitudinal Y axis. The two traces are not linear (especially the SPT in external rotation) with two different slopes: the VPT is less accurate than the SPT in this particular channel with some uncertainties due to the set-up.

Figures VII.6a and b show the M/L bending moments Mx in dorsi and plantarflexion with both external and internal rotations about the longitudinal Y axis. The results are linear with the same slope for the two pylon transducers.

Figures VII.7a and b show the A/P bending moments Mz in dorsi and plantarflexion with both external and internal rotations about the longitudinal Y axis. The results are linear with the same slope for the two pylon transducers.

	Dorsi	flexion	Internal	Theta	Yint = 30°	
	VPT		SPT			
Loading	Fx					
Weight	Applied	Predicted	Applied	Predicted	difference	
in N	in N	in N	in N	in N	in N	
0	0.0	2.9	0.0	-0.8	3.7	
9.32	-8.1	-8.0	-8.1	-2.5	-5.5	
58.37	-50.5	-61.9	-50.5	-49.7	-12.2	
107.42	-93.0	-110.0	-93.0	-89.0	-21.0	
156.47	-135.5	-154.2	-135.5	-133.2	-21.1	
205.52	-178.0	-198.67	-178.0	-177.5	-21.2	
156.47	-135.5	-153.9	-135.5	-133.3	-20.6	
107.42	-93.0	-127.3	-93.0	-89.0	-38.3	
58.37	-50.5	-61.0	-50.5	-49.8	-11.2	
9.32	-8.1	-7.97	-8.1	-2.42	-5.6	
0	0.0	4.6	0.0	-1.8	6.4	
	mean diff %	**19.6**	**mean diff %**	**-2.2**		
Loading	Fz					
Weight	Applied	Predicted	Applied	Predicted	difference	
in N	in N	in N	in N	in N	in N	
0	0.0	-0.03	0.0	-1.42	1.4	
9.32	-4.7	-5.45	-4.7	-2.52	-2.9	
58.37	-29.2	-29.16	-29.2	-25.78	-3.4	
107.42	-53.7	-49.91	-53.7	-53.24	3.3	
156.47	-78.2	-71.26	-78.2	-85.50	14.2	
205.52	-102.8	-90.41	-102.8	-115.60	25.2	
156.47	-78.2	-69.66	-78.2	-85.27	15.6	
107.42	-53.7	-47.95	-53.7	-57.88	9.9	
58.37	-29.2	-28.51	-29.2	-28.20	-0.3	
9.32	-4.7	-4.79	-4.7	-4.65	-0.1	
0	0.0	0.10	0.0	-2.02	2.1	
	mean diff %	**-7.4**	**mean diff %**	**3.2**		

Table VII.14b : The two shear forces Fx (A/P) and Fz (M/L) — axial load Fy was not considered — in dorsiflexion and internal rotation (Θy = 30°) using the bench table and recording simultaneously two pylon transducers (VPT and SPT).. Table VII.14b also shows the difference of the results between the two transducers which should the smallest as possible.

	Dorsi	flexion	External	Theta	Yext= - 42°
	VPT	l = 0.337 m	SPT	l = 0.212 m	
Loading	Mx				
Weight	Applied	Predicted	Applied	Predicted	
in N	in Nm	in Nm	in Nm	in Nm	
0	0.00	0.11	0.00	0.20	
9.32	2.10	2.22	1.32	1.83	
58.37	13.16	12.83	8.26	8.34	
107.42	24.22	25.22	15.20	14.23	
156.47	35.28	34.38	22.14	20.94	
205.52	46.34	45.48	29.09	27.25	
156.47	35.28	33.97	22.14	21.15	
107.42	24.22	23.63	15.20	14.64	
58.37	13.16	12.87	8.26	8.13	
9.32	2.10	2.26	1.32	1.83	
0	0.00	0.13	0.00	0.20	
	mean diff %	**-1.6**	**mean diff %**	**-3.8**	
Loading	My				
Weight	Applied	Predicted	Applied	Predicted	
in N	in Nm	in Nm	in Nm	in Nm	
0	0.0	0.03	0.0	0.25	
9.32	0.0	0.02	0.0	0.25	
58.37	0.0	-0.08	0.0	0.05	
107.42	0.0	-0.27	0.0	0.50	
156.47	0.0	-0.34	0.0	0.50	
205.52	0.0	-0.48	0.0	0.87	
156.47	0.0	-0.30	0.0	0.62	
107.42	0.0	-0.35	0.0	0.37	
58.37	0.0	-0.08	0.0	0.12	
9.32	0.0	0.01	0.0	0.00	
0	0.0	0.02	0.0	0.00	
Loading	Mz				
Weight	Applied	Predicted	Applied	Predicted	
in N	in Nm	in Nm	in Nm	in Nm	
0	0.00	0.22	0.00	-0.42	
9.32	2.33	2.46	1.46	1.46	
58.37	14.62	14.19	9.17	8.94	
107.42	26.90	26.12	16.88	18.85	
156.47	39.19	38.26	24.59	24.75	
205.52	51.47	50.95	32.30	32.44	
156.47	39.19	38.19	24.59	24.75	
107.42	26.90	26.50	16.88	16.64	
58.37	14.62	14.28	9.17	8.94	
9.32	2.33	2.41	1.46	1.25	
0	0.00	0.18	0.00	-0.21	
	mean diff %	**-2.2**	**mean diff %**	**1.0**	

Table VII.14c: The three bending moments in dorsiflexion with external (Θy = - 42°) using the bench table and recording simultaneously two pylon transducers (VPT and SPT). Considering the difference in the lever arms among the different set ups, no difference could be calculated. There was no transverse torque My applied.

	Dorsi	**flexion**	**Internal**	**Theta**	**Yint = 30°**	
	VPT	**l = 0.271 m**	SPT	**l = 0.145 m**		
Loading	**Mx**					
Weight	Applied	Predicted	Applied	Predicted		
in N	in Nm	in Nm	in Nm	in Nm		
0	0.00	0.23	0.00	0.08		
9.32	-1.55	-1.39	-0.83	0.2		
58.37	-9.74	-10.68	-5.23	-5.29		
107.42	-17.92	-19.96	-9.62	-9.76		
156.47	-26.11	-29.25	-14.02	-14.04		
205.52	-34.29	-38.50	-18.41	-18.71		
156.47	-26.11	-26.30	-14.02	-14.24		
107.42	-17.92	-19.91	-9.62	-9.76		
58.37	-9.74	-10.81	-5.23	-5.7		
9.32	-1.55	-1.40	-0.83	0.2		
0	0.00	0.27	0.00	0.09		
	mean diff %	9.7	**mean diff %**	2.3		
Loading	**My**					
Weight	Applied	Predicted	Applied	Predicted		
in N	in Nm	in Nm	in Nm	in Nm		
0	0.0	0.11	0.0	0.25		
9.32	0.0	0.10	0.0	0.01		
58.37	0.0	0.03	0.0	0.25		
107.42	0.0	0.01	0.0	0.25		
156.47	0.0	-0.03	0.0	0.25		
205.52	0.0	-0.14	0.0	0.37		
156.47	0.0	-0.08	0.0	0.37		
107.42	0.0	-0.12	0.0	0.37		
58.37	0.0	0.03	0.0	0.00		
9.32	0.0	0.10	0.0	0.00		
0	0.0	0.10	0.0	0.12		
Loading	**Mz**					
Weight	Applied	Predicted	Applied	Predicted		
in N	in Nm	in Nm	in Nm	in Nm		
0	0.00	1.64	0.00	0.27		
9.32	1.98	3.24	1.06	0.83		
58.37	12.42	12.19	6.67	7.49		
107.42	22.85	21.20	12.27	12.28		
156.47	33.29	30.57	17.88	17.27		
205.52	43.73	39.30	23.48	22.26		
156.47	33.29	30.37	17.88	17.06		
107.42	22.85	21.33	12.27	12.07		
58.37	12.42	12.43	6.67	6.87		
9.32	1.98	3.24	1.06	0.83		
0	0.00	1.66	0.00	0.39		
	mean diff %	-6.1	**mean diff %**	0.1		

Table VII.14d : The three bending moments in dorsiflexion with internal ($\Theta y = 30°$) using the bench table and recording simultaneously two pylon transducers (VPT and SPT). Considering the difference in the lever arms among the different set ups, no difference could be calculated. There was no transverse torque My applied

	Plantar	flexion	External	Theta	Yext = - 34°
	VPT		SPT		
Loading	Fx		Fx		
Weight	Applied	Predicted	Applied	Predicted	difference
in N	in N	in N	in N	in N	in N
0	0.0	2.3	0.0	0.1	2.2
9.32	7.7	8.0	7.7	2.5	5.6
58.37	48.4	40.9	48.4	50.6	-9.7
107.42	89.1	74.7	89.1	88.9	-14.2
156.47	129.7	110.0	129.7	127.3	-17.3
205.52	170.4	140.0	170.4	170.6	-30.6
156.47	129.7	106.3	129.7	127.3	-21.0
107.42	89.1	69.7	89.1	- 88.8	17.5
58.37	48.4	35.4	48.4	53.0	16.7
9.32	7.7	6.1	7.7	2.5	32.9
0	0.0	0.07	0.0	0.1	6.0
	mean diff %	**-18.8**	**mean diff %**	**1.4**	
Loading	Fz		Fz		
Weight	Applied	Predicted	Applied	Predicted	difference
in N	in N	in N	in N	in N	in N
0	0.00	1.88	0.00	0.09	1.8
9.32	-5.21	-2.45	-5.21	-2.57	0.1
58.37	-32.64	-27.23	-32.64	-33.03	5.8
107.42	-60.07	-58.77	-60.07	-64.53	5.8
156.47	-87.50	-84.14	-87.50	-91.04	6.9
205.52	-114.93	-111.90	-114.93	-116.11	4.2
156.47	-87.50	-83.87	-87.50	-91.26	7.4
107.42	-60.07	-58.54	-60.07	-62.19	3.7
58.37	-32.64	-26.17	-32.64	-33.09	6.9
9.32	-5.21	-2.72	-5.21	-3.08	0.4
0	0.00	1.90	0.00	0.11	1.8
	mean diff %	**-7.4**	**mean diff %**	**3.3**	

Table VII.15a: The two shear forces Fx (A/P) and Fz (M/L) — axial load Fy was not considered — in plantarflexion and external rotation (Θy = -34°) using the bench table and recording simultaneously two pylon transducers (VPT and SPT).. Table VII.15a also shows the difference of the results between the two transducers, which should the smallest as possible.

	Plantar	flexion	Internal	Theta	Yint = 33°
	VPT		SPT		
Loading	Fx				
Weight	Applied	Predicted	Applied	Predicted	difference
in N	in N	in N	in N	in N	in N
0	0.0	0.0	0.0	0.04	0.0
9.32	7.8	12.6	7.8	15.2	-2.6
58.37	49.0	62.5	49.0	52.1	10.4
107.42	90.1	113.1	90.1	91.3	21.7
156.47	131.2	154.2	131.2	133.1	21.1
205.52	172.4	199.74	172.4	167.9	31.8
156.47	131.2	157.1	131.2	133.2	24.0
107.42	90.1	114.7	90.1	93.9	20.9
58.37	49.0	57.8	49.0	54.4	3.4
9.32	7.8	10.69	7.8	15.27	-4.6
0	0.0	-1.4	0.0	0.1	-1.5
	mean diff %	**21.7**	**mean diff %**	**3.3**	
Loading	Fz				
Weight	Applied	Predicted	Applied	Predicted	difference
in N	in N	in N	in N	in N	in N
0	0.0	1.62	0.0	0.07	1.6
9.32	5.1	6.16	5.1	5.09	1.1
58.37	31.8	36.20	31.8	32.44	3.8
107.42	58.5	65.27	58.5	59.67	5.6
156.47	85.2	95.45	85.2	88.50	7.0
205.52	111.9	127.30	111.9	115.84	11.5
156.47	85.2	93.57	85.2	88.10	5.5
107.42	58.5	62.32	58.5	60.17	2.2
58.37	31.8	32.80	31.8	32.82	0.0
9.32	5.1	3.98	5.1	4.43	-0.5
0	0.0	0.04	0.0	-0.12	0.2
	mean diff %	**10.1**	**mean diff %**	**3.0**	

Table VII.15b : The two shear forces Fx (A/P) and Fz (M/L) — axial load Fy was not considered — in plantarflexion and internal rotation ($\Theta y = 33°$) using the bench table and recording simultaneously two pylon transducers (VPT and SPT).. Table VII.15b also shows the difference of the results between the two transducers which should the smallest as possible.

	Plantar	flexion	External	Theta	Yext = - 34°
	VPT	l = 0.271 m	SPT	l = 0.145 m	
Loading	Mx				
Weight	Applied	Predicted	Applied	Predicted	
in N	in Nm	in Nm	in Nm	in Nm	
0	0.00	0.10	0.00	0.00	
9.32	-1.41	-1.45	-0.76	-0.99	
58.37	-8.85	-10.36	-4.75	-5.29	
107.42	-16.28	-19.24	-8.74	-9.76	
156.47	-23.71	-28.06	-12.73	-13.83	
205.52	-31.14	-36.93	-16.72	-18.10	
156.47	-23.71	-28.11	-12.73	-13.83	
107.42	-16.28	-19.81	-8.74	-9.76	
58.37	-8.85	-10.40	-4.75	-5.29	
9.32	-1.41	-1.46	-0.76	-0.96	
0	0.00	0.10	0.00	0.00	
	mean diff %	**18.6**	**mean diff %**	**10.2**	
Loading	My				
Weight	Applied	Predicted	Applied	Predicted	
in N	in Nm	in Nm	in Nm	in Nm	
0	0.0	0.04	0.0	0.08	
9.32	0.0	0.05	0.0	-0.12	
58.37	0.0	0.03	0.0	-0.37	
107.42	0.0	0.11	0.0	-0.37	
156.47	0.0	0.14	0.0	0.12	
205.52	0.0	0.19	0.0	0.25	
156.47	0.0	0.19	0.0	0.00	
107.42	0.0	0.04	0.0	0.00	
58.37	0.0	0.06	0.0	-0.12	
9.32	0.0	0.06	0.0	-0.12	
0	0.0	0.04	0.0	0.06	
	mean diff	**0.11**	**mean diff**	**-0.07**	
Loading	Mz				
Weight	Applied	Predicted	Applied	Predicted	
in N	in Nm	in Nm	in Nm	in Nm	
0	0.00	0.03	0.00	0.29	
9.32	-2.09	-1.74	-1.12	0.42	
58.37	-13.11	-11.27	-7.02	-6.03	
107.42	-24.13	-20.67	-12.91	-11.03	
156.47	-35.15	-30.05	-18.81	-16.44	
205.52	-46.17	-39.59	-24.71	-21.43	
156.47	-35.15	-30.20	-18.81	-16.23	
107.42	-24.13	-21.07	-12.91	-11.24	
58.37	-13.11	-11.21	-7.02	-6.03	
9.32	-2.09	-1.76	-1.12	0.21	
0	0.00	0.02	0.00	0.31	
	mean diff %	**-14.1**	**mean diff %**	**-13.6**	

Table VII.15c: The three bending moments in plantarflexion with external (Θy = - 34°) using the bench table and recording simultaneously two pylon transducers (VPT and SPT). Considering the difference in the lever arms, no difference could be calculated. There was no transverse torque My applied.

	Plantar	flexion	Internal	Theta	Yint = 33°
	VPT	l = 0.271 m	SPT	l = 0.145 m	
Loading	Mx				
Weight	Applied	Predicted	Applied	Predicted	
in N	in Nm	in Nm	in Nm	in Nm	
0	0.00	0.09	0.00	0.41	
9.32	1.38	1.76	0.74	1.22	
58.37	8.62	10.74	4.63	5.7	
107.42	15.85	19.90	8.51	9.97	
156.47	23.09	28.96	12.40	14.65	
205.52	30.33	37.98	16.29	18.71	
156.47	23.09	29.00	12.40	14.65	
107.42	15.85	19.97	8.51	10.37	
58.37	8.62	10.86	4.63	5.29	
9.32	1.38	1.62	0.74	1.22	
0	0.00	0.04	0.00	0.41	
	mean diff %	25.5	mean diff %	18.2	
Loading	My				
Weight	Applied	Predicted	Applied	Predicted	
in N	in Nm	in Nm	in Nm	in Nm	
0	0.0	0.01	0.0	0.00	
9.32	0.0	0.02	0.0	0.25	
58.37	0.0	0.00	0.0	0.00	
107.42	0.0	0.17	0.0	0.12	
156.47	0.0	0.27	0.0	0.37	
205.52	0.0	0.21	0.0	-0.12	
156.47	0.0	0.16	0.0	0.00	
107.42	0.0	0.14	0.0	0.25	
58.37	0.0	0.04	0.0	0.25	
9.32	0.0	-0.02	0.0	0.00	
0	0.0	-0.05	0.0	-0.12	
	mean diff	0.14	mean diff	0.12	
Loading	Mz				
Weight	Applied	Predicted	Applied	Predicted	
in N	in Nm	in Nm	in Nm	in Nm	
0	0.00	0.04	0.00	0.42	
9.32	-2.12	-1.43	-1.14	-0.21	
58.37	-13.27	-10.32	-7.12	-5.41	
107.42	-24.41	-18.96	-13.11	-11.03	
156.47	-35.56	-27.70	-19.09	-15.81	
205.52	-46.71	-36.41	-25.08	-21.22	
156.47	-35.56	-27.74	-19.09	-15.81	
107.42	-24.41	-19.12	-13.11	-10.61	
58.37	-13.27	-10.37	-7.12	-5.62	
9.32	-2.12	-1.46	-1.14	-0.62	
0	0.00	-0.05	0.00	0.21	
	mean diff %	-22.0	mean diff %	-18.5	

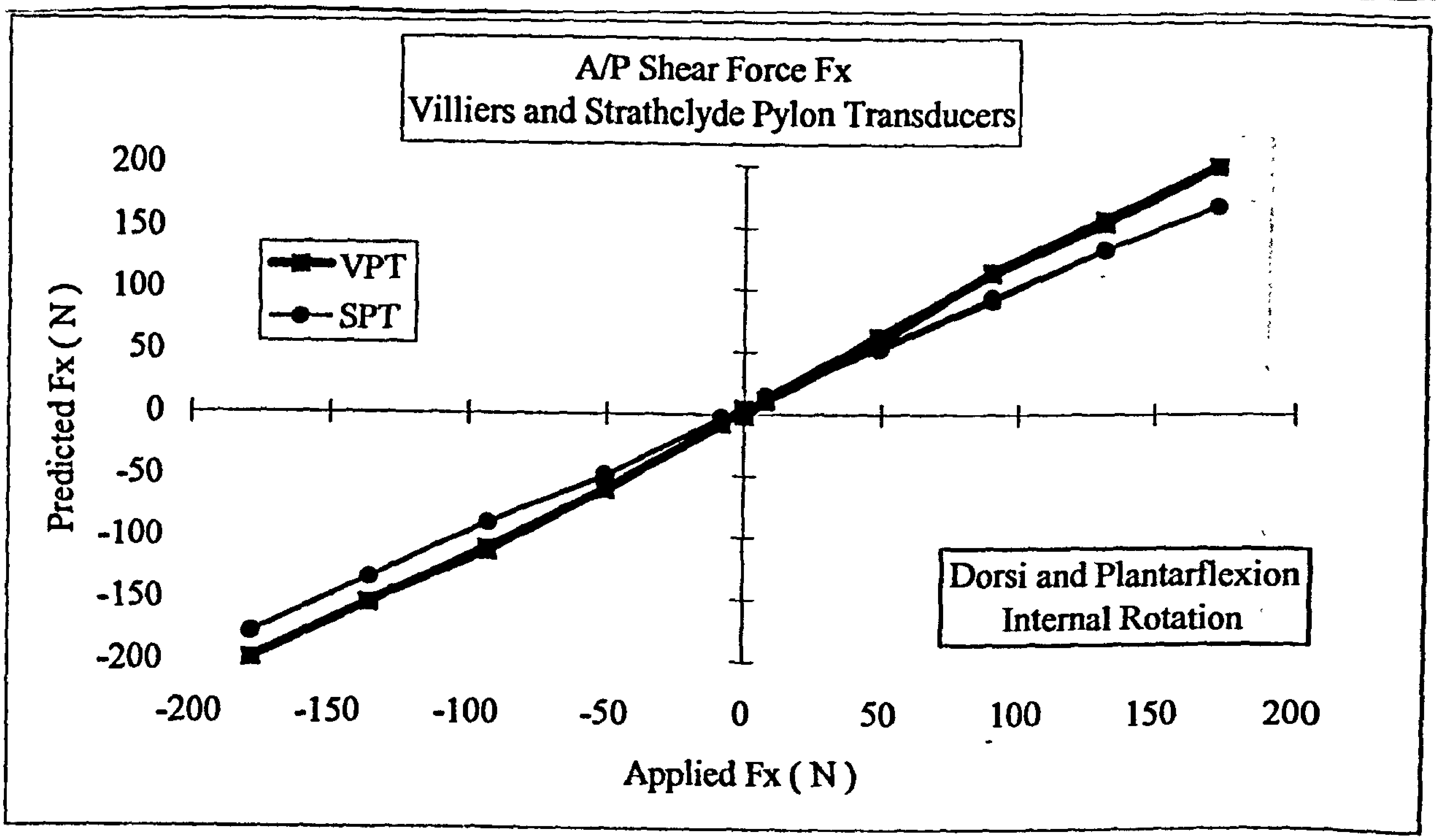
Table VII.15d: The three bending moments in plantarflexion with internal ($\Theta y = 33°$) using the bench table and recording simultaneously two pylon transducers (VPT and SPT). Considering the difference in the lever arms, no difference could be calculated. There was no transverse torque My applied.

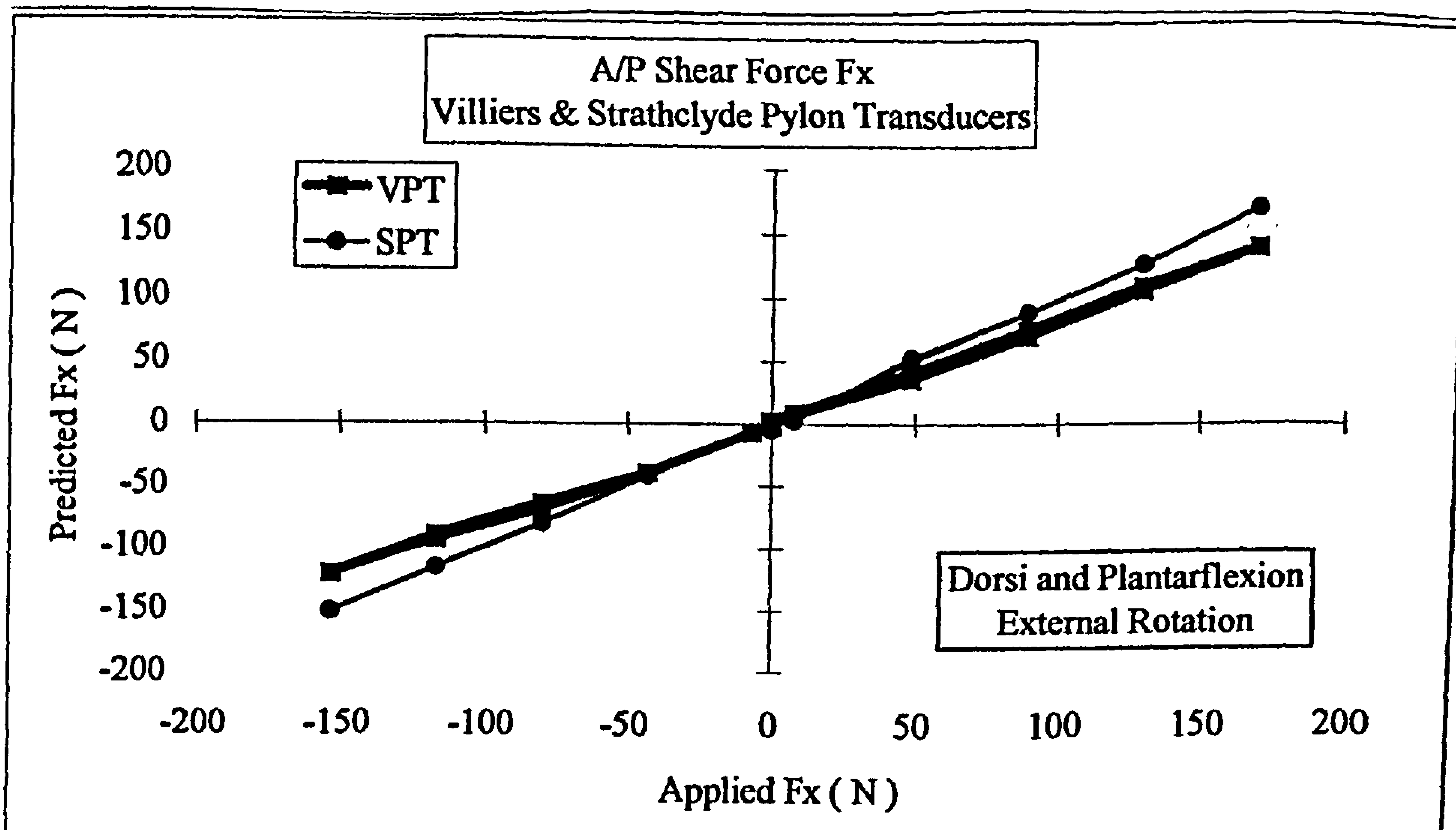
Fx	Fy	Fz	Mx	My	Mz
Bridge voltage in V					
3	6	3	3	3	3
Gains					
1000	1000	1000	200	500	200

0.4208	0	0	-0.0133	0.0055	-0.0042
0.0234	**-0.4010**	0	-0.0348	0.0131	-0.0441
0	0	**0.4384**	0.0026	-0.0224	-0.0144
0	0	0	**-0.0347**	0	0
0	0	0	0	**-0.0212**	0
0	0	0	0	0	**0.0355**

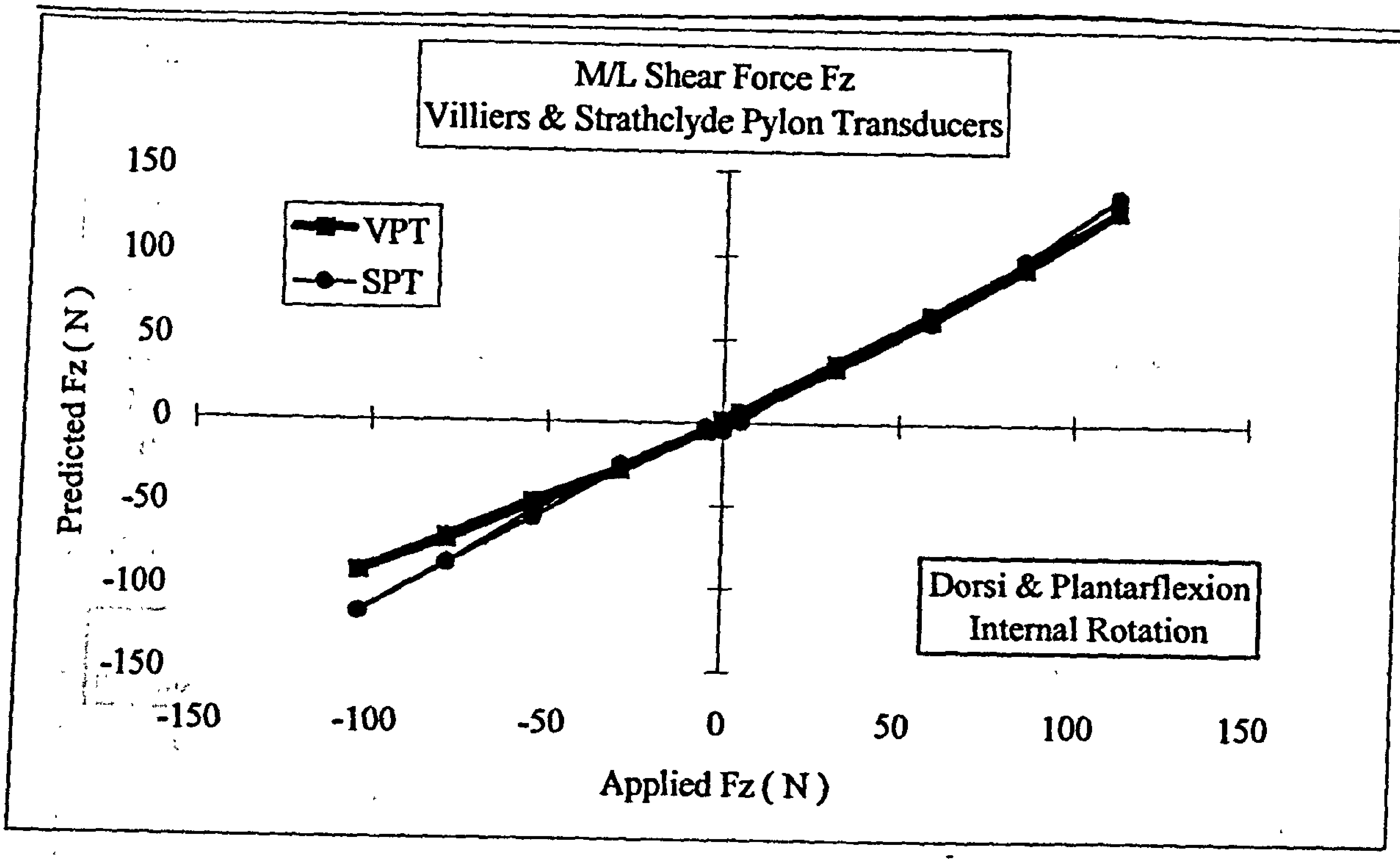
in N or N.m / computer units

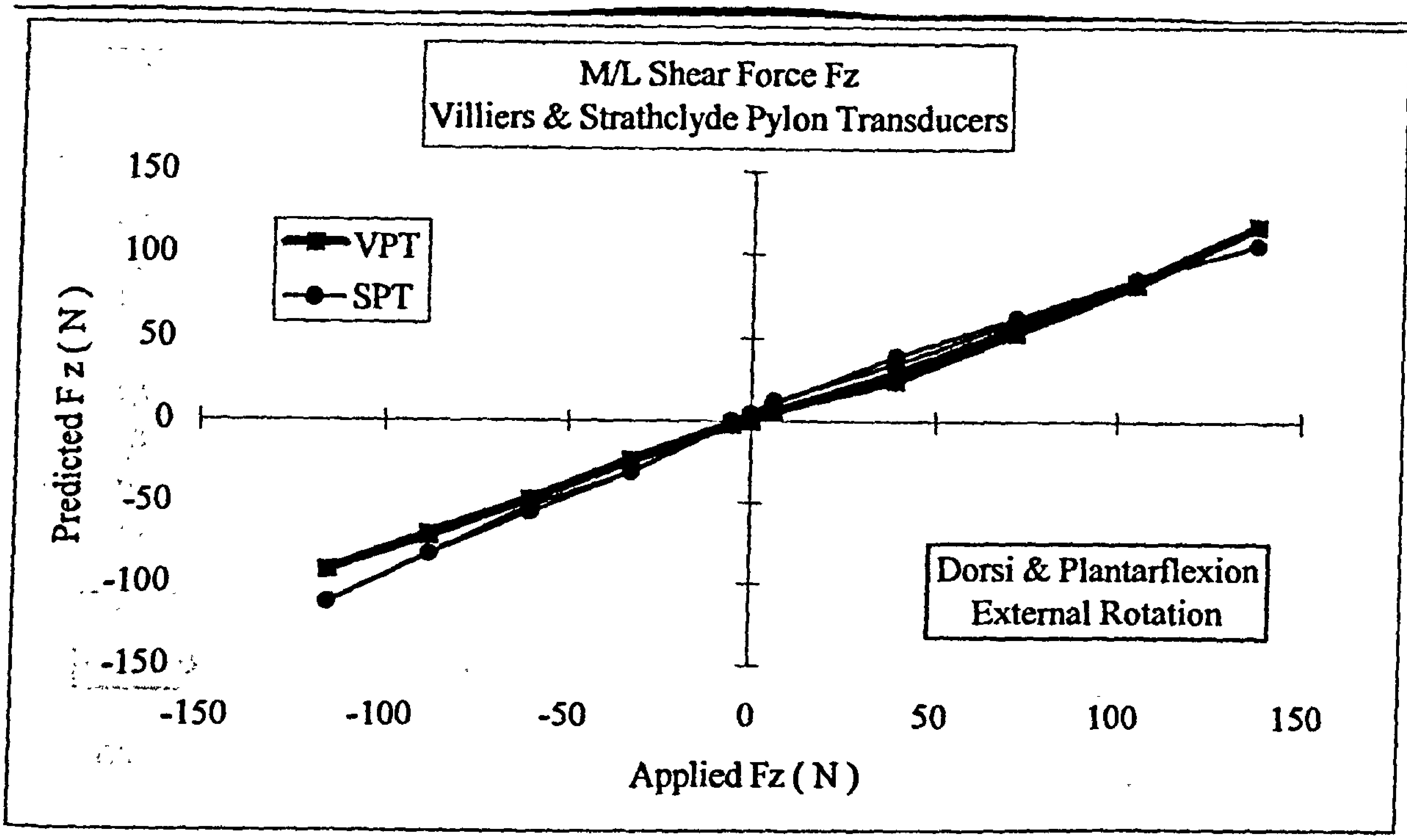
Table VII.16: The bridge voltages, gain settings and calibration matrix used to study the data recorded from the SPT through a set of six amplifiers and Acquire data acquisition system (Ni Ling, 1996).



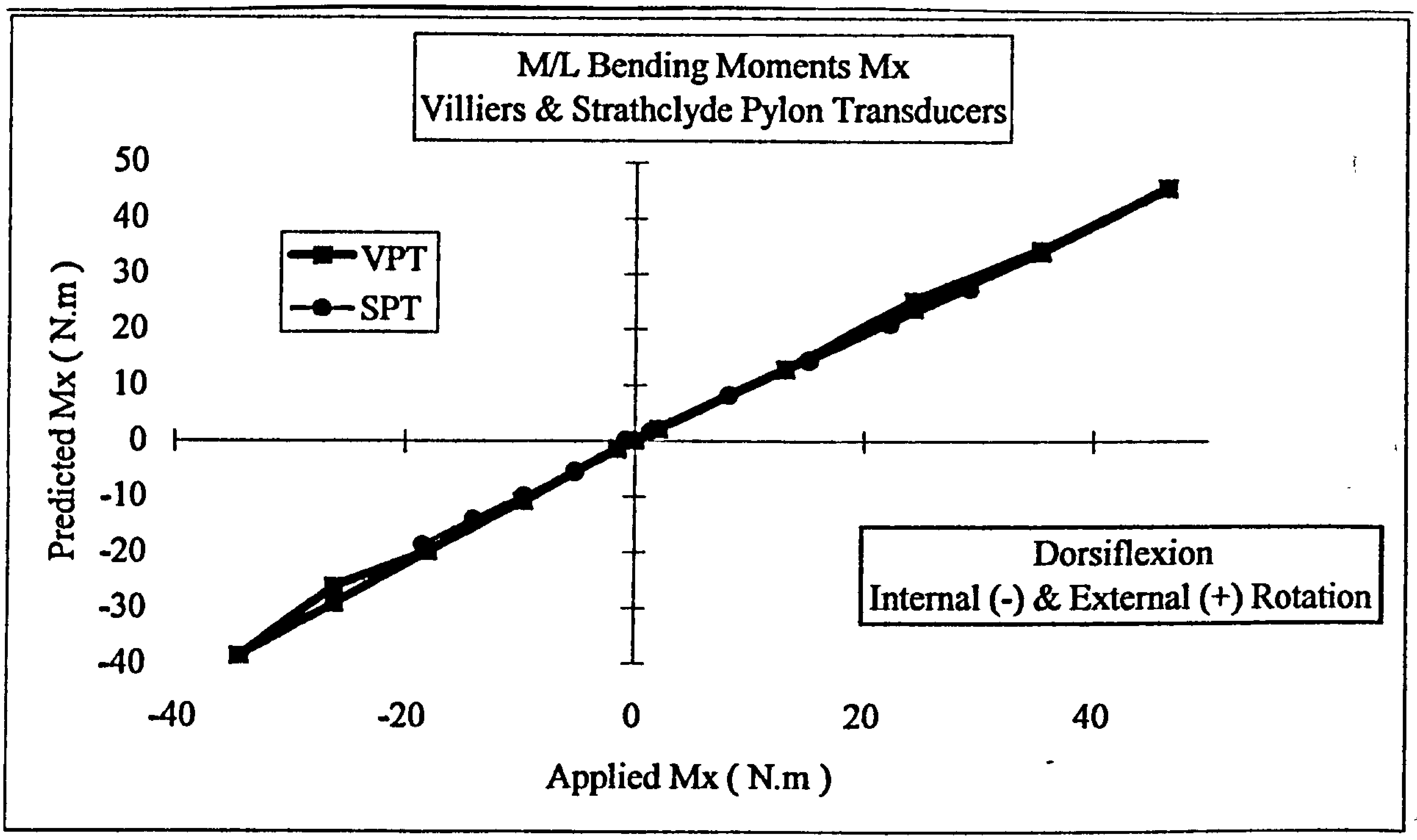


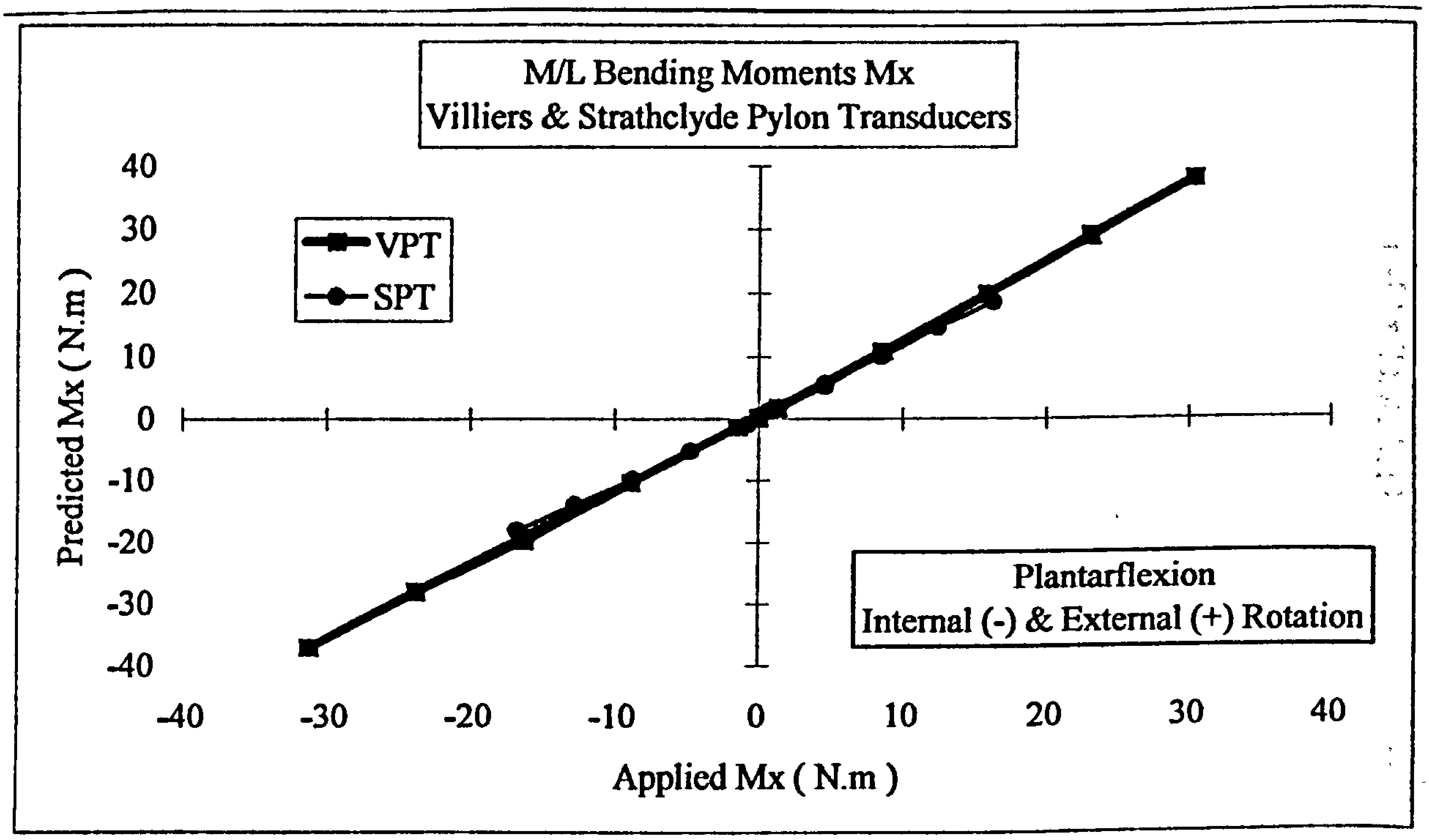
Figures VII.4a and b: Figure VII.4a (top) shows the A/P shear force Fx in dorsi and plantarflexion with an internal rotation about the longitudinal Y axis. Figure VII.4b (bottom) shows the same channel and set-up with external rotation. The two traces are linear with two different slopes : the VPT is less accurate than the SPT in this particular channel with some uncertainties due to the set-up.



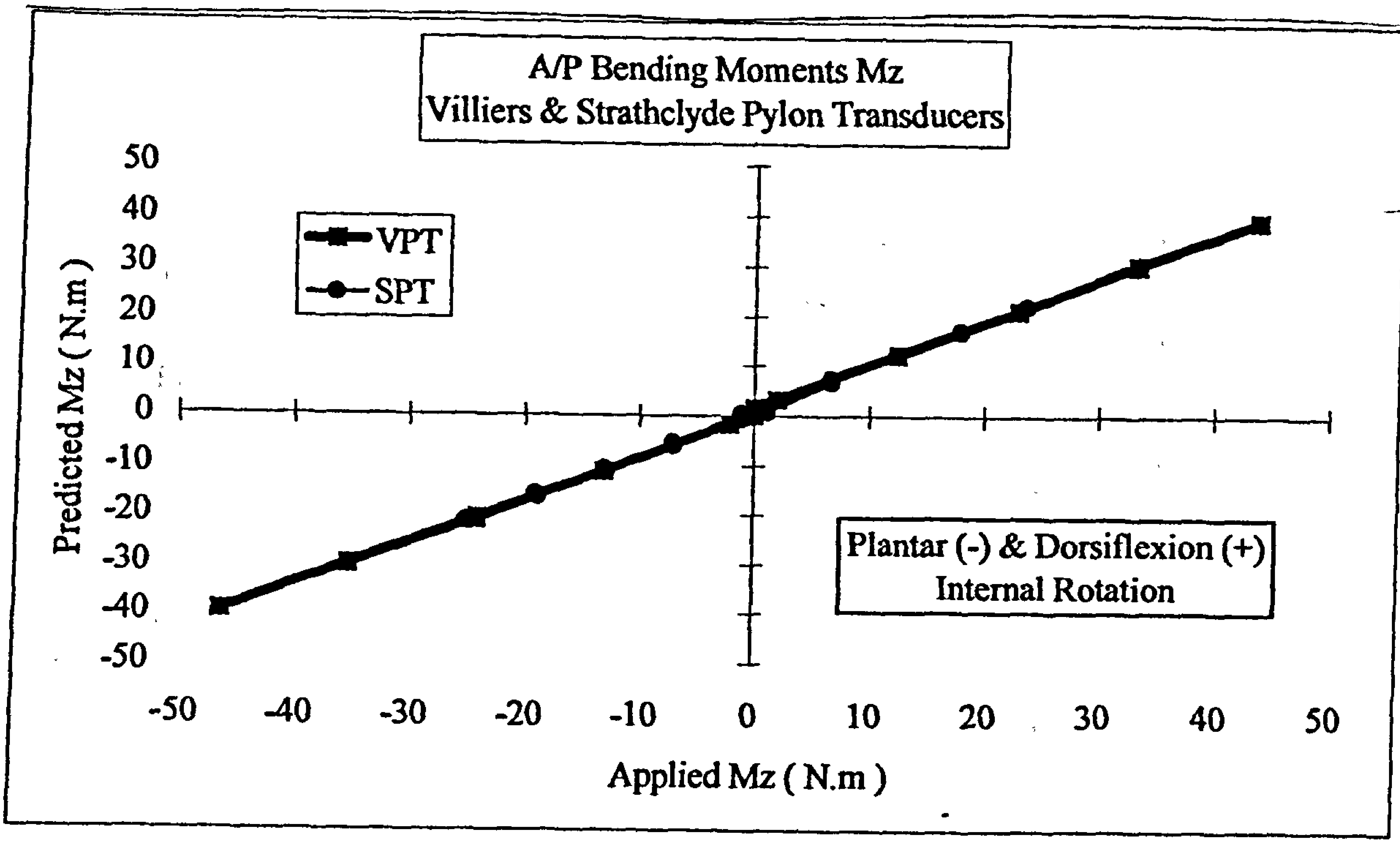


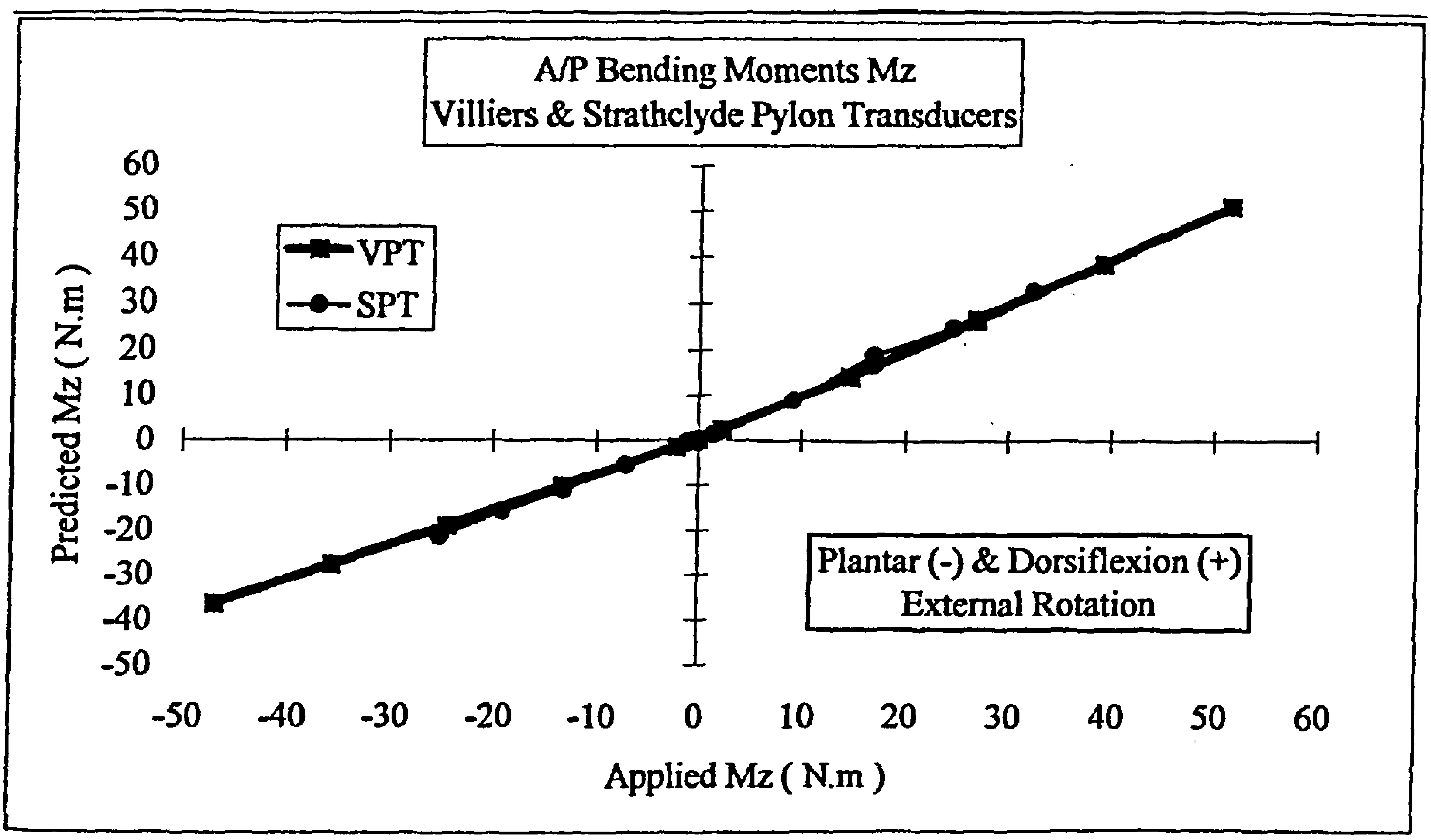
Figures VII.5A and b: Figure VII.5a (top) shows the M/L shear force Fz in dorsi and plantarflexion with an internal rotation about the longitudinal Y axis. Figure VII.5b (bottom) shows the same channel in a similar configuration except an external rotation about the Y axis. The traces are not linear between dorsi and plantarflexion. The slopes are not equal and globally, the VPT is less accurate in this particular channel but with some uncertainties due to the set-up.





Figures VII.6a and b : Figure VII.6a (top) shows the M/L bending moments Mx in dorsiflexion with an internal (negative values) and an external (positive values) rotations about the longitudinal Y axis. The traces are linear and the slopes are equal : the traces coming from the two transducers are superimposed on one another.





Figures VII.7a and b: Figure VII.7a (top) shows the A/P bending moments Mz in plantar (negative values) and dorsiflexion (positive values) with an internal rotation about the longitudinal Y axis. Figure VII.7b (bottom) shows the same channel in plantar and dorsiflexion with an external rotation. The traces are linear and the slopes are equal: the traces coming from the two transducers are superimposed on one another.

	Torque	Positive			
	VPT		SPT		
Loading	Fx				
Weight	Applied	Predicted	Applied	Predicted	difference
in N	in N	in N	in N	in N	in N
0.0	0.0	-0.1	0.0	1.83	-1.93
17.7	0.0	2.7	0.0	1.6	1.10
116.0	0.0	-1	0.0	1.3	-2.33
214.1	0.0	0.2	0.0	3.8	-3.62
116.0	0.0	2.8	0.0	3.9	-1.10
17.7	0.0	1.4	0.0	1.6	-0.24
0.0	0.0	0.1	0.0	-0.6	0.70
	mean diff	**1.22**	**mean diff**	**2.46**	
Loading	Fy				-
Weight	Applied	Predicted	Applied	Predicted	difference
in N	in N	in N	in N	in N	in N
0.0	0.0	0.6	0.0	-2.4	3.02
17.7	0.0	-27.8	0.0	-1.6	-26.22
116.0	0.0	-210	0.0	5.3	-215.33
214.1	0.0	-388.2	0.0	-4.9	-383.31
116.0	0.0	-212	0.0	-6.0	-205.99
17.7	0.0	-31.8	0.0	-4.2	-27.61
0.0	0.0	-3	0.0	-4.8	1.83
	mean diff	**-173.96**	**mean diff**	**-2.27**	
Loading	Fz				
Weight	Applied	Predicted	Applied	Predicted	difference
in N	in N	in N	in N	in N	in N
0.0	0.0	0.04	0.0	0.01	0.03
17.7	0.0	0.92	0.0	-0.22	1.14
116.0	0.0	0.17	0.0	0.98	-0.81
214.1	0.0	0.20	0.0	0.54	-0.34
116.0	0.0	5.18	0.0	0.05	5.13
17.7	0.0	1.17	0.0	0.99	0.18
0.0	0.0	0.72	0.0	-0.26	0.98
	mean diff	**1.53**	**mean diff**	**0.47**	

Table VII.17a: The three forces in a pure positive transverse torque My. The set up is describes in section 8.3.3. All the results were as expected excluding the axial load channel Fy of the VPT: in torque positive, the Fy response is negative with a predicted value of - 388 N for a applied torque of 10.7 N.m with an axial load of 0 N. See section 7.4.5 and 8.4.5 for explanations.

11.VII.6 The study of the transverse torque My using the bench table and recording simultaneously the two pylon transducers: the new Villiers Pylon Transducer (VPT) and the Strathclyde Pylon Transducer (SPT)

Tables VII.17 and VII.18 show the mean values of two static tests performed in transverse torque, positive and negative directions. The two pylons (VPT and SPT) were simultaneously recorded, using the bench table. The set-up was described in sections 7.4.5 and 8.4.5. The only applied bending moments was in the transverse plane about the longitudinal Y axis. Therefore, the five other channels should have a small response due to the cross effects. Unfortunately, some important values were recorded in the axial channel Fy of the VPT.

The different positions were as follows:

Table VII.17: the three forces and the three moments in torque positive

Table VII.18: the three force and the three moments in torque negative.

Figure VII.8 shows the traces recorded from the two pylon transducers. Both were linear. See sections 7.4.5, 7.8 and 7.9 for more details and conclusion.

	Torque	Positive			
	VPT		SPT		
Loading	Mx				
Weight	Applied	Predicted	Applied	Predicted	difference
in N	in N.m	in N.m	in N.m	in N.m	in %
0.0	0.0	-0.05	0.0	0	-0.05
17.7	0.0	-0.04	0.0	-0.2	0.16
116.0	0.0	0.17	0.0	-0.2	0.37
214.1	0.0	0.20	0.0	0	0.20
116.0	0.0	0.03	0.0	0	0.03
17.7	0.0	0.00	0.0	0.2	-0.20
0.0	0.0	-0.10	0.0	0	-0.10
	mean diff	0.07	mean diff	-0.04	
Loading	My				
Weight	Applied	Predicted	Applied	Predicted	difference
in N	in N.m	in N.m	in N.m	in N.m	in N.m
0.0	0.0	-0.03	0.0	-0.61	0.6
17.7	0.9	0.71	0.9	0.78	-0.1
116.0	5.8	5.40	5.8	5.53	-0.1
214.1	10.7	10.00	10.7	10.51	-0.5
116.0	5.8	5.18	5.8	5.54	-0.4
17.7	0.9	0.74	0.9	0.78	0.0
0.0	0.0	0	0.0	-0.12	0.9
	mean diff %	-11.97	mean diff %	-6.84	
Loading	Mz				
Weight	Applied	Predicted	Applied	Predicted	difference
in N	in N.m	in N.m	in N.m	in N.m	in %
0.0	0.0	-0.32	0.00	-0.19	-0.13
17.7	0.0	-1.06	0.00	-1.65	0.59
116.0	0.0	-0.51	0.00	-0.82	0.31
214.1	0.0	-0.83	0.00	-0.82	-0.01
116.0	0.0	-0.70	0.00	-0.82	0.12
17.7	0.0	-0.95	0.00	-1.24	0.29
0.0	0.0	-0.32	0.00	-0.19	-0.13
	mean diff	-0.81	mean diff	-1.07	

Table VII.17b : The three moments in a pure transverse torque My set-up. All the results were as expected.

	Torque	Negative			
	VPT		SPT		
Loading	Fx		Fx		
Weight	Applied	Predicted	Applied	Predicted	difference
in N	in N	in N	in N	in N	in N
0.0	0.0	0.0	0.0	0.4	-0.38
17.7	0.0	5.2	0.0	0.6	4.59
116.0	0.0	-0.6	0.0	-1.4	0.78
214.1	0.0	-0.3	0.0	-1.3	1.06
116.0	0.0	-0.4	0.0	-1.4	1.02
17.7	0.0	-3.0	0.0	-1.9	-1.11
0.0	0.0	0.0	0.0	0.7	-0.62
	mean diff	**0.21**	**mean diff**	**-1.06**	
Loading	Fy		Fy		
Weight	Applied	Predicted	Applied	Predicted	difference
in N	in N	in N	in N	in N	in N
0.0	0.0	1.7	0.0	-0.64	2.33
17.7	0.0	29.5	0.0	0.17	29.31
116.0	0.0	212.8	0.0	-0.54	213.35
214.1	0.0	389.0	0.0	-0.88	389.88
116.0	0.0	216.7	0.0	1.24	215.50
17.7	0.0	31.7	0.0	-1.85	33.53
0.0	0.0	0.3	0.0	0.66	-0.37
	mean diff	**175.94**	**mean diff**	**-0.37**	
Loading	Fz		Fz		
Weight	Applied	Predicted	Applied	Predicted	difference
in N	in N	in N	in N	in N	in N
0.0	0.00	-0.01	0.00	0.41	-0.42
17.7	0.00	-0.05	0.00	0.25	-0.30
116.0	0.00	-3.46	0.00	-0.78	-2.68
214.1	0.00	-6.17	0.00	-0.87	-5.30
116.0	0.00	-2.90	0.00	-0.05	-2.85
17.7	0.00	0.27	0.00	-0.18	0.45
0.0	0.00	0.00	0.00	0.28	-0.28
	mean diff	**-2.46**	**mean diff**	**-0.33**	

Table VII.18a: The three forces in a pure My negative torque set-up. All the results were as expected excluding the axial load channel Fy of the VPT: in torque negative, the Fy response is positive with a predicted value of 389 N for a applied torque of - 10.7 N.m with 0 N as axial load. See the caption of table VII.17a for more explanations.

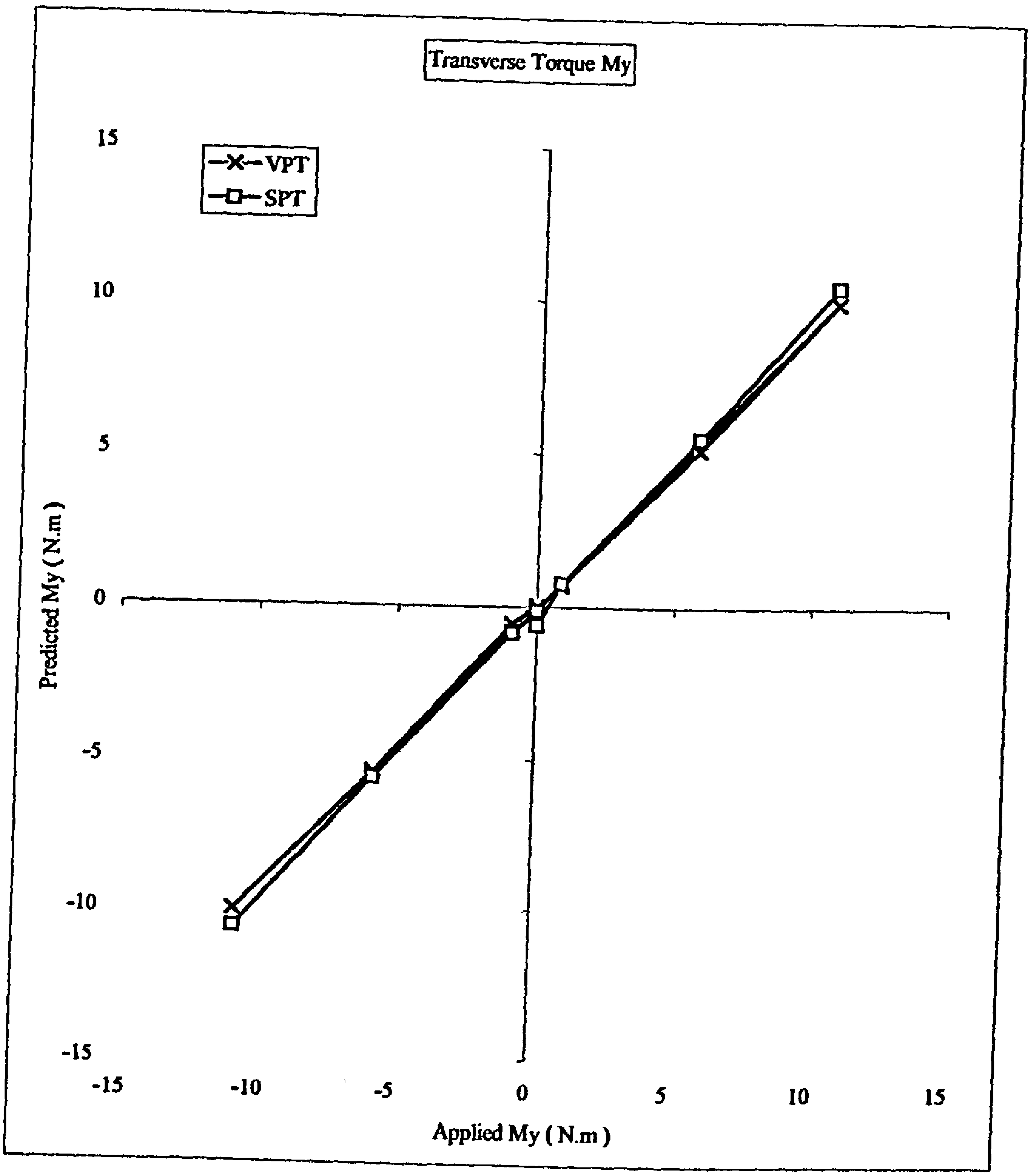


Figure VII.8: Applied versus Predicted values in transverse torque My simultaneously recorded from the two pylon transducers (VPT and SPT) using the bench table.

	Torque	Negative			
	VPT		SPT		
Loading	Mx				
Weight	Applied	Predicted	Applied	Predicted	difference
in N	in N.m	in N.m	in N.m	in N.m	in %
0.0	0.00	0.00	0.00	-0.81	0.81
17.7	0.00	-0.02	0.00	-0.20	0.18
116.0	0.00	-0.14	0.00	-0.20	0.06
214.1	0.00	-0.26	0.00	-0.20	-0.06
116.0	0.00	-0.02	0.00	0.00	-0.02
17.7	0.00	0.02	0.00	-0.41	0.43
0.0	0.00	0.00	0.00	0.00	0.00
	mean diff	-0.08	mean diff	-0.20	
Loading	My				
Weight	Applied	Predicted	Applied	Predicted	difference
in N	in N.m	in N.m	in N.m	in N.m	in N.m
0.0	0.0	0.05	0.0	-0.25	0.3
17.7	-0.9	-0.61	-0.9	-0.81	0.2
116.0	-5.8	-5.39	-5.8	-5.56	0.2
214.1	-10.7	-10.01	-10.7	-10.59	0.6
116.0	-5.8	-5.41	-5.8	-5.59	0.2
17.7	-0.9	-0.56	-0.9	-0.86	0.3
0.0	0.0	0.07	0.0	-0.12	0.2
	mean diff %	-17.54	mean diff %	-3.92	
Loading	Mz				
Weight	Applied	Predicted	Applied	Predicted	difference
in N	in N.m	in N.m	in N.m	in N.m	in %
0.0	0.00	0.00	0.00	-0.46	0.46
17.7	0.00	1.40	0.00	1.83	-0.43
116.0	0.00	0.29	0.00	-0.25	0.54
214.1	0.00	0.28	0.00	0.17	0.11
116.0	0.00	0.29	0.00	0.38	-0.09
17.7	0.00	1.08	0.00	1.62	-0.54
0.0	0.00	0.00	0.00	-0.66	0.66
	mean diff	0.67	mean diff	0.75	

Table VII.18b: The three moments in a pure My negative transverse torque set-up. All the results were as expected.

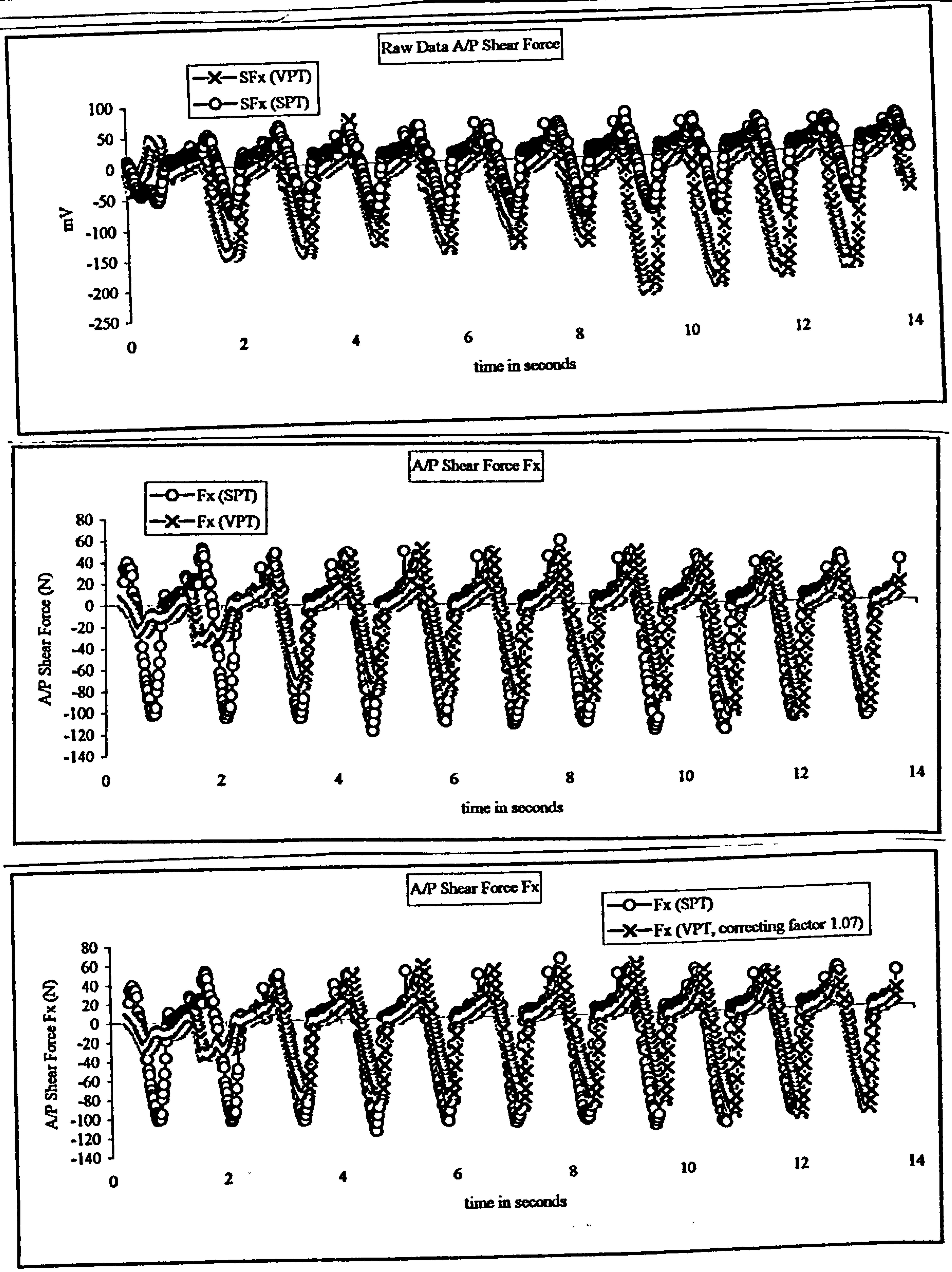


Figure VII.9: From trial n°2, the A/P shear force Fx, simultaneously recorded from the two pylon transducers (VPT and SPT) is shown: raw data in mV (top), after applying the corresponding calibration matrix to each pylon transducer (middle) and after applying the corresponding calibration matrix to each pylon transducer plus the correcting factors to the VPT, in N, (bottom).

11.VII.7 Dynamic tests using simultaneously the Villiers Pylon Transducer and the Strathclyde Pylon Transducer fitted on the shank tube of a transfemoral amputee

11.VII.7.1 THE TRIALS N°1 AND 2 IN WHICH DATA WERE RECORDED AT A SAMPLING FREQUENCY OF 64 HZ THROUGH THE PORTABLE DATA ACQUISITION SYSTEM USED IN THE PATIENTS' TESTS

Two trials were performed recording simultaneously two pylon transducers, namely, the Villiers Pylon Transducer (VPT) and the Strathclyde Pylon Transducer (SPT) fitted on the artificial shank tube of one transfemoral amputee (see section 7.6). These two trials were similar: the two transducers were recorded at the same sampling frequency of 64 Hz. The data acquisition system used for the VPT was the fully portable system described in chapter 7. For the SPT, the data acquisition system was a set of 6 amplifiers used with Acquire programme (Phillips, 1990). A 15 metres cable coupled the SPT with the amplifiers. Therefore, the patient only walked in the gait laboratory. The results from each trial are presented as follows:

Ten strides (14 s, 861 rows in Excel®) were randomly chosen and are shown in a graphic form. From these strides, each of the six channels is shown in the same page. From top to bottom, one has:

- the raw data traces, in millivolts versus time in seconds (mV vs. s) (top). To be clear in the reading of the graphs, the M/L shear force Fz and the M/L bending moment Mx have two vertical axes with different scale: the right axis is for the SPT while the left one is for the VPT;

- the processed data after applying the calibration matrix calculated in section 6.7 for the VPT and the one established by Ni Ling (1996) for the SPT and shown in table 12.VII.16, in N or N.m versus a base of time in seconds (middle). It is obvious that the comparison of the two bending moments Mx and Mz values at the ankle (Mx_{VPT} and Mz_{VPT}) and shank tube level (Mx_{SPT} and Mz_{SPT}) must be evaluated following the equations 7.35 and 7.36 (see section 7.6.1).

- the processed data after applying both the calibration matrices and the factors calculated in section 7.7, only for he VPT, in N or N.m versus a base of time in seconds (bottom). It is thus possible to compare the traces before and after applying the factors to justify the use of such a proceeding. To improve the reading, these graphs have been magnified. They are shown at the recto of the corresponding page.

The trial n°1 has been shown in section 7.8 (figures 7.25 and 7.26). Figures VII.9 to VII.14 correspond to the trial n°2.

All these figures show that the traces coming from the two pylon transducers are parallel and thus the new Villiers Pylon Transducer is able to record accurately the six components of the gait.

The factors, applied to the VPT and calculated in section 7.7.1, improve the accuracy of the results expressed by the VPT.

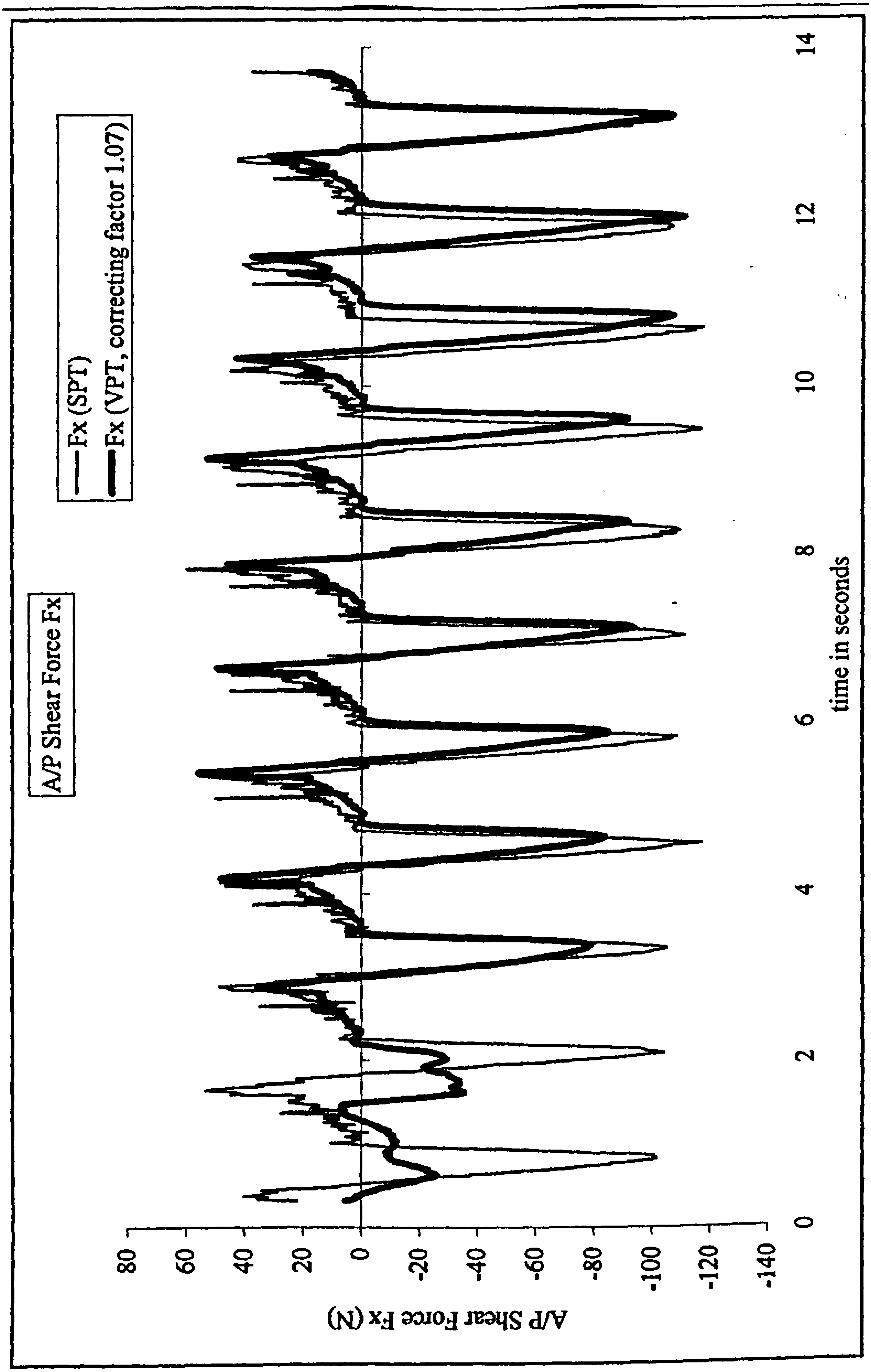


Figure VII.9a: The same as figure VII.9 (bottom) but magnified to improve the reading.

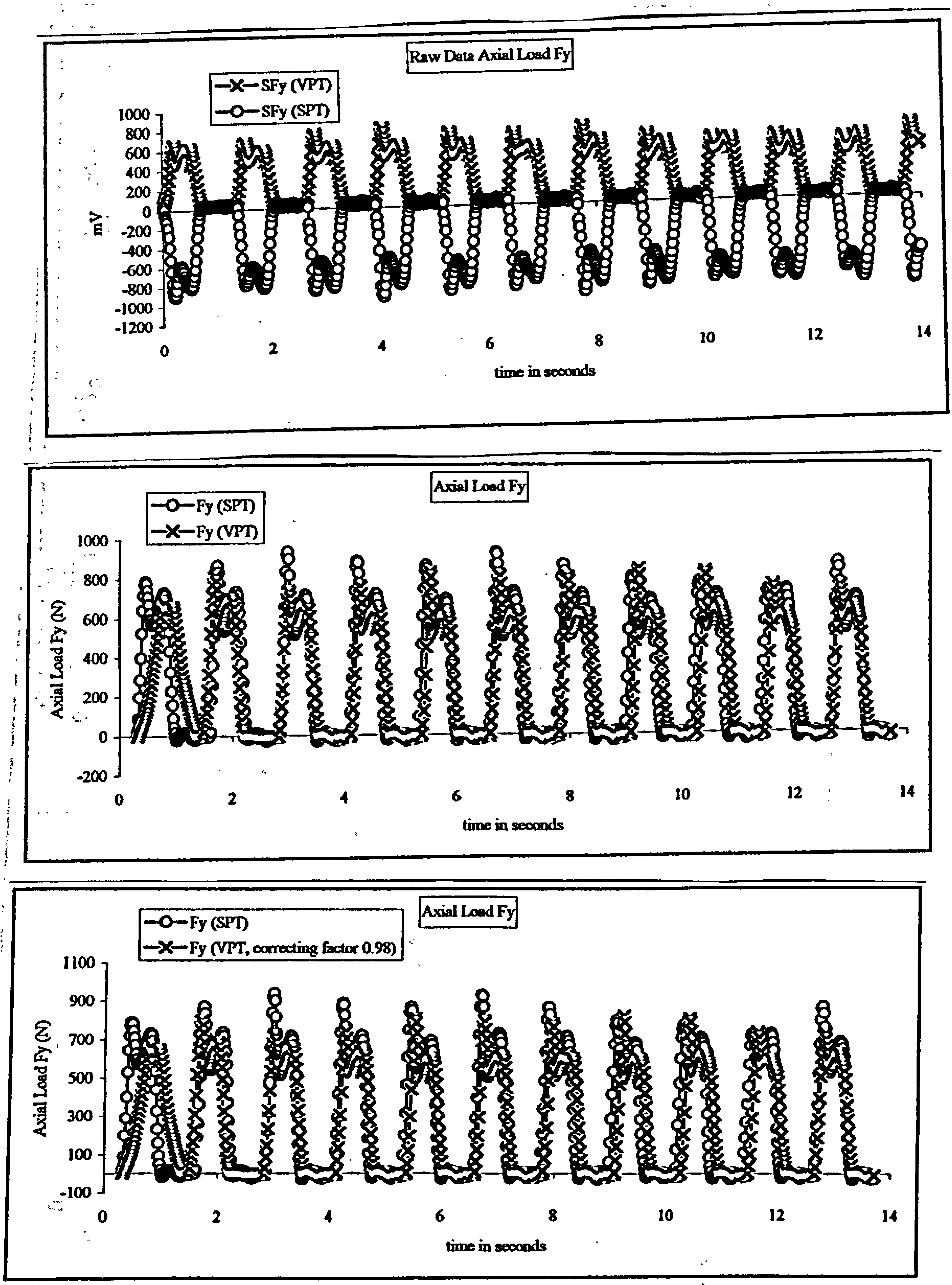


Figure VII.10: From trial n°2, the axial load Fy, simultaneously recorded from the two pylon transducers (VPT and SPT) is shown: raw data in mV (top), after applying the corresponding calibration matrix to each pylon transducer (middle) and after applying the corresponding calibration matrix to each pylon transducer plus the correcting factors to the VPT, in N, (bottom).

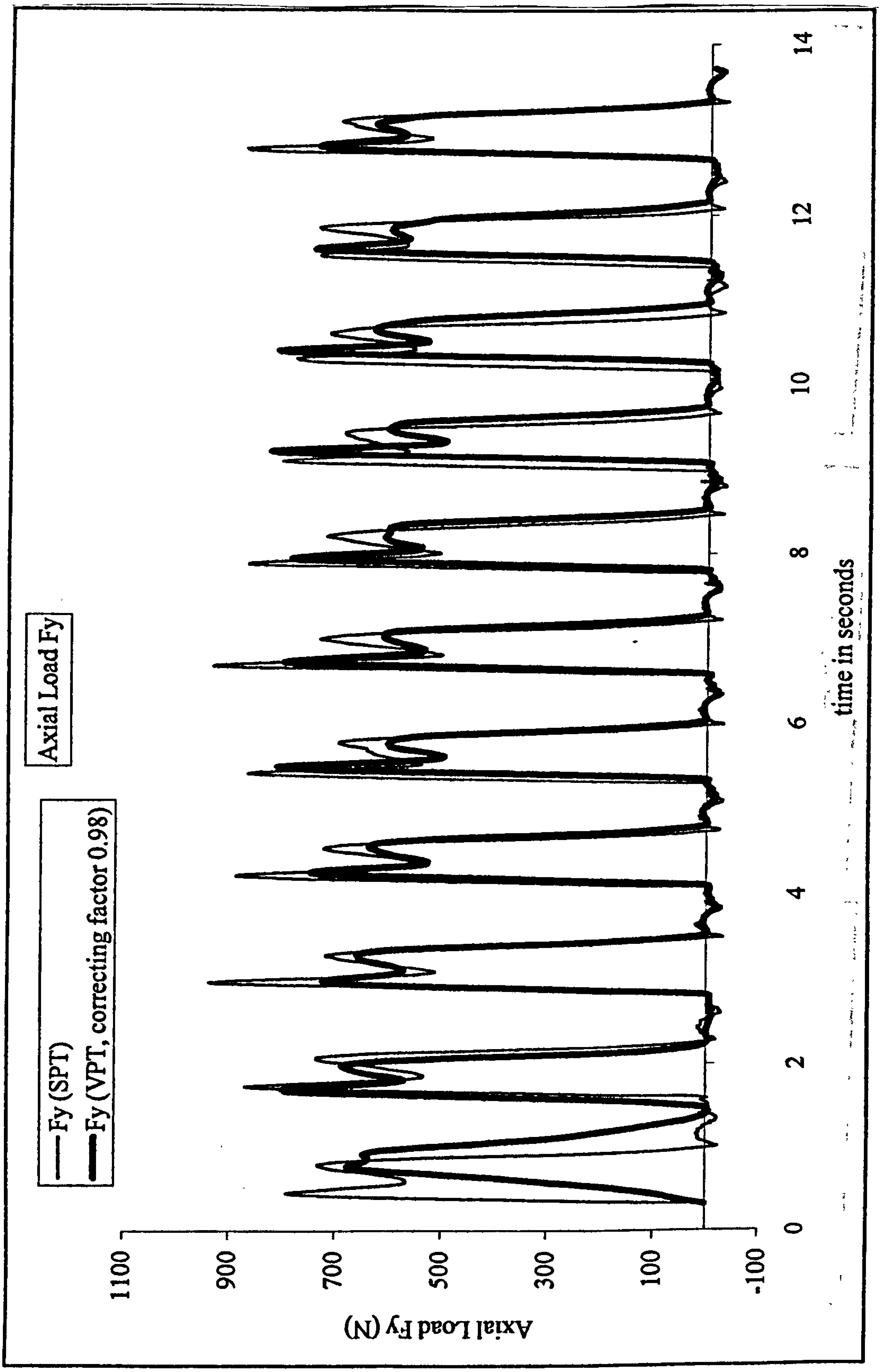


Figure VII.10a: The same as figure VII.10 (bottom) but magnified to improve the reading.

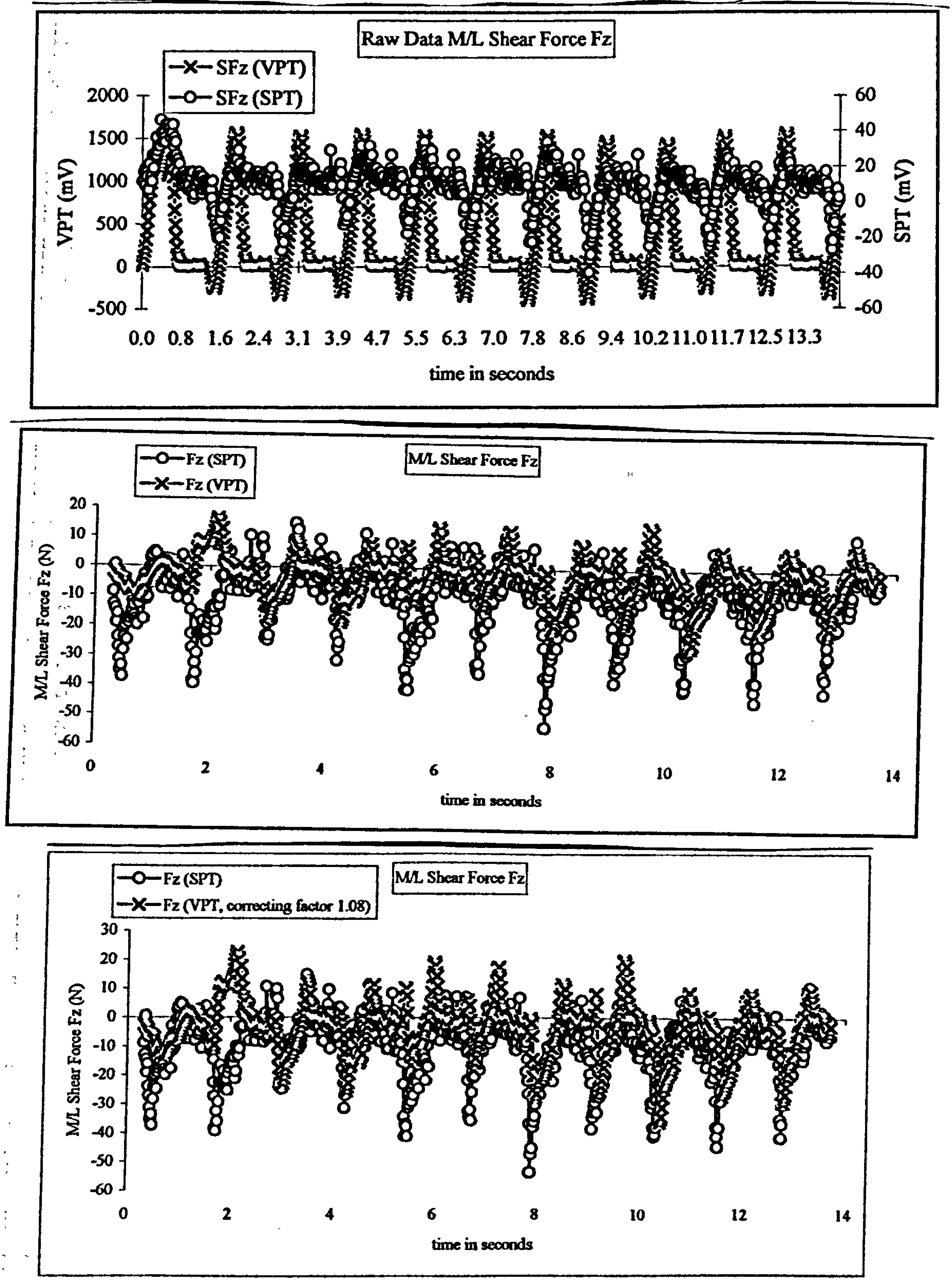


Figure VII.11: From trial n°2, the M/L shear force Fz, simultaneously recorded from the two pylon transducers (VPT and SPT) is shown: raw data in mV (one scale for each transducer) (top), after applying the corresponding calibration matrix to each pylon transducer (middle) and after applying the corresponding calibration matrix to each pylon transducer plus the correcting factors to the VPT, in N, (bottom).

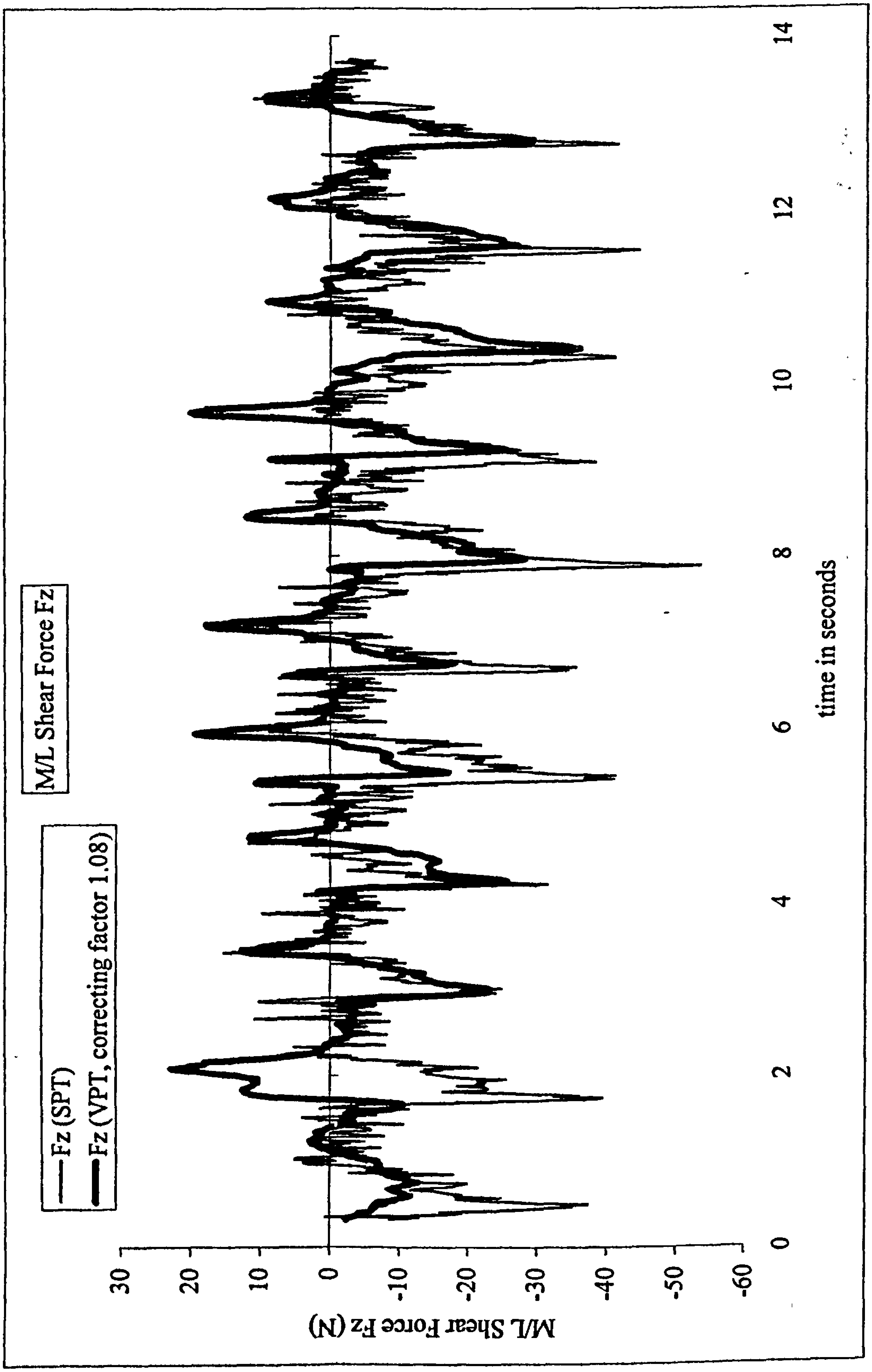
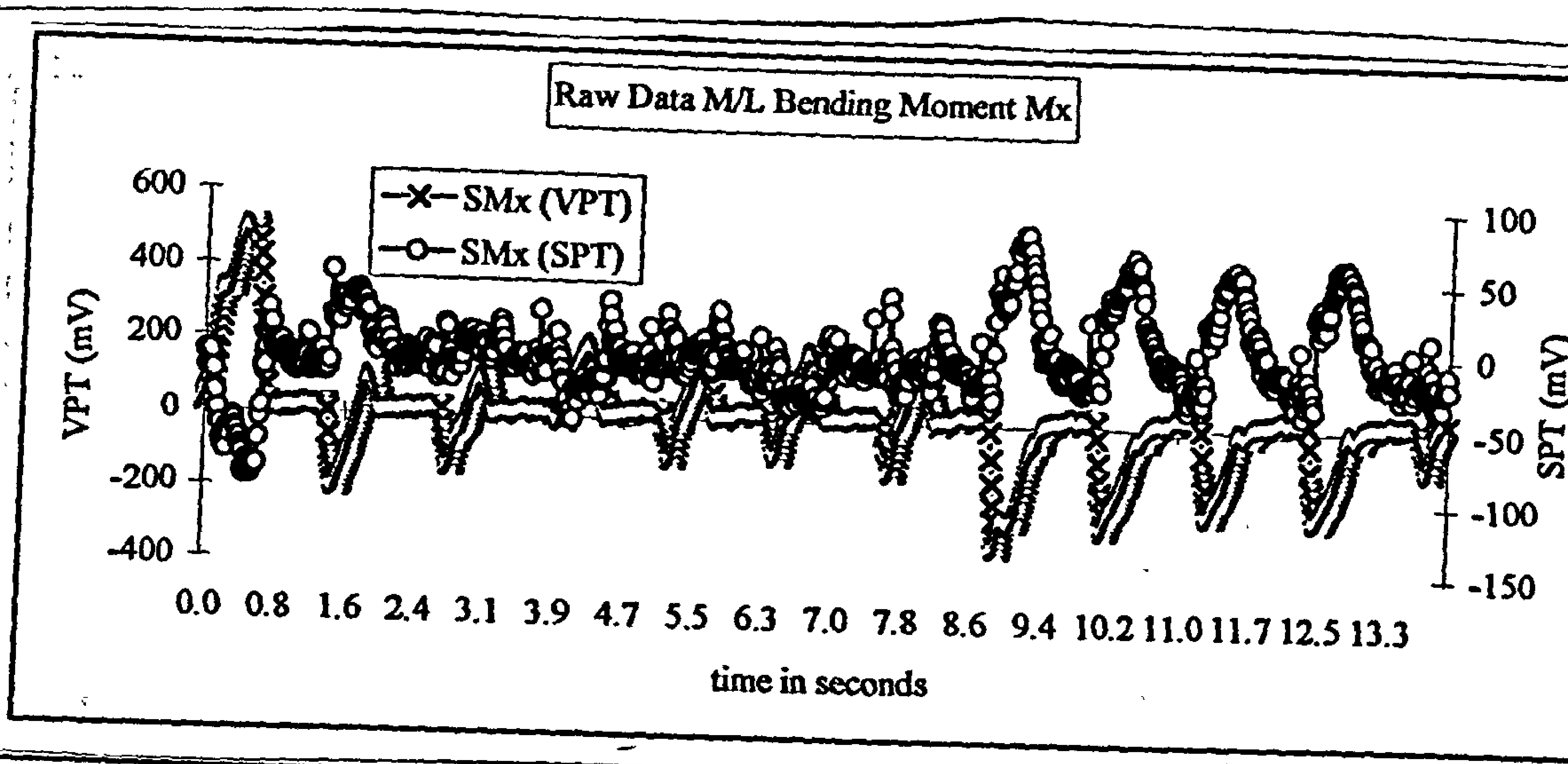
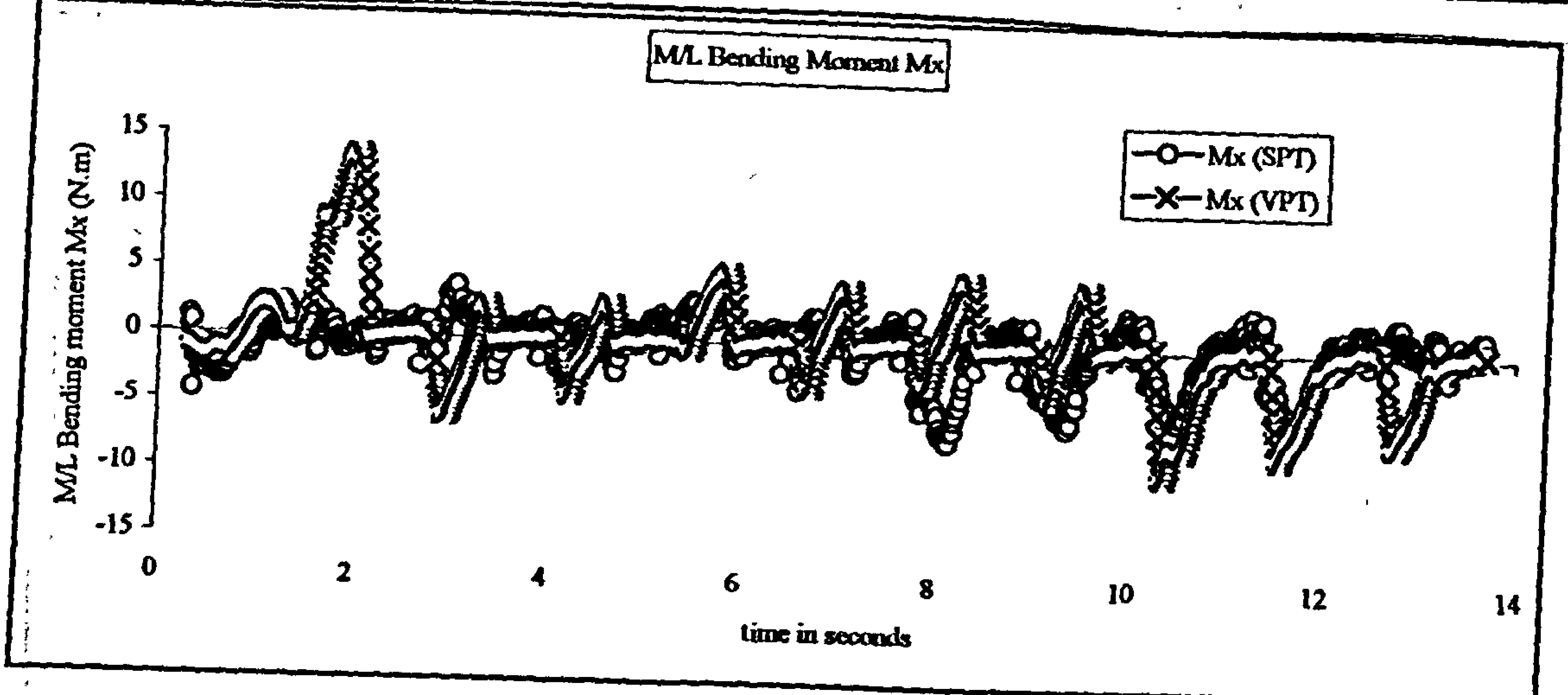


Figure VII.11a: The same as figure VII.11 (bottom) but magnified to improve the reading.





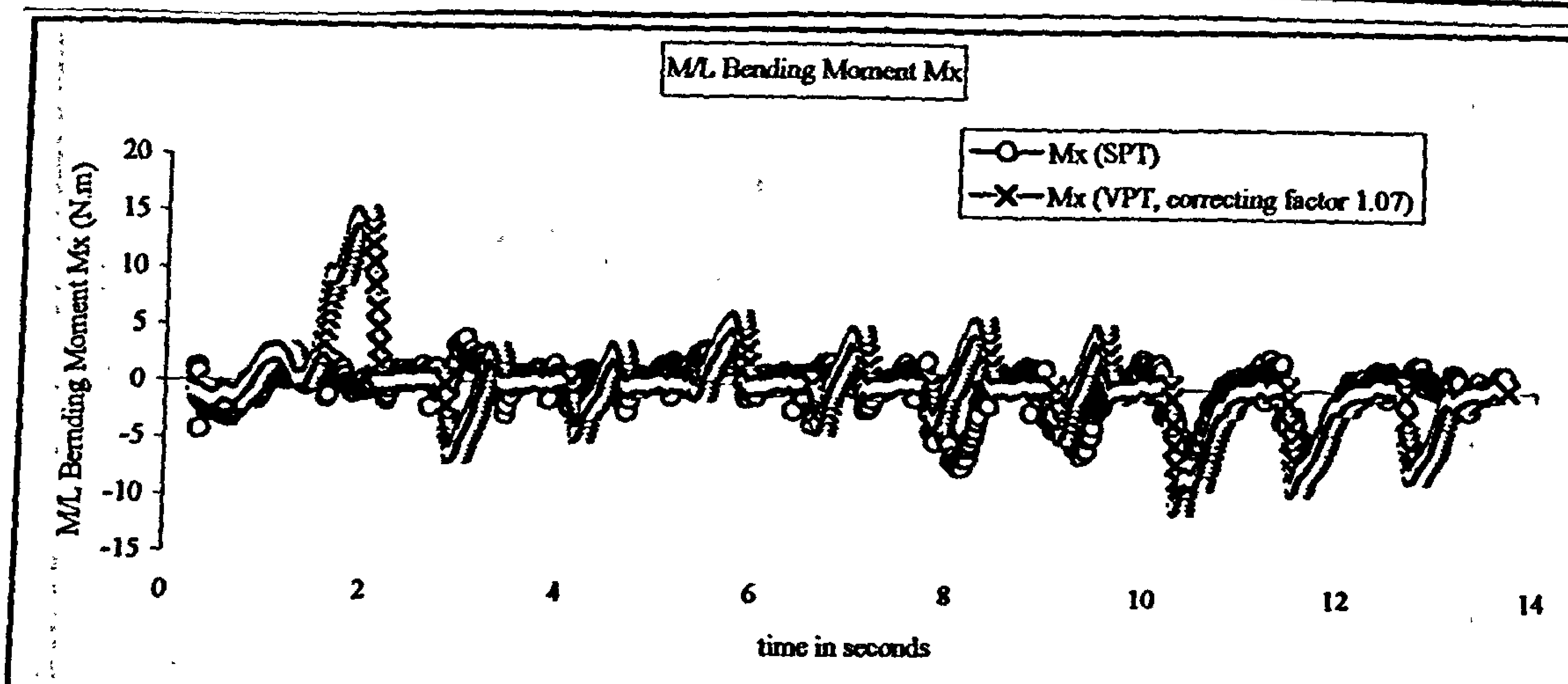


Figure VII.12: From trial n°2, the M/L bending moment Mx, simultaneously recorded from the two pylon transducers (VPT and SPT) is shown: raw data in mV (one scale for each transducer) (top), after applying the corresponding calibration matrix to each pylon transducer, in N.m (middle) and after applying the corresponding calibration matrix to each pylon transducer plus the correcting factors to the VPT, in N.m, (bottom).

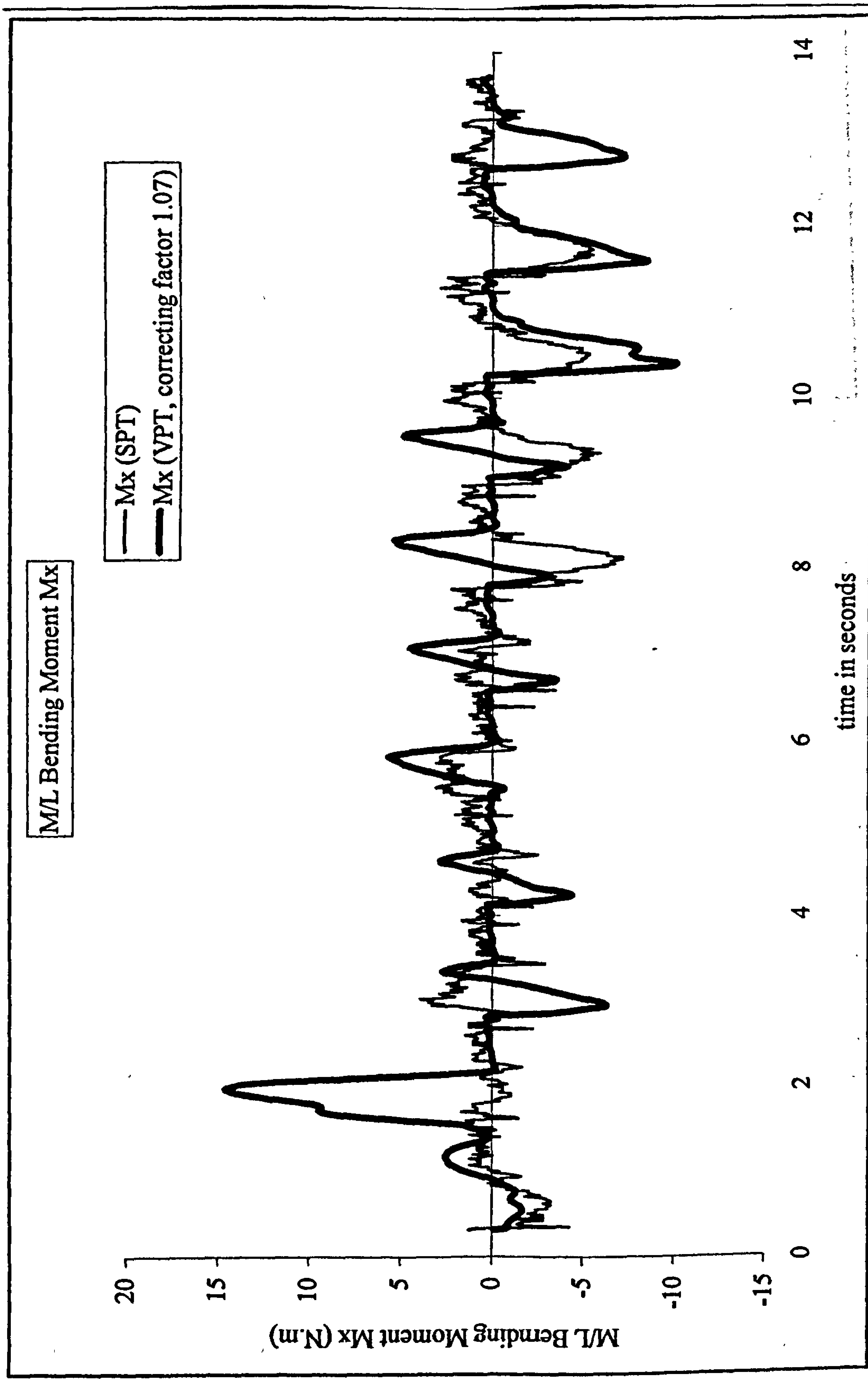


Figure VII.12a: The same as figure VII.12 (bottom) but magnified to improve the reading.

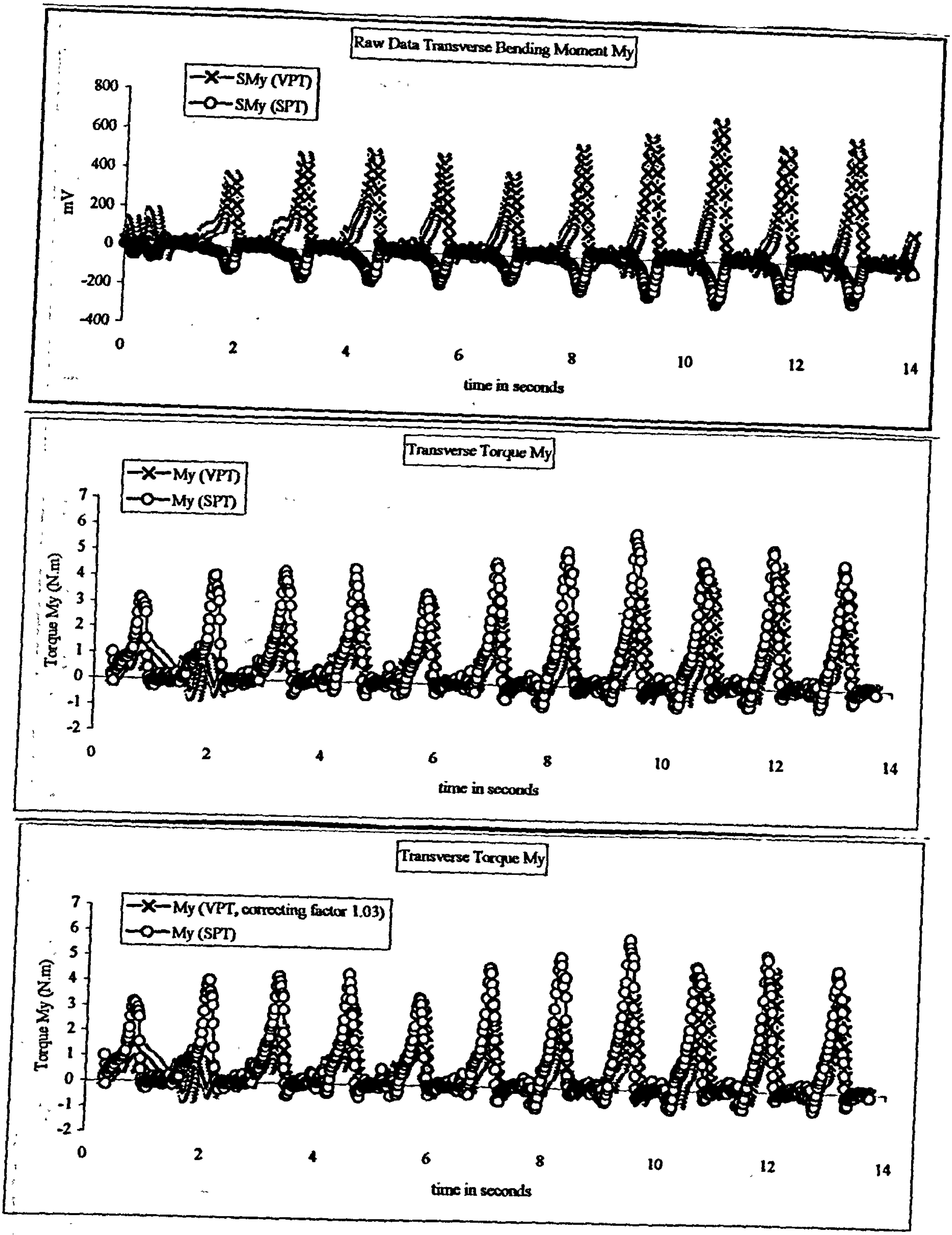


Figure VII.13: From trial n°2, the transverse torque My, simultaneously recorded from the two pylon transducers (VPT and SPT) is shown: raw data in mV (one scale for each transducer) (top), after applying the corresponding calibration matrix to each pylon transducer, in N.m (middle) and after applying the corresponding calibration matrix to each pylon transducer plus the correcting factors to the VPT, in N.m, (bottom).

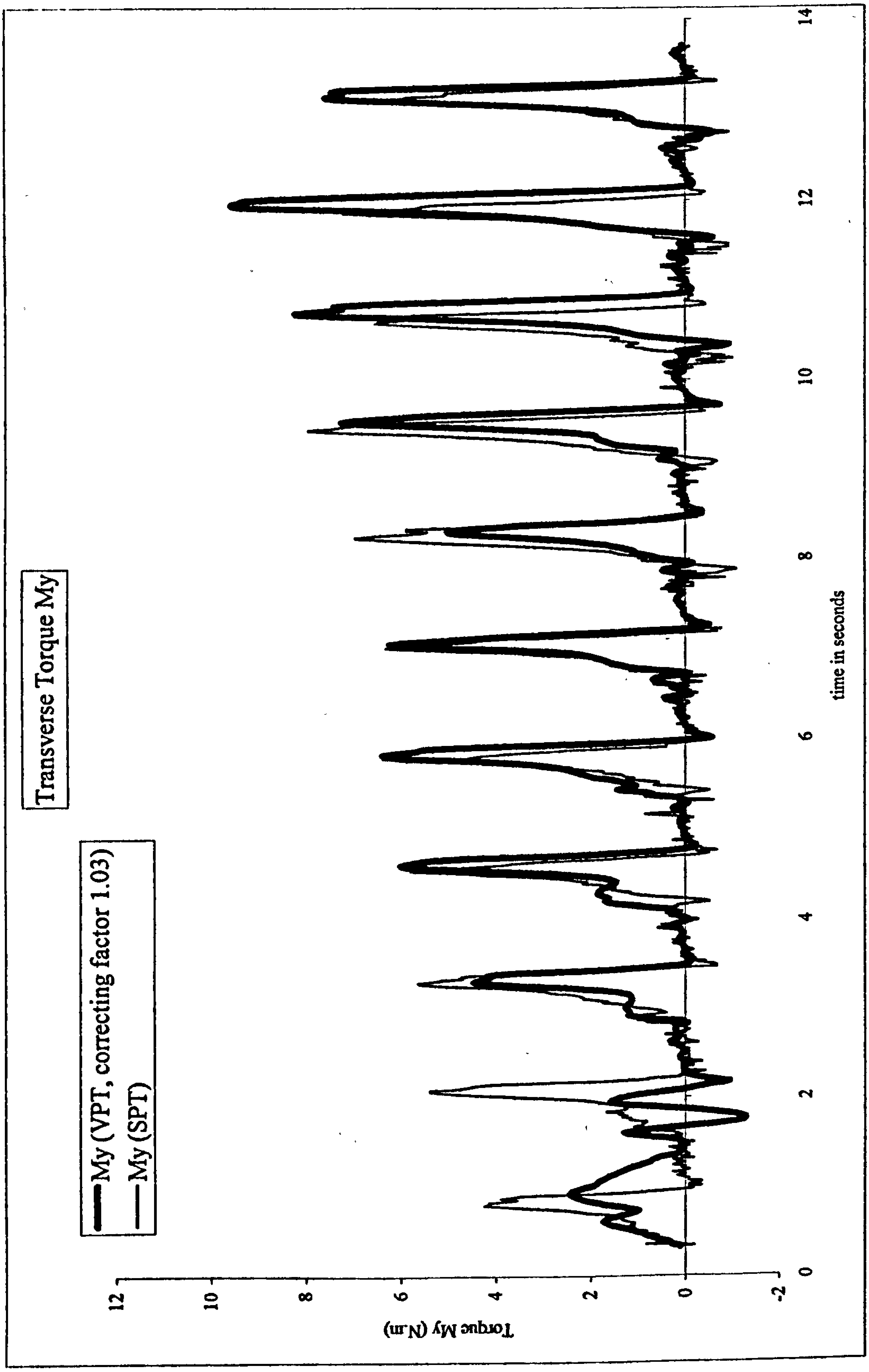


Figure VII.13a: The same as figure VII.13 (bottom) but magnified to improve the reading.

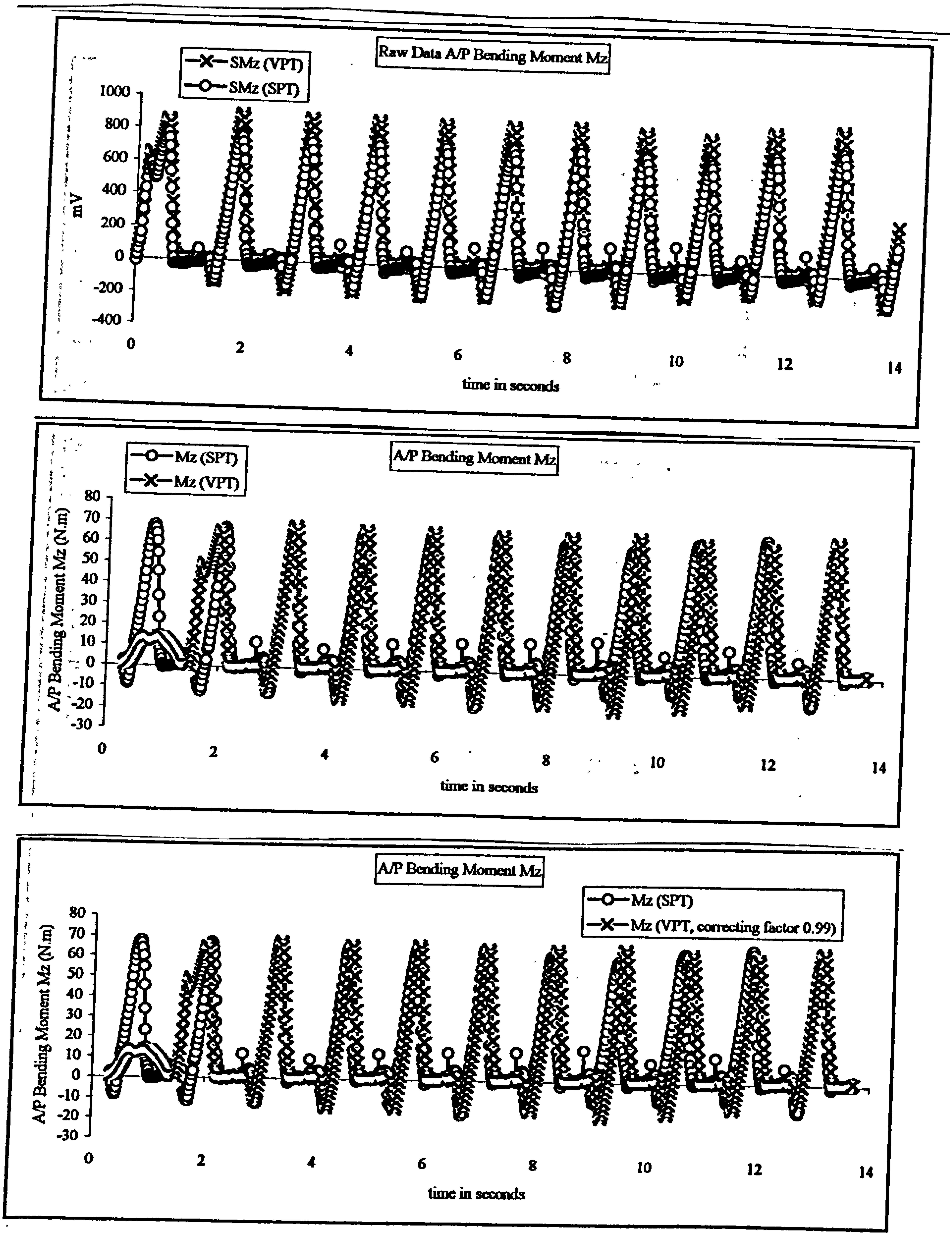


Figure VII.14: From trial n°2, the A/P bending moment Mz, simultaneously recorded from the two pylon transducers (VPT and SPT) is shown: raw data in mV (one scale for each transducer) (top), after applying the corresponding calibration matrix to each pylon transducer, in N.m (middle) and after applying the corresponding calibration matrix to each pylon transducer plus the correcting factors to the VPT, in N.m, (bottom).

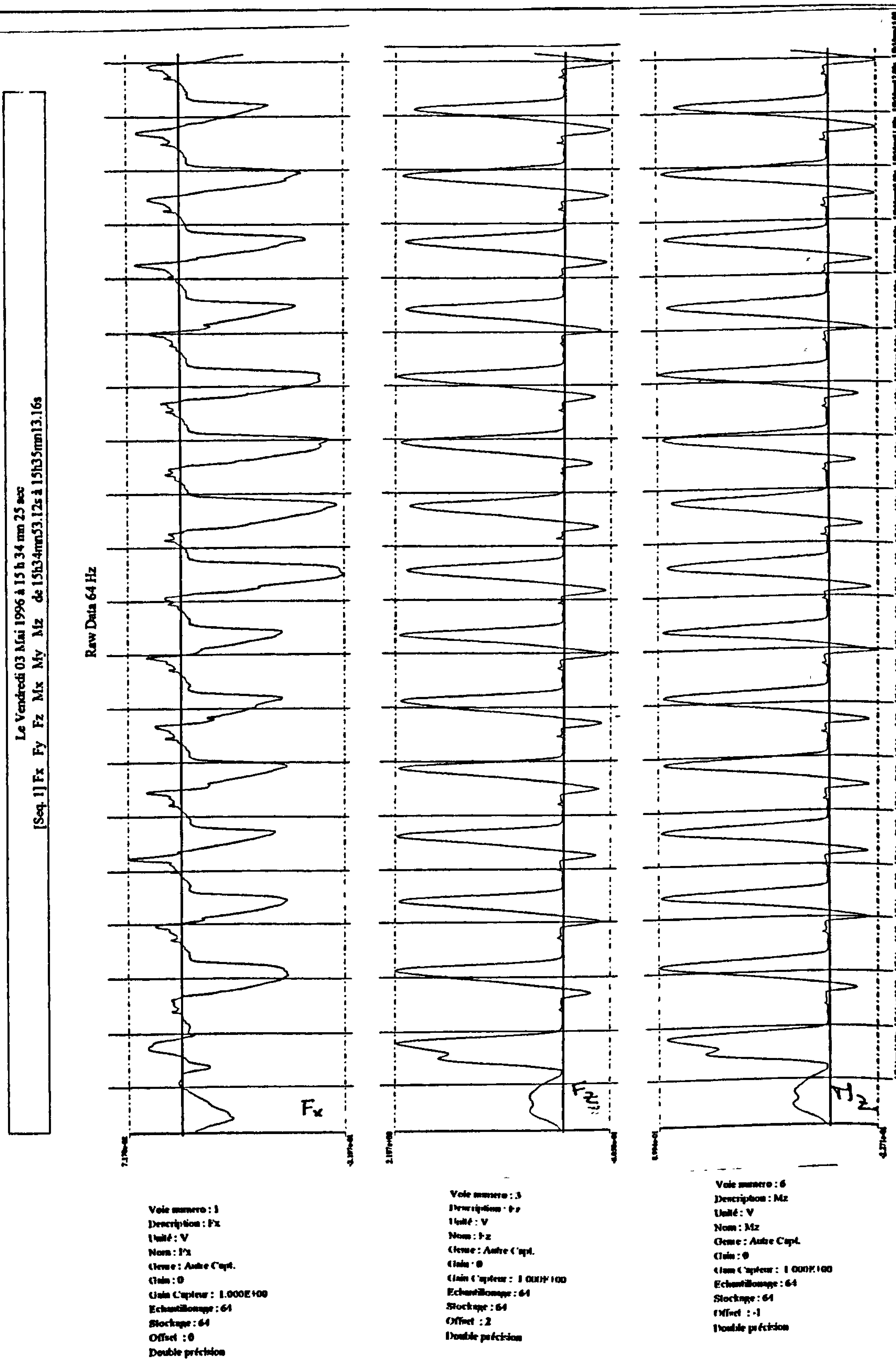


Figure VII.15a: From trial n°2 (sampling frequency of 64 Hz, 20 s, approximately 15 strides), raw data recorded from the VPT through the portable data acquisition system: A/P shear force Fx, M/L shear force Fz and M/L bending moment Mz. Raw data from M/L shear force and bending moment are presented in the same figure to show how there shapes were similar. The units are V vs. a base of time in seconds.

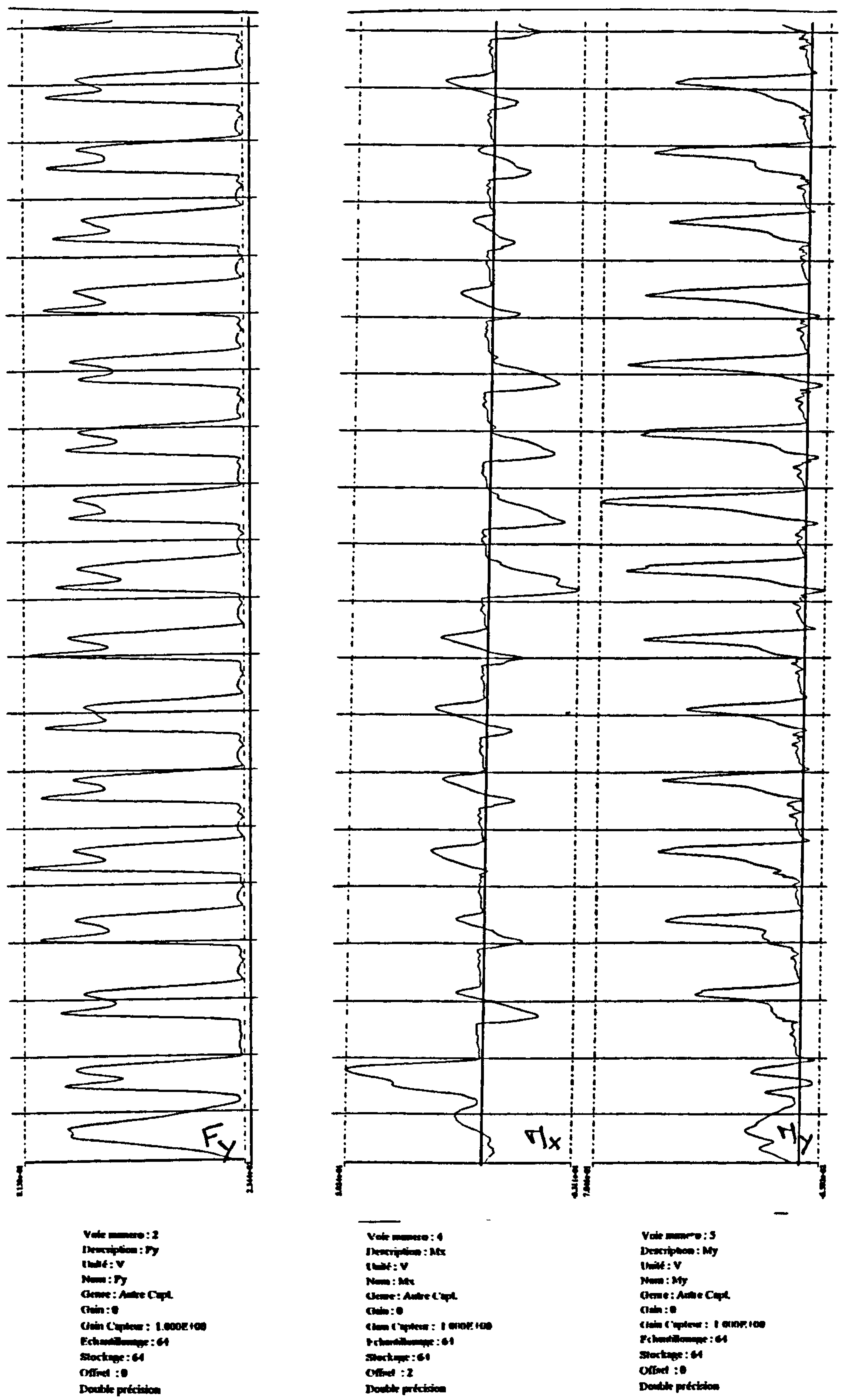


Figure VII.15b: From trial n°2 (sampling frequency of 64 Hz, 20 s, approximately 15 strides), raw data recorded from the VPT through the portable data acquisition system: axial load Fy, M/L bending moment Mx and transverse torque My. The units are V vs. a base of time in seconds.

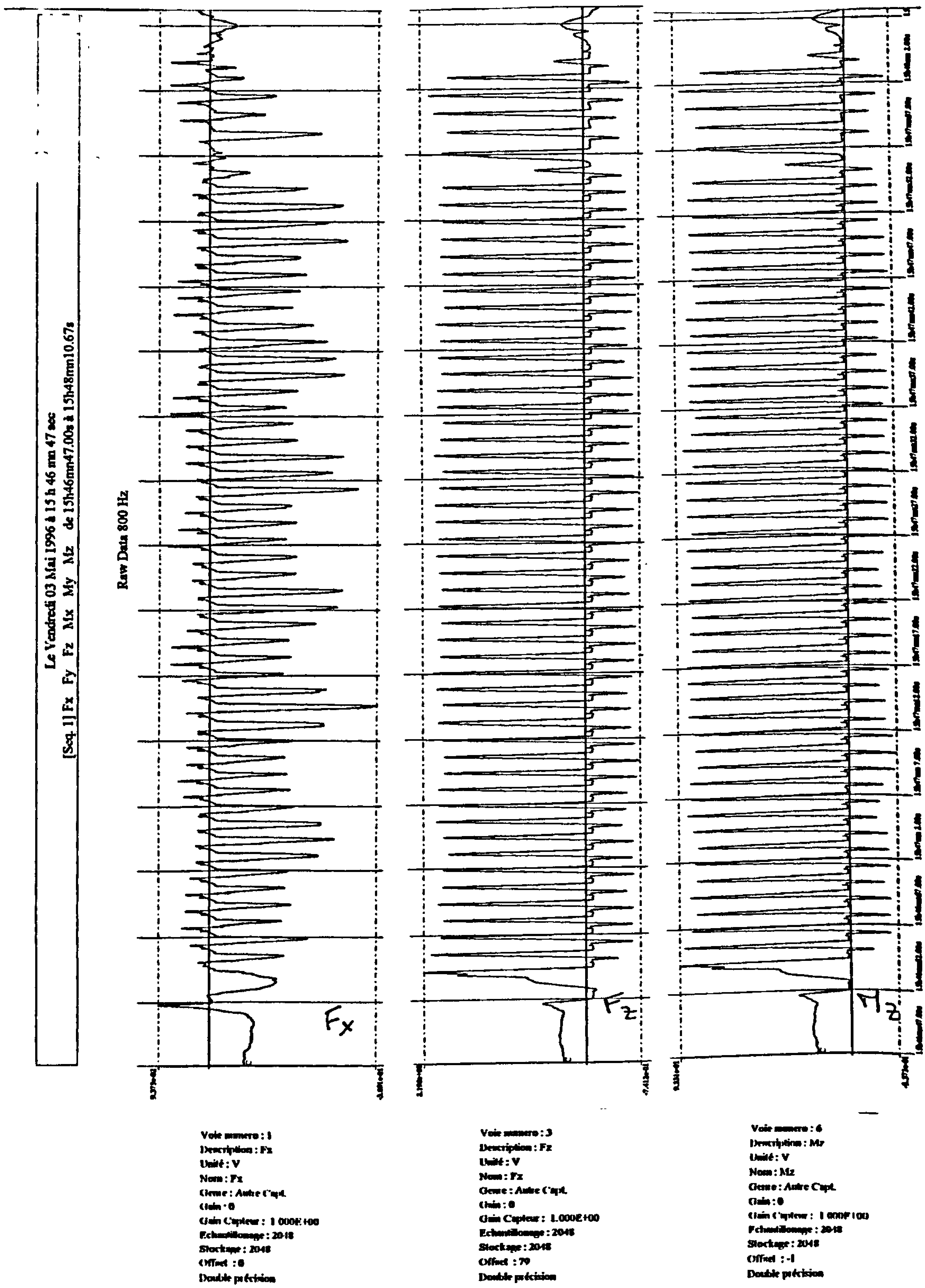


Figure VII.16a: From trial n°3 (sampling frequency of 2048 Hz, 84 s, approximately 55 strides), raw data recorded from the VPT through the portable data acquisition system: A/P shear force Fx, M/L shear force Fz and M/L bending moment Mz. Raw data from M/L shear force and bending moment are presented in the same figure to show how there shapes were similar. The units are V vs. a base of time in seconds.

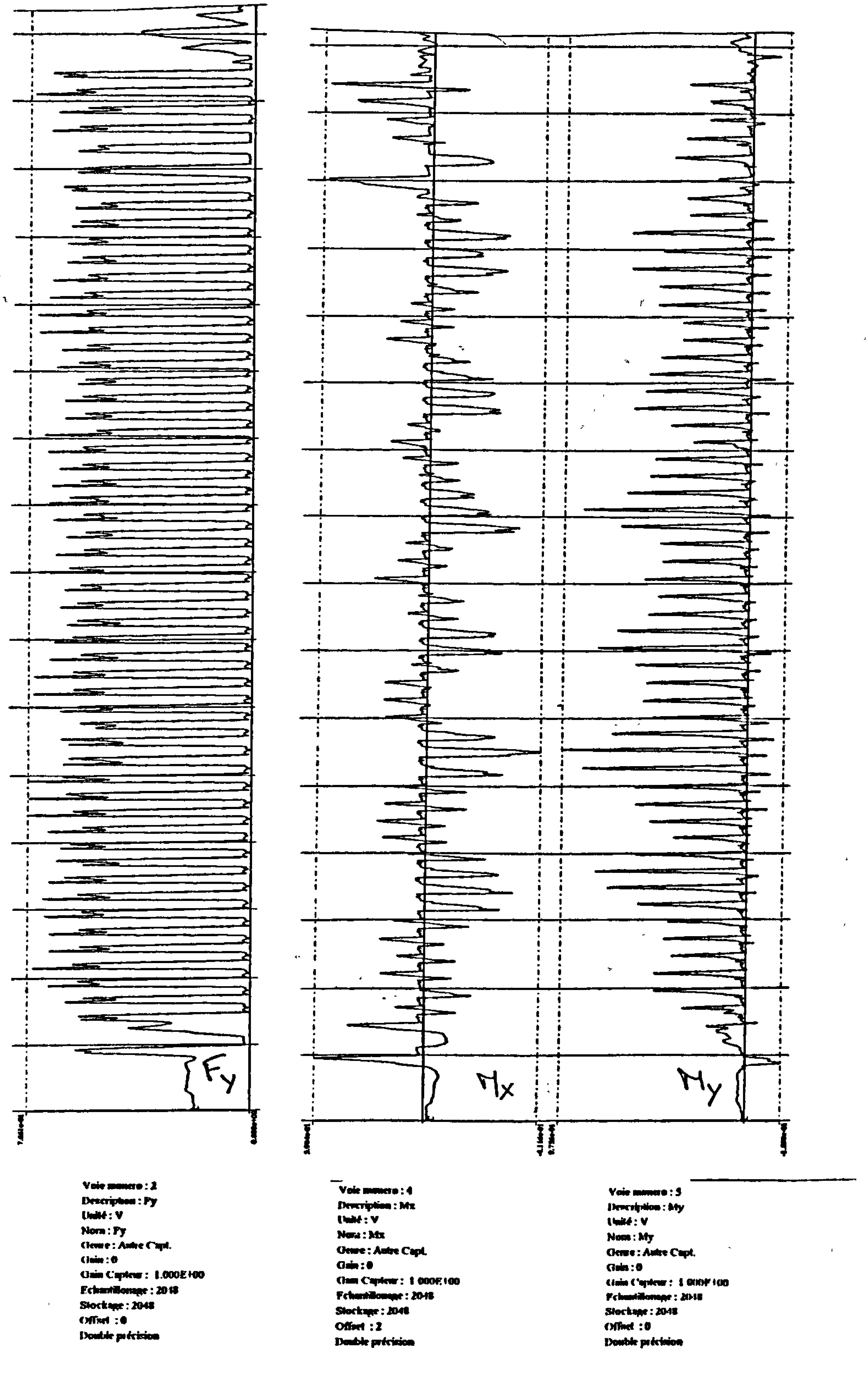
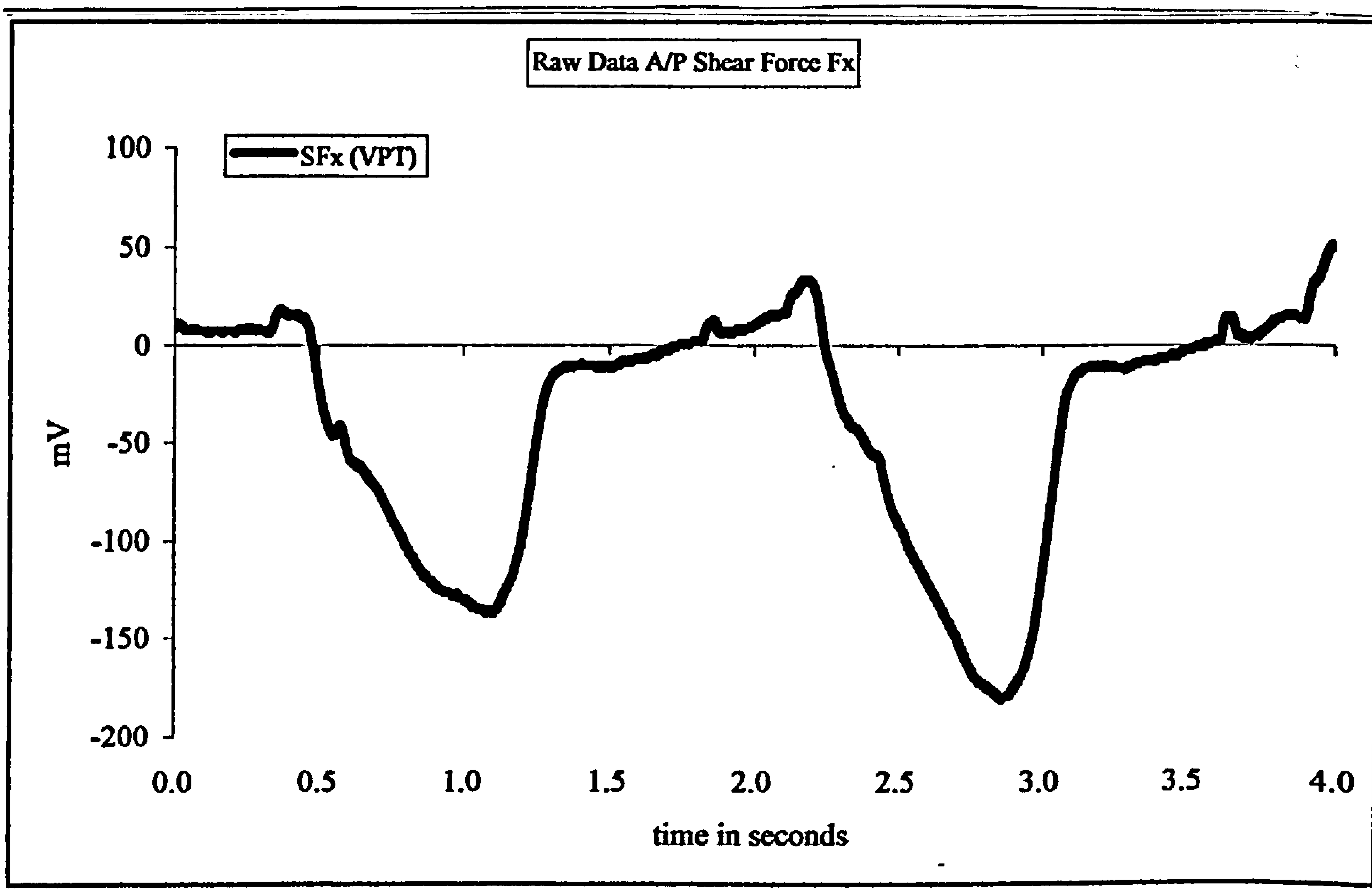


Figure VII.16b: From trial n°3 (sampling frequency of 2048 Hz, the complete test: 84 s, approximately 55 strides), raw data recorded from the VPT through the portable data acquisition system: axial load Fy, M/L bending moment Mx and transverse torque My. The units are V vs. a base of time in seconds.



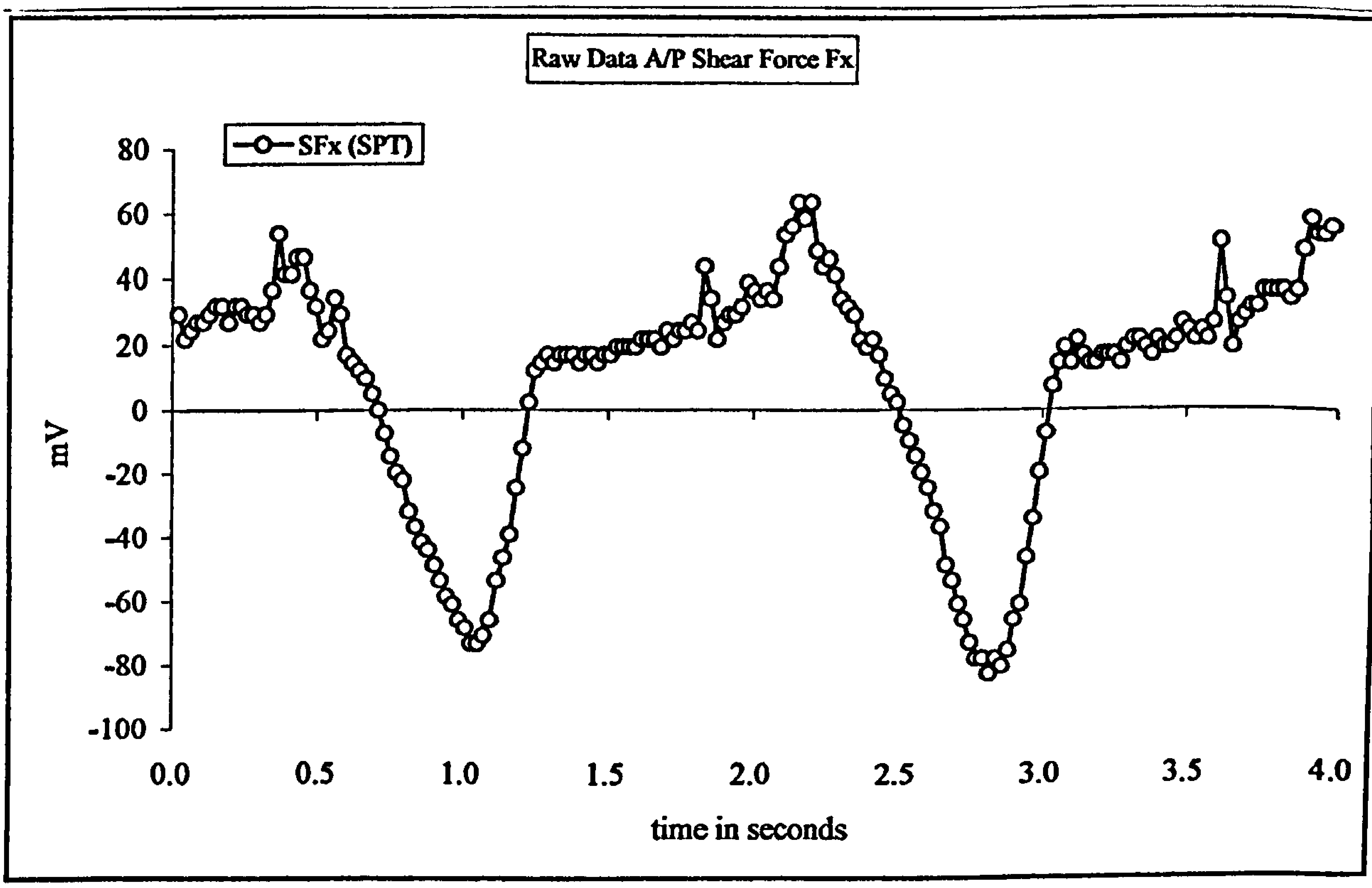


Figure VII.17a: From trial n°3 with a sampling frequency of 800 Hz for the VPT, raw data of the A/P shear force Fx, simultaneously recorded from the two pylon transducers (VPT, top and SPT, bottom) are shown. The results are in mV versus a base of time in seconds.

11.VII.7.3 THE TRIAL N°3 IN WHICH THE VILLIERS PYLON TRANSDUCER WAS RECORDED AT A SAMPLING FREQUENCY OF 2048 HZ

This trial is shown under a specific form because of the sampling frequency of 2048 Hz used to record the VPT. This procedure was adopted to eliminate the Butterworth 4th order filter, having a cut-off frequency of 6 Hz when the sampling frequency is 64 Hz (see section 7.3). This was done, having the goal to verify if the data were modified by the automatic numerical filtering. Therefore, it was necessary to choose in a random manner two strides (duration 2.93 seconds = 6000 rows in the spreadsheet). This were the maximum data being calculated by the spreadsheet.

The raw data from each pylon transducer are shown in two different graphs. The processed data recorded from the two pylon transducers are shown simultaneously on the same graphs.

The schedule of the following pages is as follows:

Figures VII.17a, VII.17b and VII.17c show respectively raw data, processed data and processed data with the correcting factors recorded in A/P shear force Fx. Theses data were recorded from the VPT and the SPT;

Figures VII.18a to VII.18c, have the same arrangement for axial load Fy.

Figures VII.19a to VII.19c, have the same arrangement for M/L shear force Fz.

Figures VII.20a to VII.22c, are equivalent for the three bending moments .

All these figures show that a high sampling frequency does not affect the results. It is thus proved that the choice of a sampling rate of 64 Hz was an accurate choice considering the requirements expressed in chapter 1.

Here also, the use of the multiplying factors (see graphs with "c" as subscript and section 7.7.1) improves the results recorded through the new Villiers Pylon Transducer.

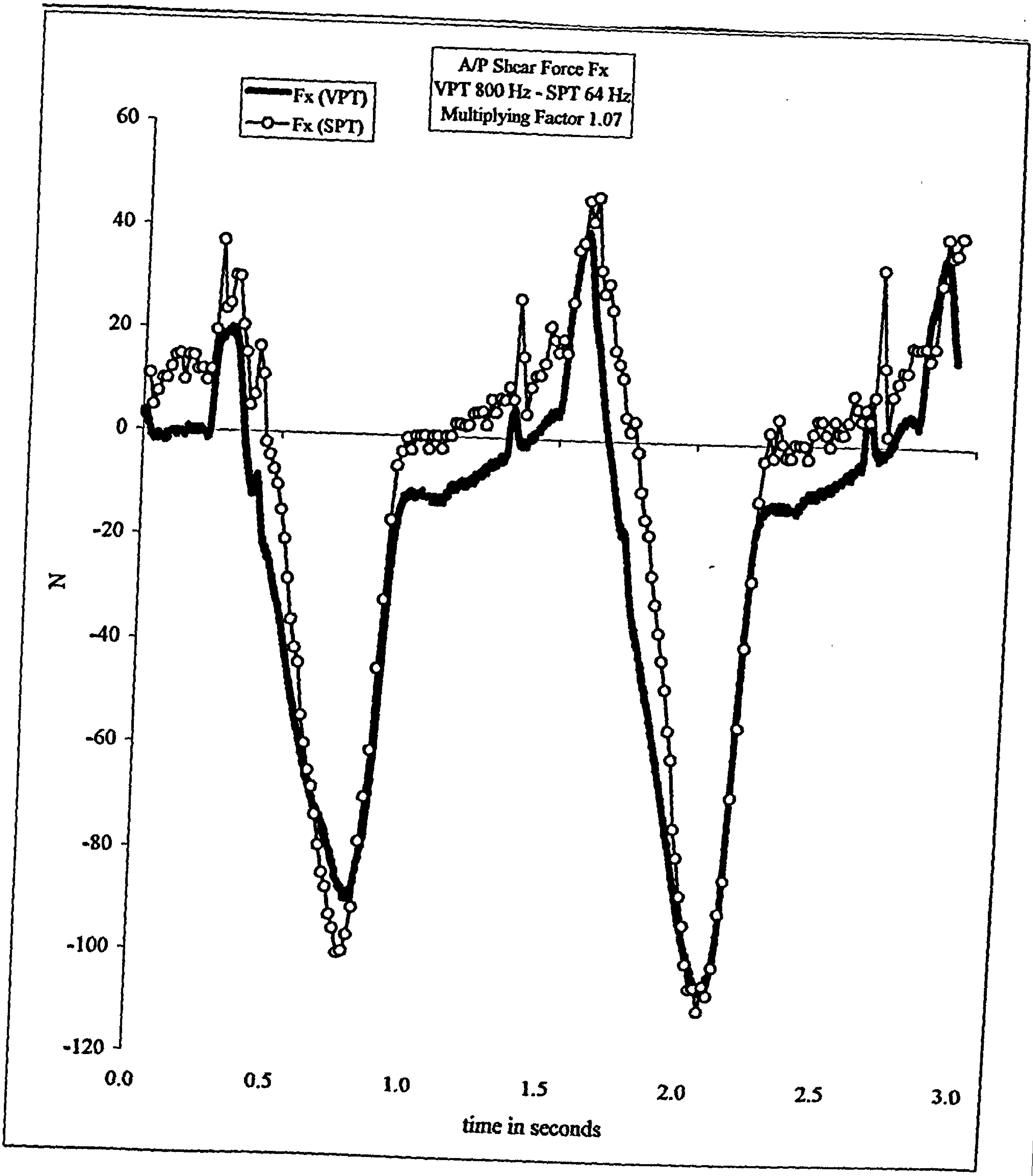


Figure VII.17c: From trial n°3 with a sampling frequency of 800 Hz for the VPT, the A/P shear force Fx, simultaneously recorded from the two pylon transducers (VPT and SPT) is shown after applying the corresponding calibration matrix to each pylon transducer. The correcting factor of 1.07, established in section 7.8.1 for the A/P shear force Fx, was applied to the new Villiers Pylon Transducer (VPT)The results are in N versus a base of time in seconds.

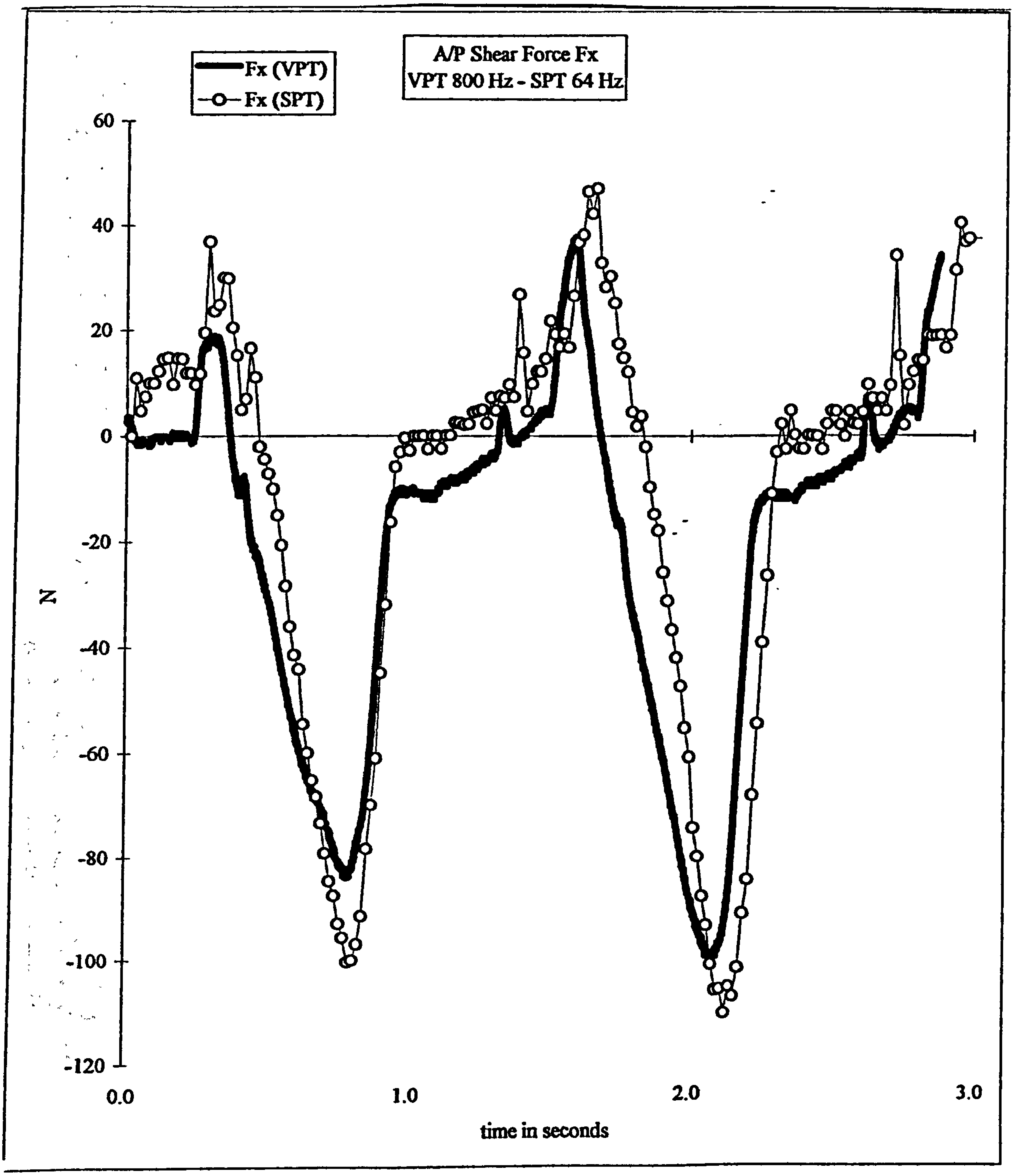


Figure VII.17b: From trial n°3 with a sampling frequency of 800 Hz for the VPT, the A/P shear force Fx, simultaneously recorded from the two pylon transducers (VPT and SPT) is shown after applying the corresponding calibration matrix to each pylon transducer. The results are in N versus a base of time in seconds.

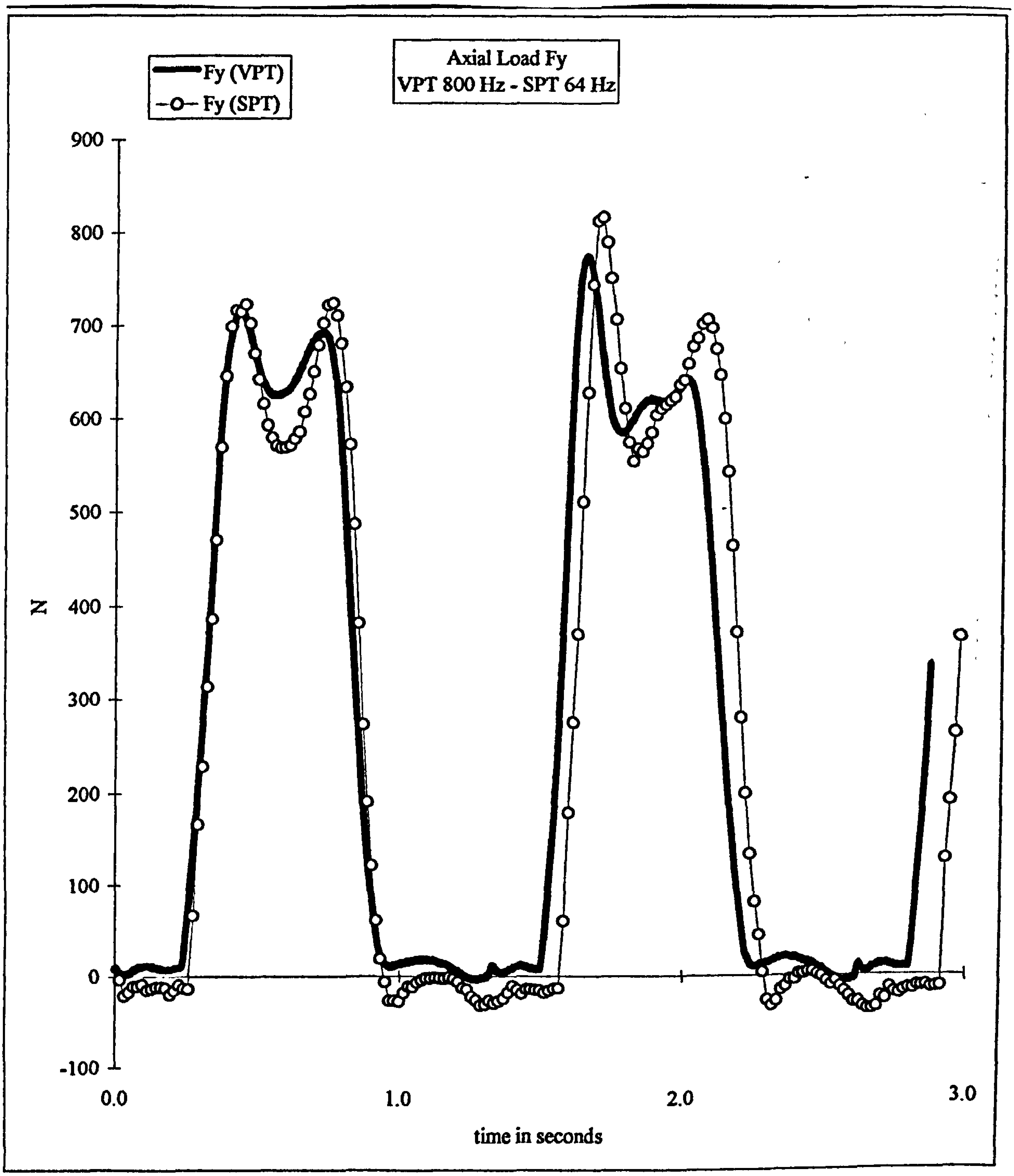
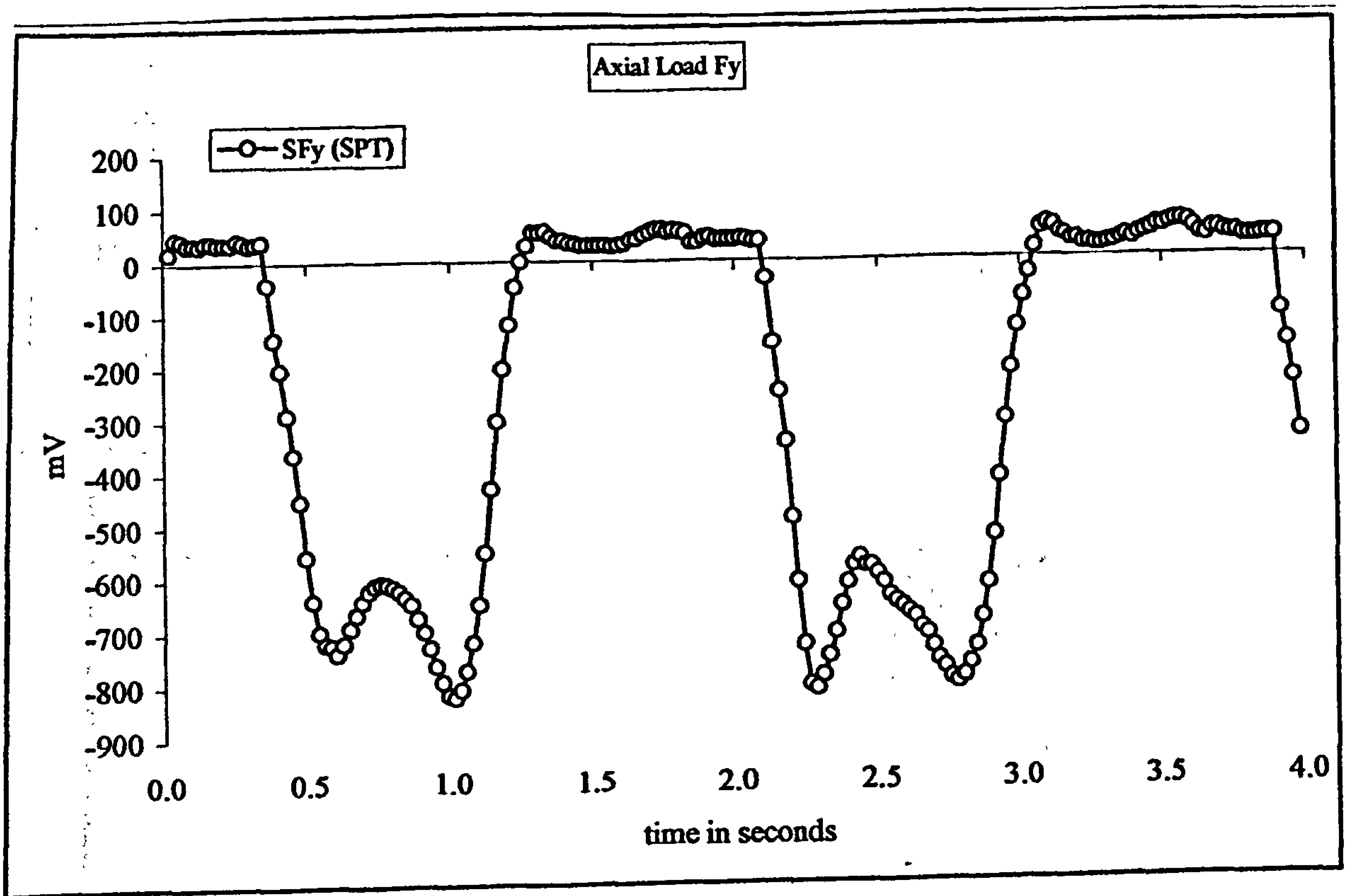


Figure VII.18b: From trial n°3 with a sampling frequency of 800 Hz for the VPT, the axial load Fy, simultaneously recorded from the two pylon transducers (VPT and SPT) is shown after applying the corresponding calibration matrix to each pylon transducer. The results are in N versus a base of time in seconds.



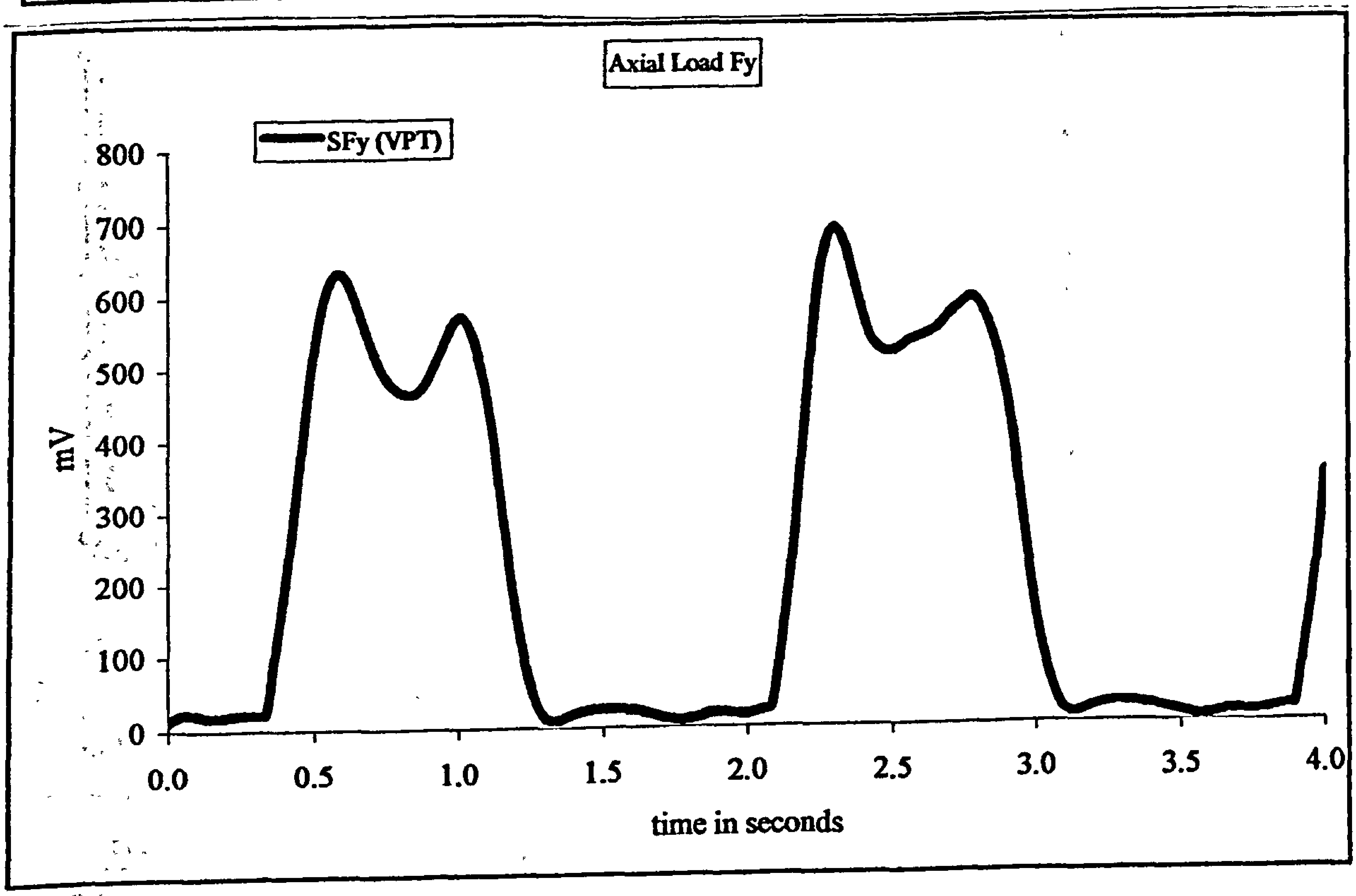


Figure VII.18a: From trial n°3 with a sampling frequency of 800 Hz for the VPT, raw data of the axial load Fy, simultaneously recorded from the two pylon transducers (VPT, top and SPT, bottom) are shown. The results are in mV versus a base of time in seconds.

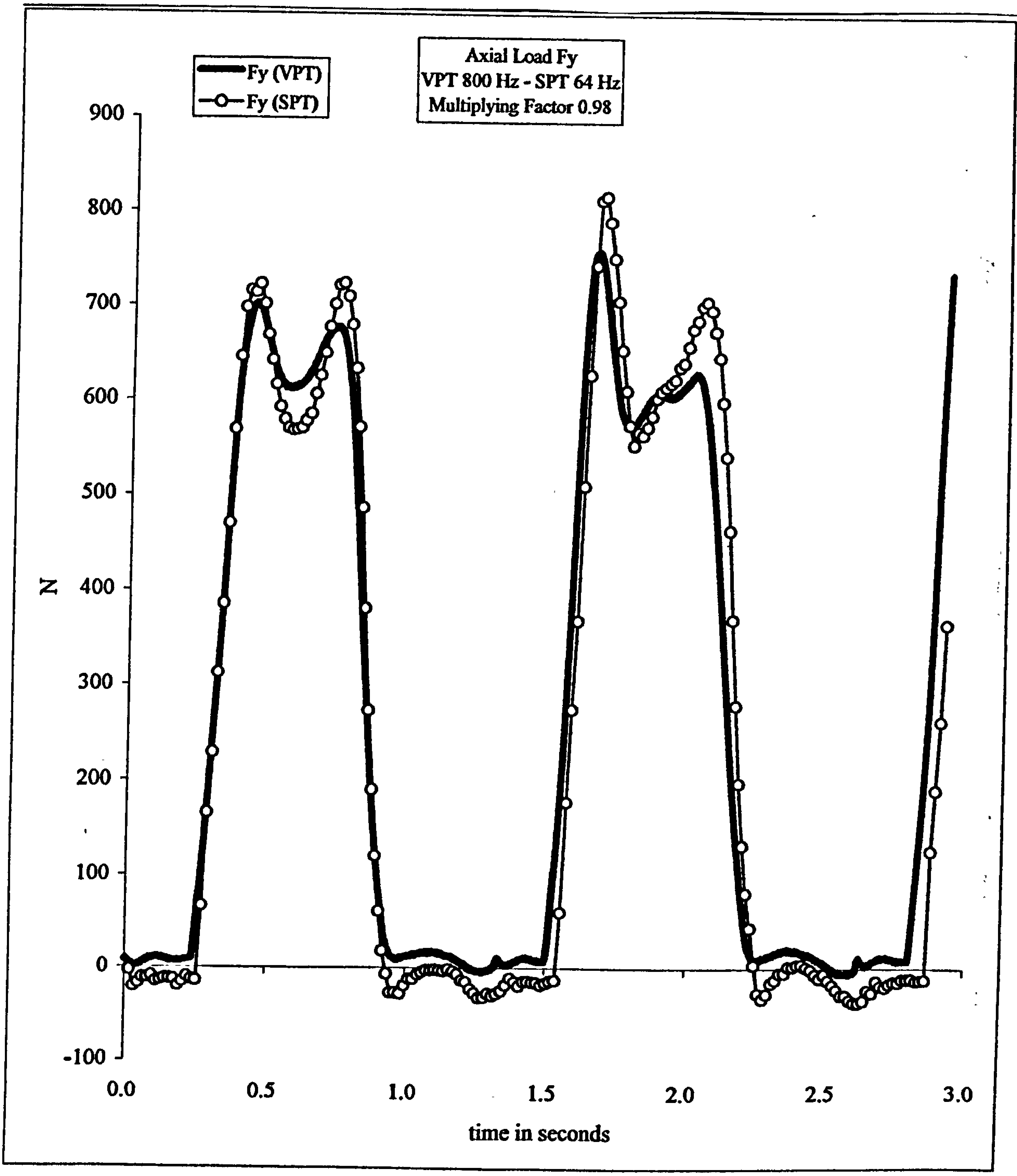
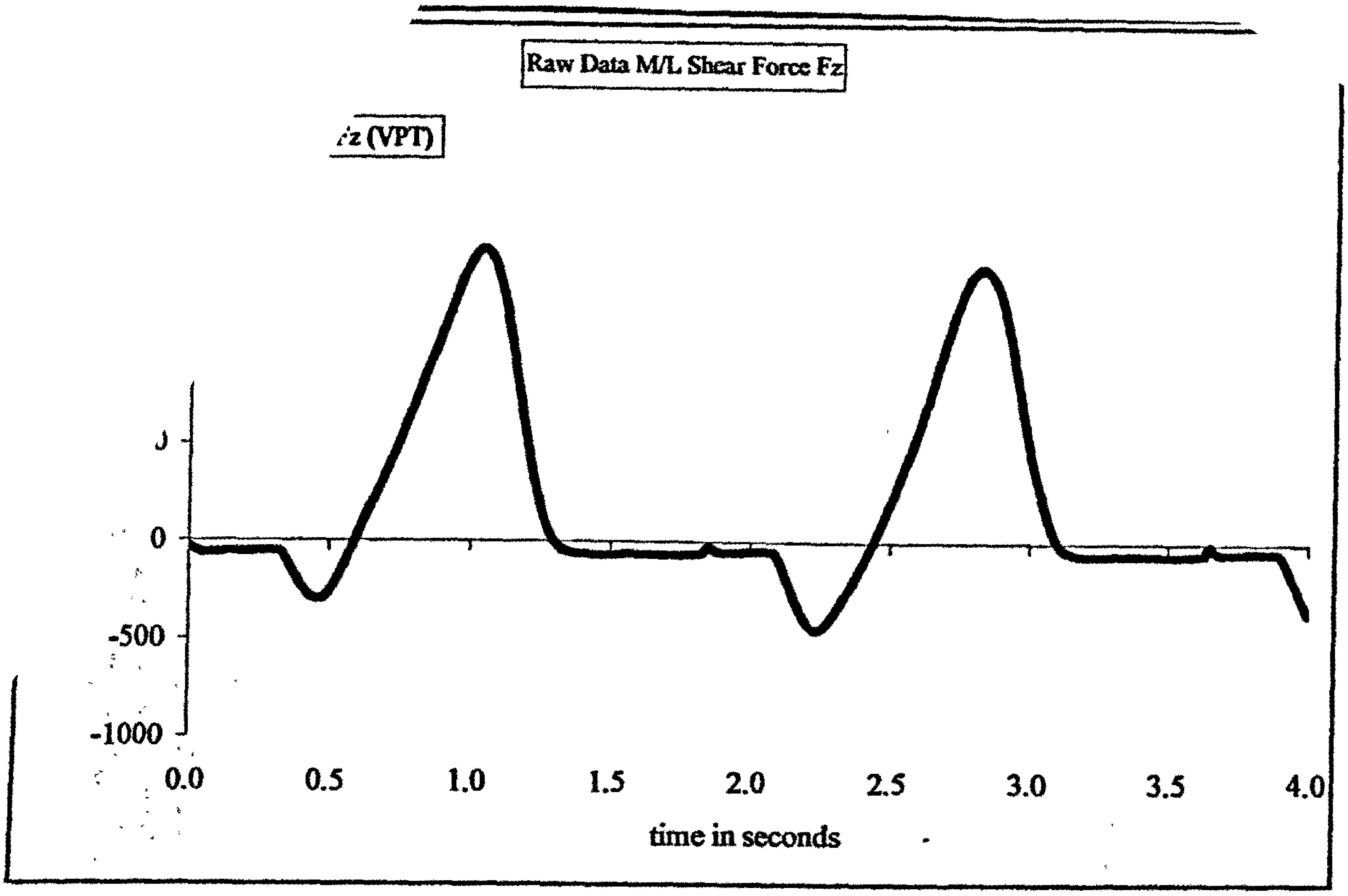


Figure VII.18c: From trial n°3 with a sampling frequency of 800 Hz for the VPT, the axial load Fy, simultaneously recorded from the two pylon transducers (VPT and SPT) is shown after applying the corresponding calibration matrix to each pylon transducer. The correcting factor of 0.98, established in section 7.8.1 for the axial load Fy, was applied to the new Villiers Pylon Transducer (VPT). The results are in N versus a base of time in seconds.



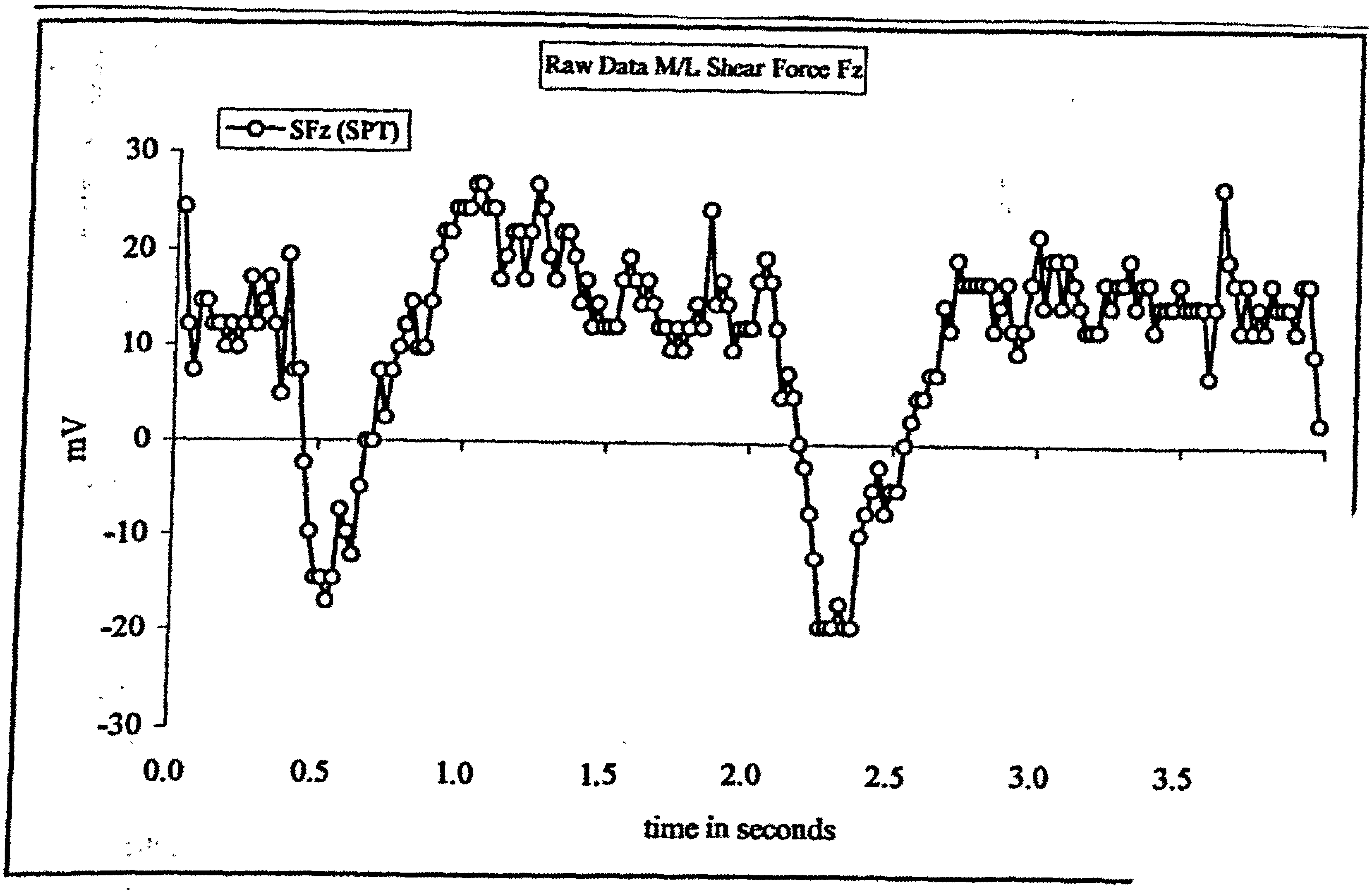


Figure VII.19a: From trial n°3 with a sampling frequency of 800 Hz for the VP
the M/L shear force Fz, simultaneously recorded from the two pylon transd
and SPT, bottom) are shown. The results are in mV versus a base of time in

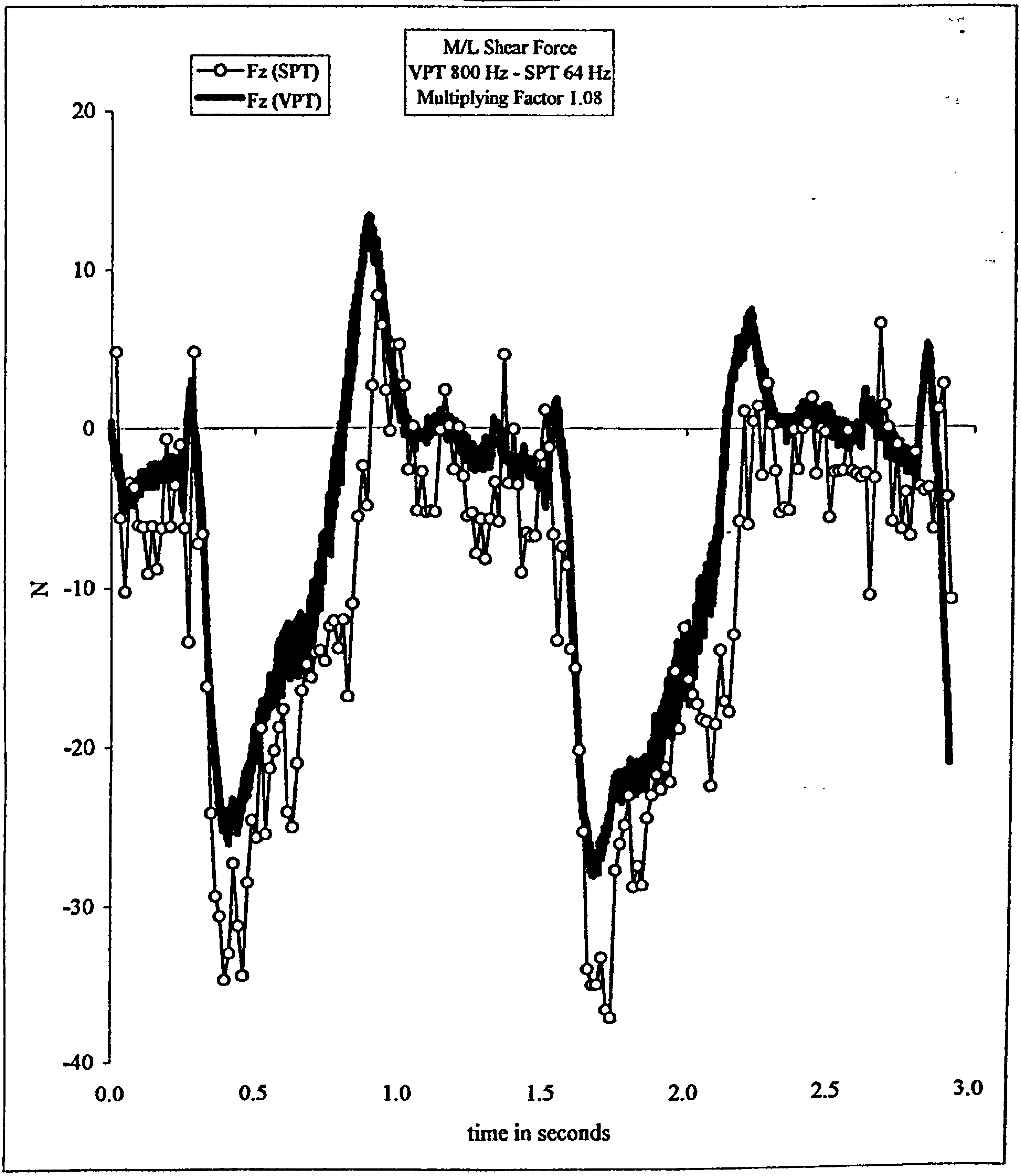


Figure VII.19c: From trial n°3 with a sampling frequency of 800 Hz for the VPT, the M/L shear force Fz, simultaneously recorded from the two pylon transducers (VPT and SPT) is shown after applying the corresponding calibration matrix to each pylon transducer. The correcting factor of 1.38, established in section 7.8.1 for the axial load Fy, was applied to the new Villiers Pylon Transducer (VPT). The results are in N versus a base of time in seconds.

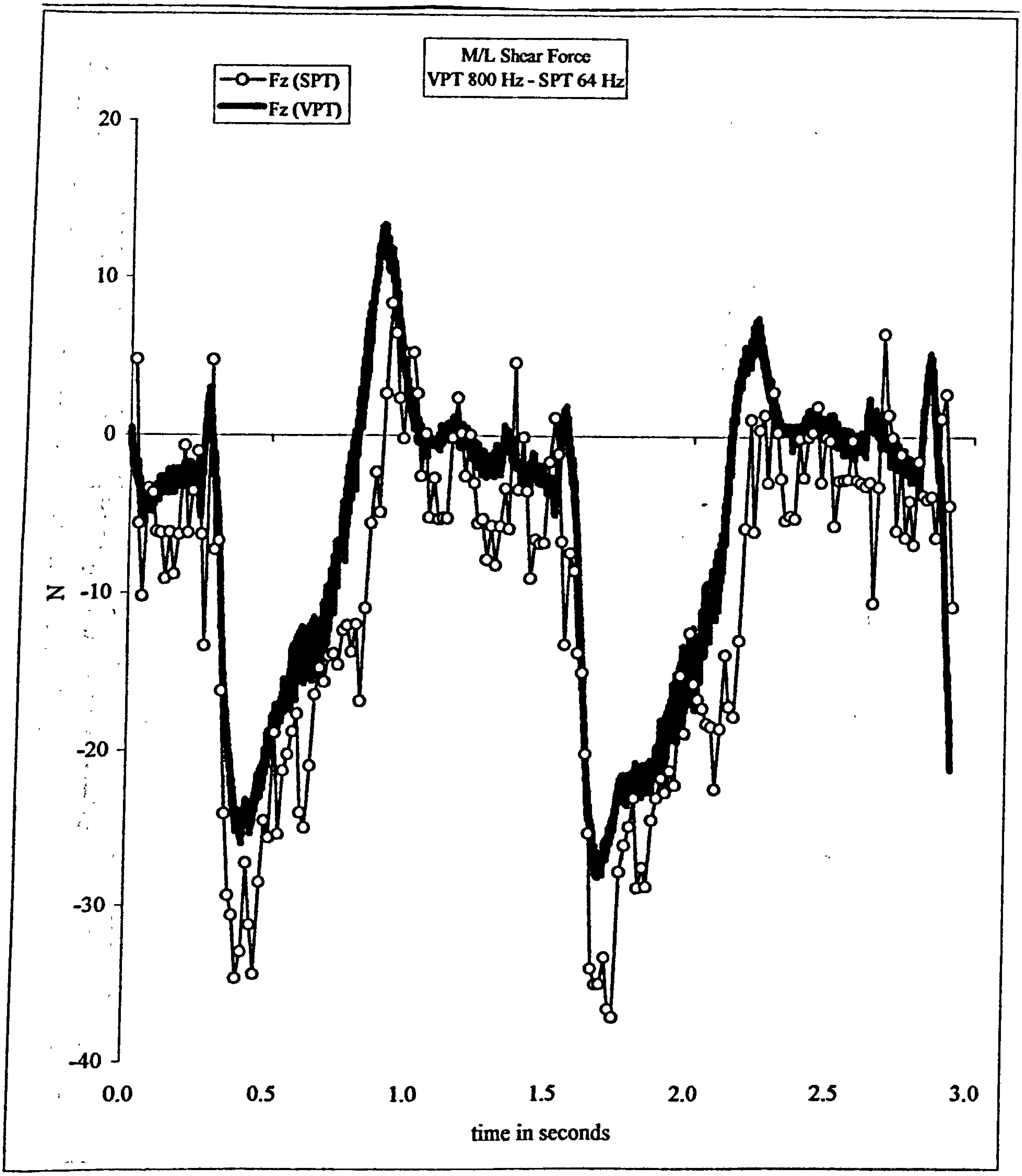


Figure VII.19b: From trial n°3 with a sampling frequency of 800 Hz for the VPT, the M/L shear force Fz, simultaneously recorded from the two pylon transducers (VPT and SPT) is shown after applying the corresponding calibration matrix to each pylon transducer. The results are in N versus a base of time in seconds.

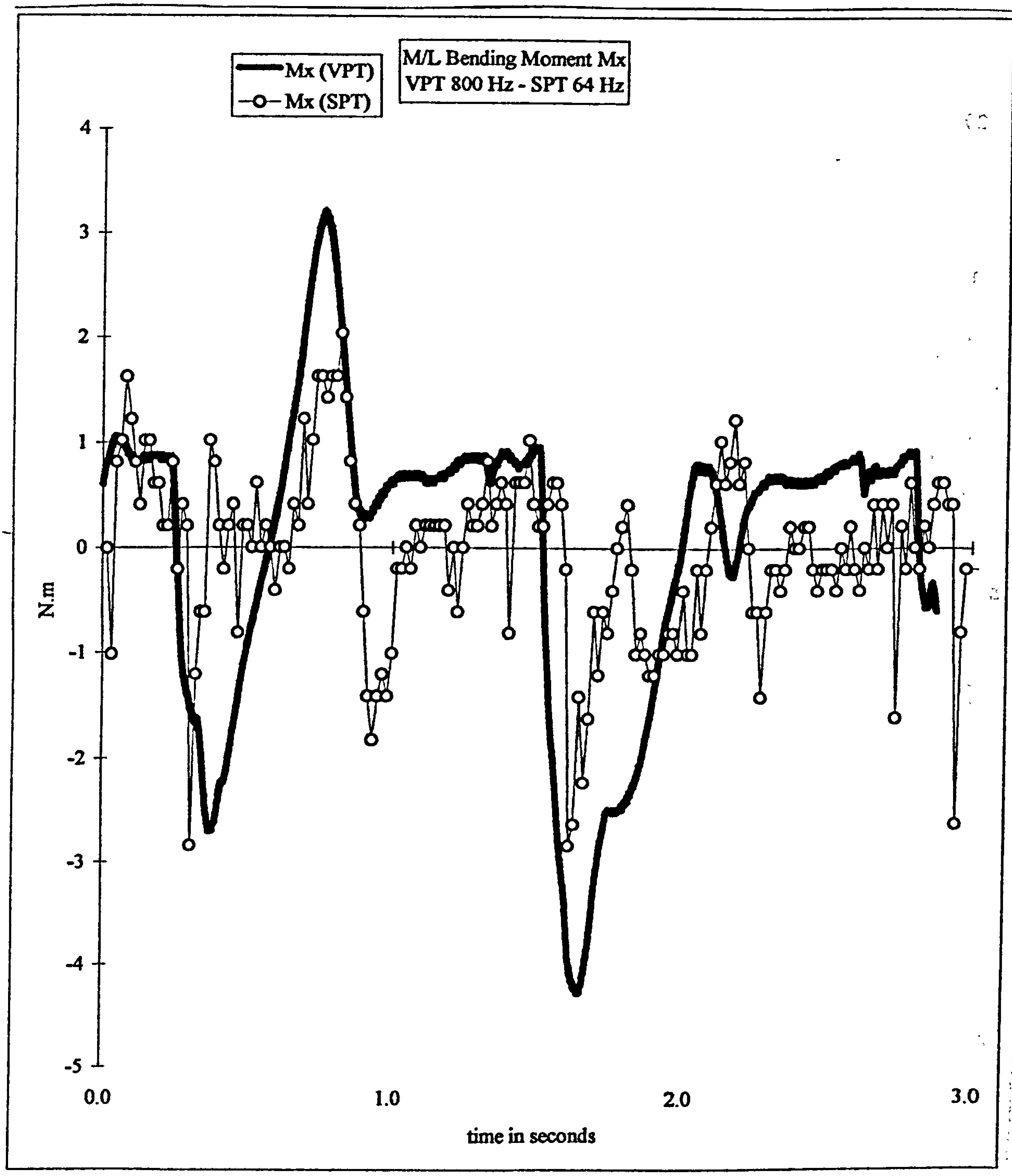
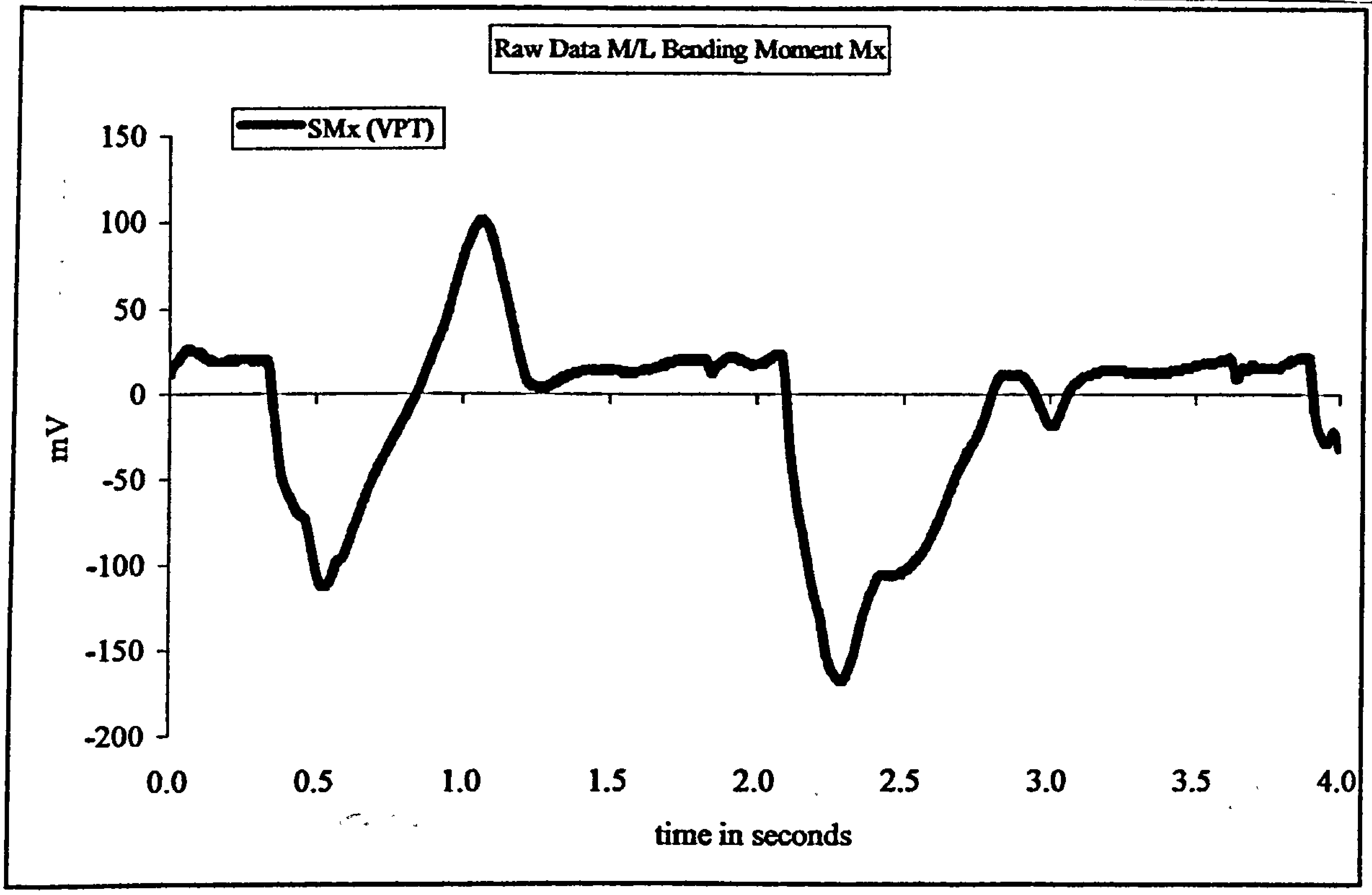


Figure VII.20b: From trial N°3 with a sampling frequency of 800 Hz for the VPT, the M/L bending moment Mx, simultaneously recorded from the two pylon transducers (VPT and SPT) is shown applying the corresponding calibration matrix to each pylon transducer. The results are in N.m versus a base of time in seconds.



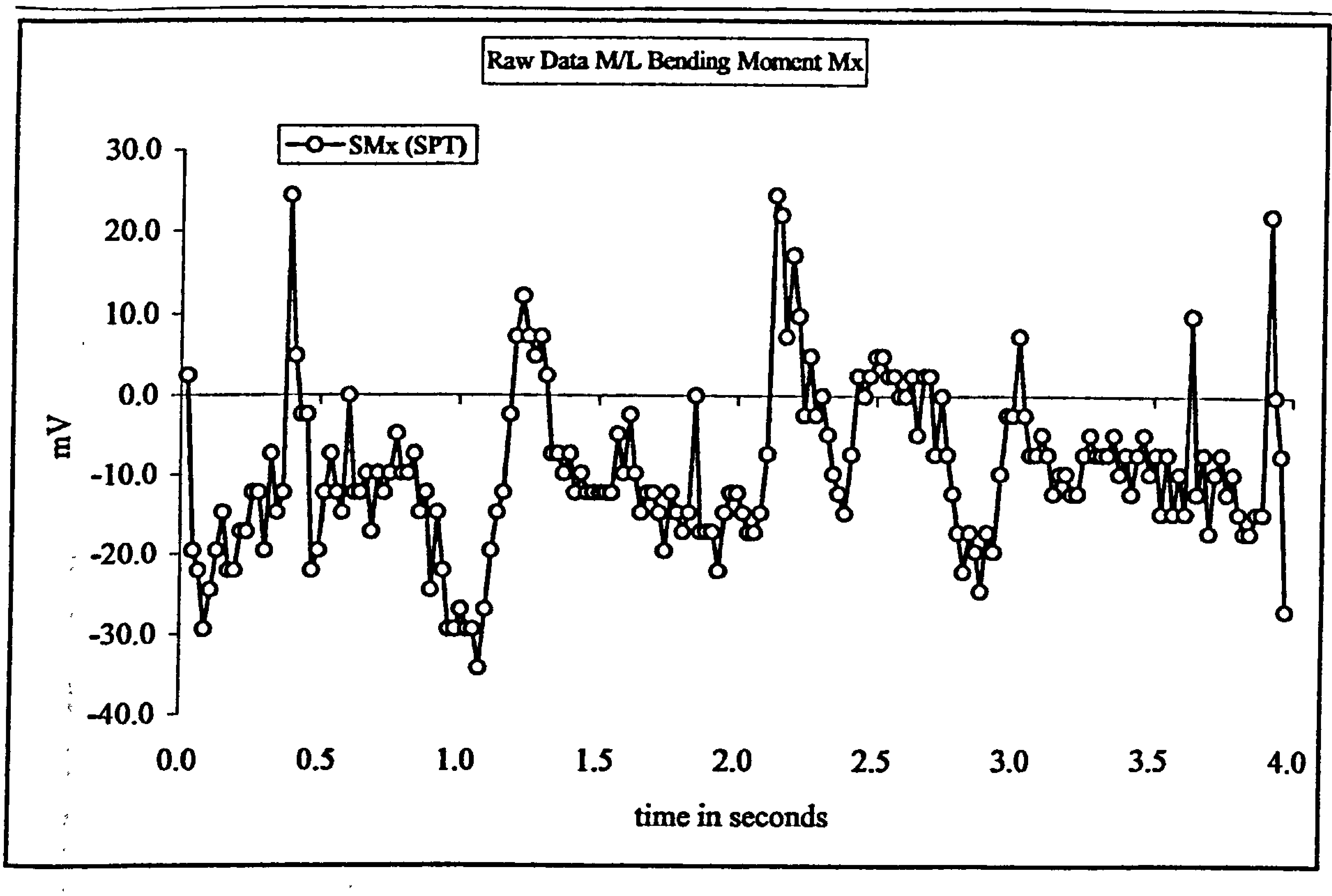


Figure VII.20a: From trial n°3 with a sampling frequency of 800 Hz for the VPT, raw data of the M/L bending moment Mx, simultaneously recorded from the two pylon transducers (VPT, top and SPT, bottom) are shown. The results are in mV versus a base of time in seconds.

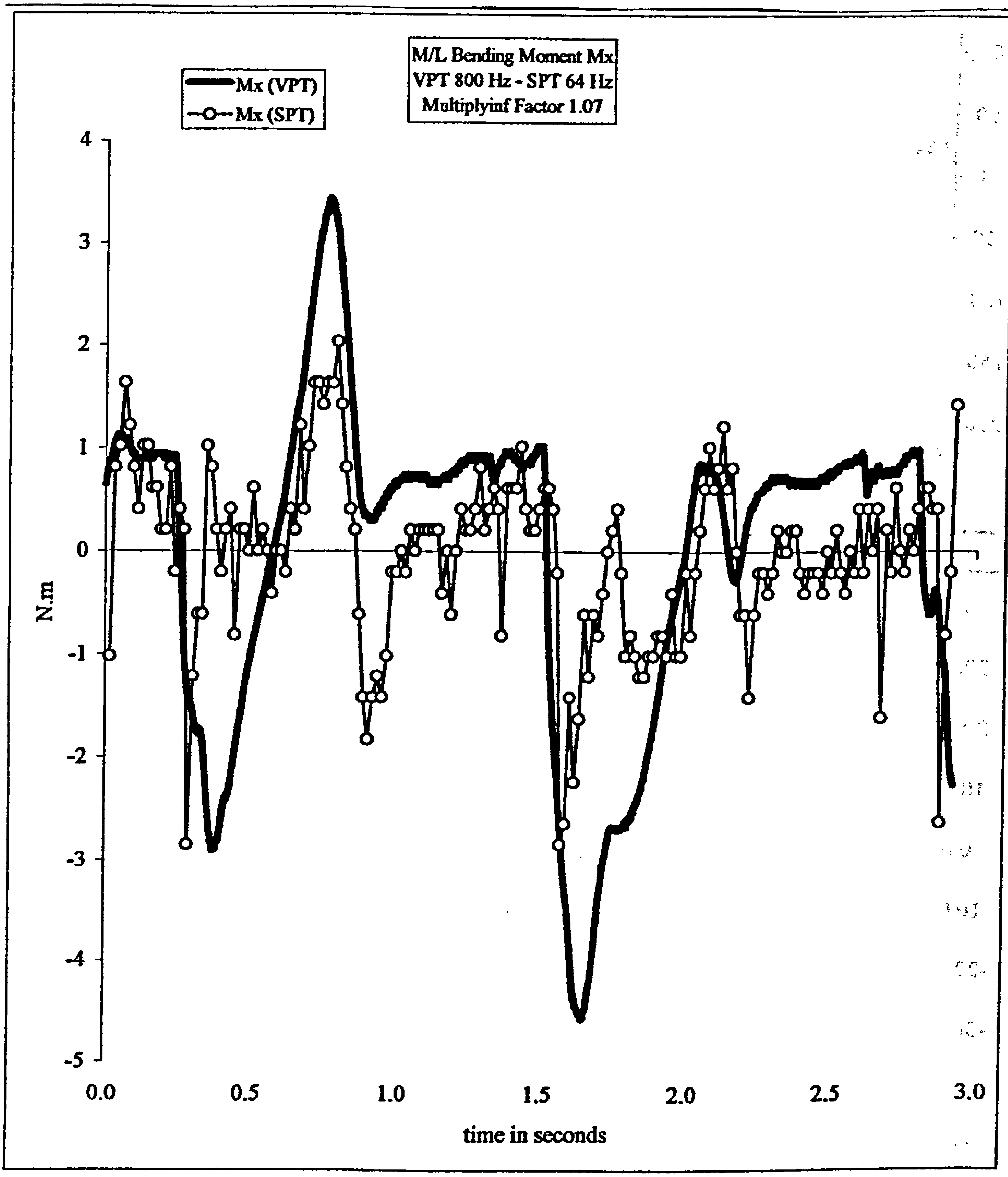
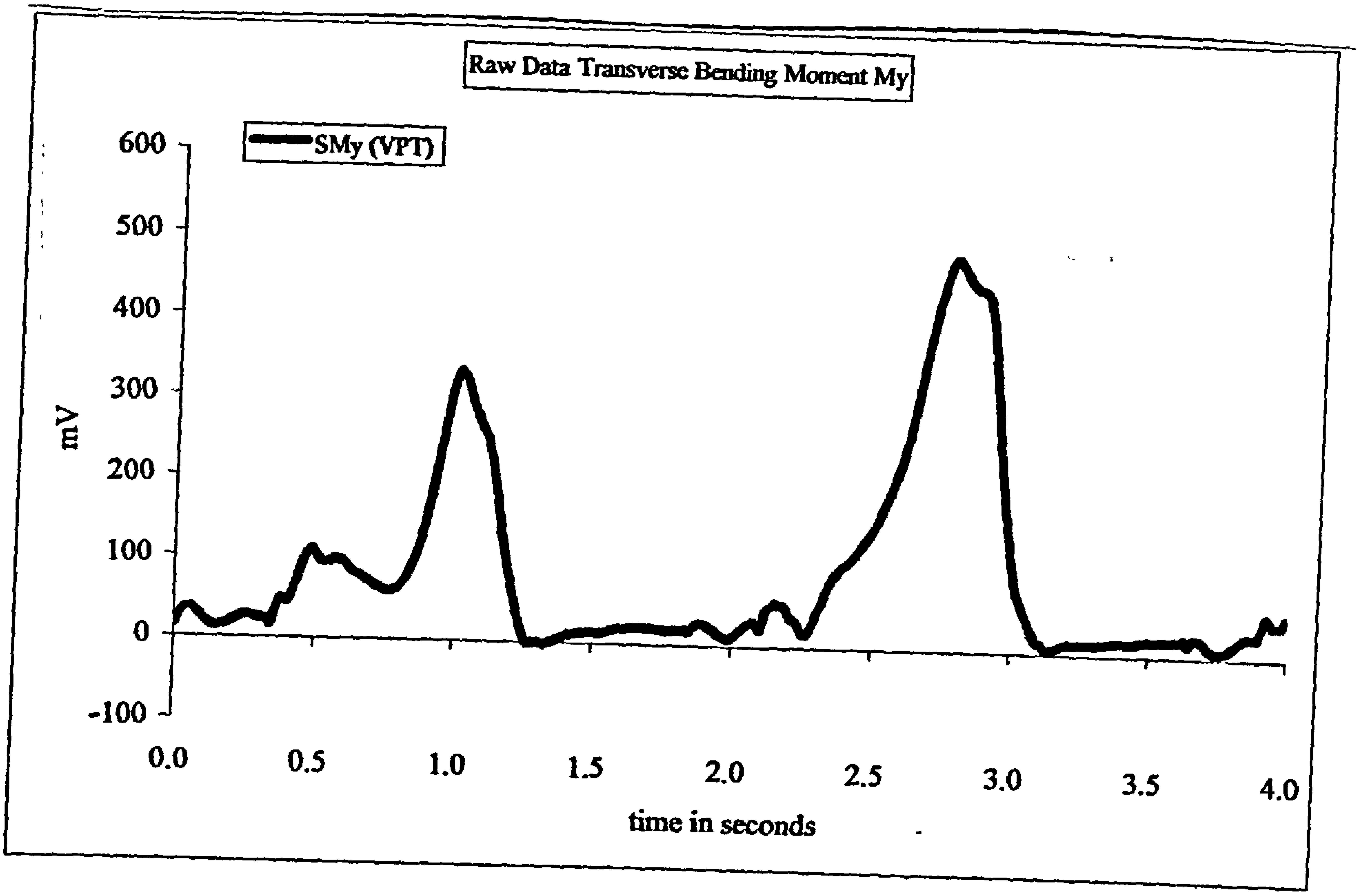


Figure VII.20c: From trial n°3 with a sampling frequency of 800 Hz for the VPT, the M/L bending moment Mx, simultaneously recorded from the two pylon transducers (VPT and SPT) is shown after applying the corresponding calibration matrix to each pylon transducer. The correcting factor of 1.07, established in section 7.8.1 for the axial load Fy, was applied to the new Villiers Pylon Transducer (VPT). The results are in N.m versus a base of time in seconds.



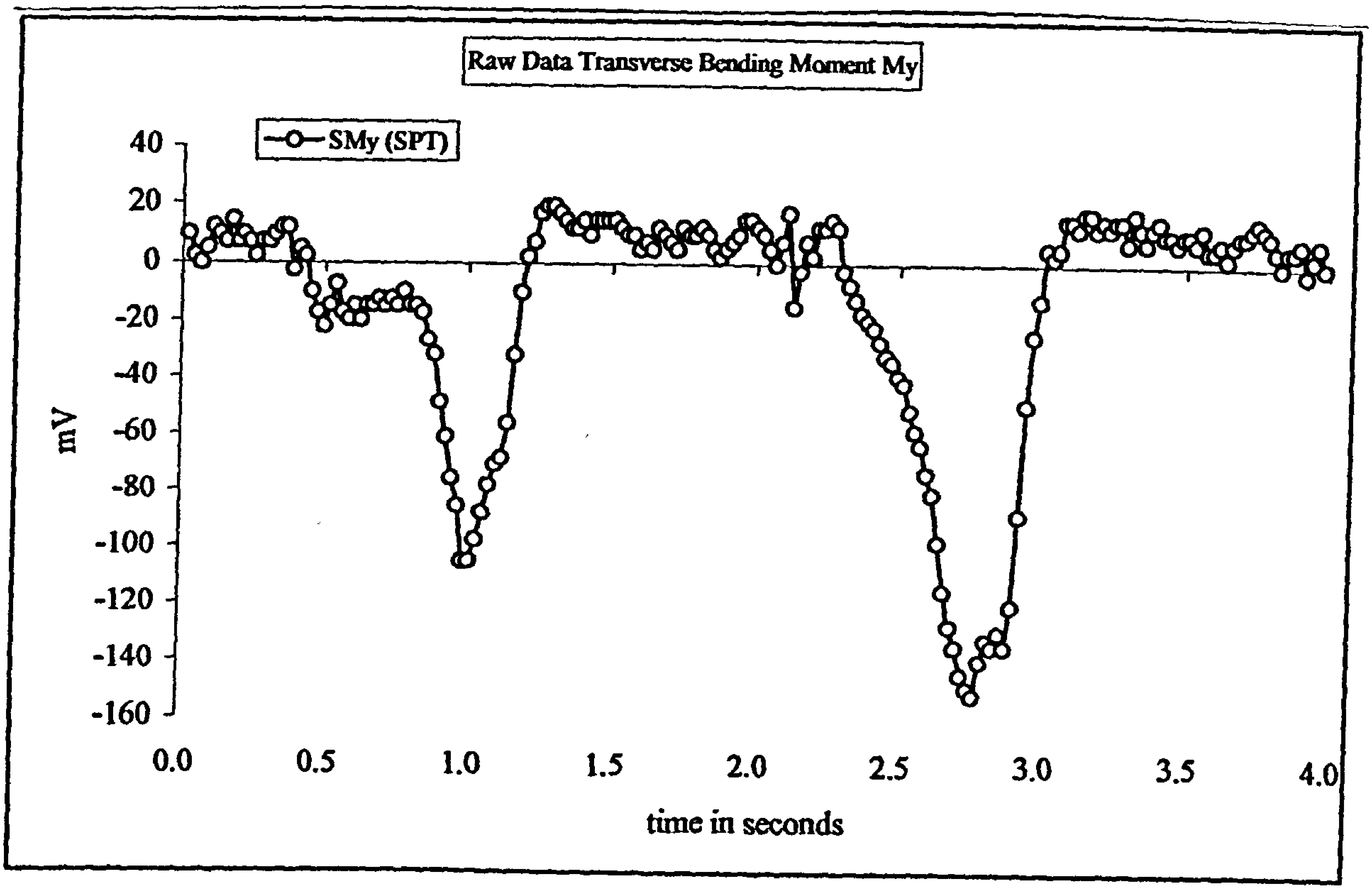


Figure VII.21a: From trial N°3 with a sampling frequency of 800 Hz for the VPT, raw data of the transverse torque My, simultaneously recorded from the two pylon transducers (VPT and SPT) are shown. The results are in mV versus a base of time in seconds.

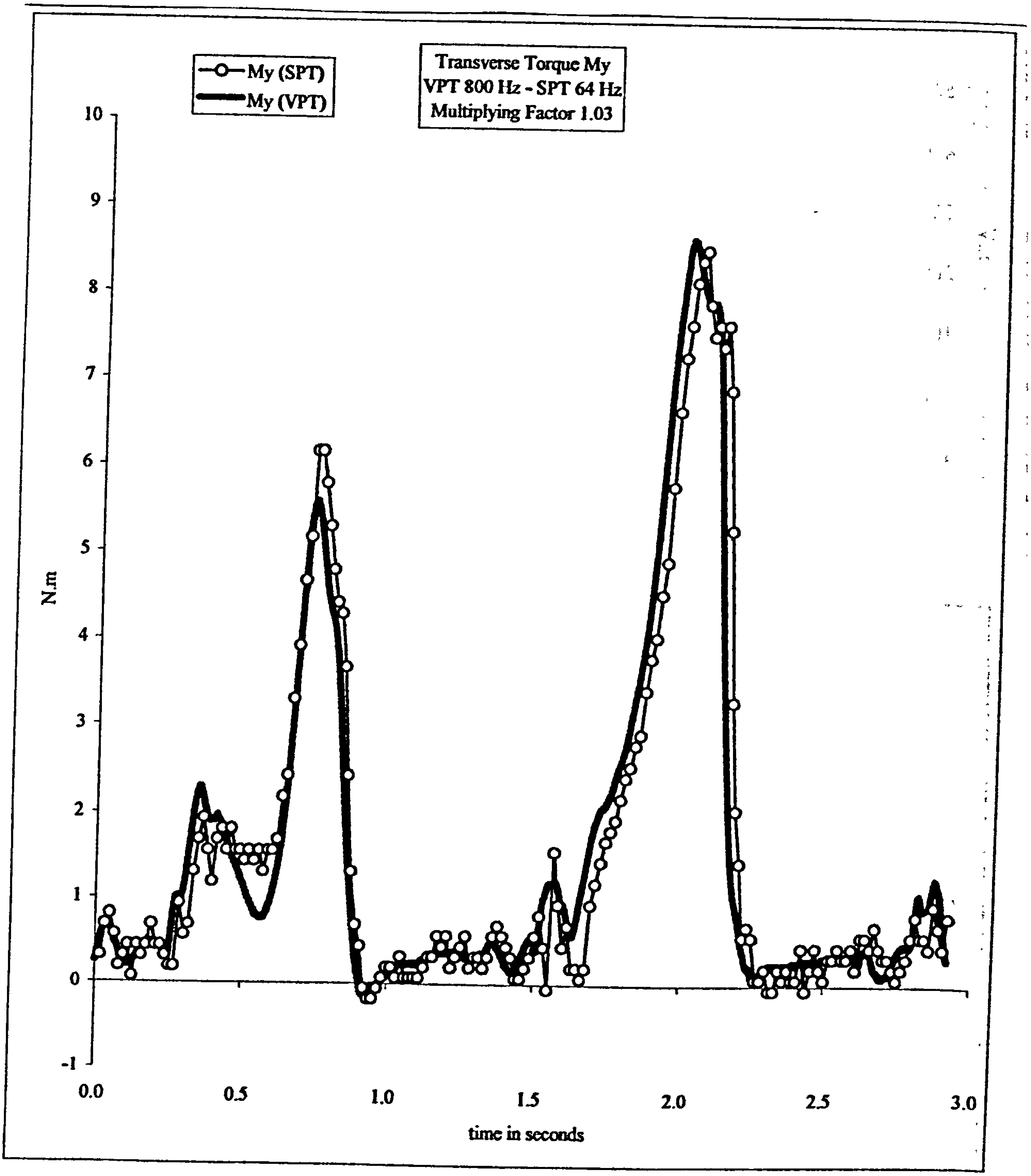


Figure VII.21c: From trial n°3 with a sampling frequency of 800 Hz for the VPT, the transverse torque My, simultaneously recorded from the two pylon transducers (VPT and SPT) is shown after applying the corresponding calibration matrix to each pylon transducer. The correcting factor is 1.03, established in section 7.8.1 for the transverse torque My, was applied to the new VPT. The results are in N.m versus a base of time in seconds.

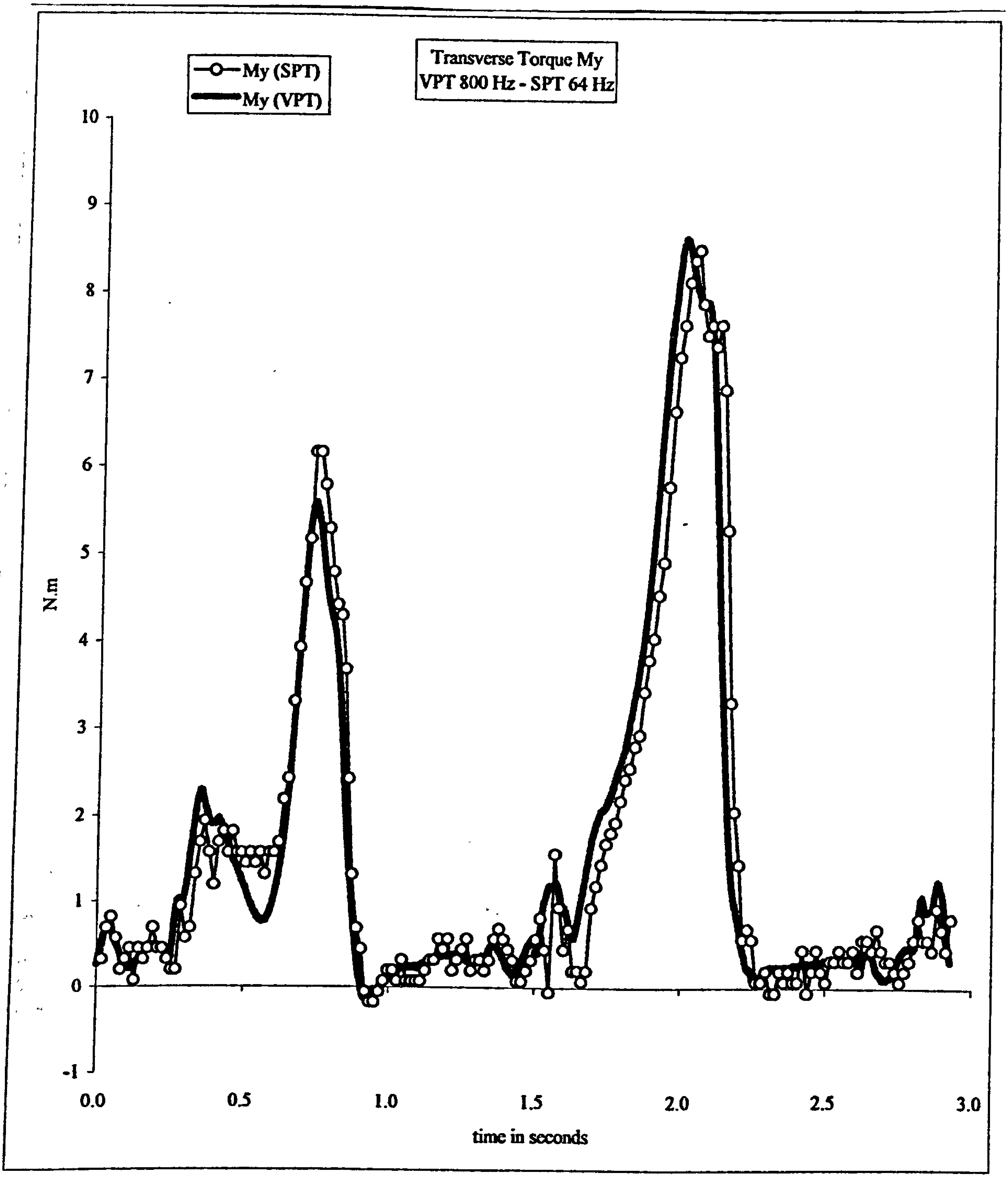


Figure VII.21b: From trial n°3 with a sampling frequency of 800 Hz for the VPT, the transverse torque My, simultaneously recorded from the two pylon transducers (VPT and SPT) is shown after applying the corresponding calibration matrix to each pylon transducer. The results are in N.m versus a base of time in seconds.

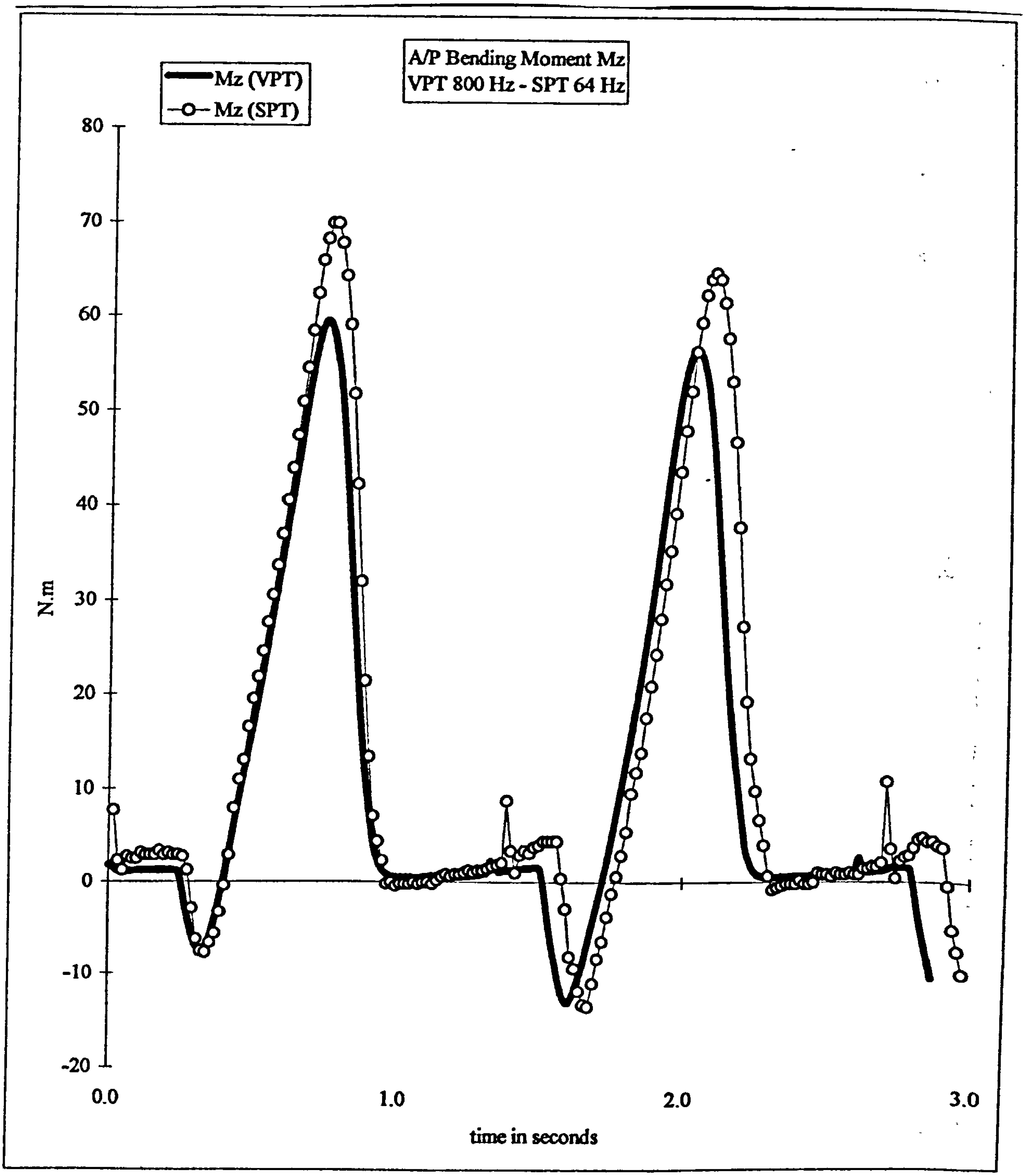
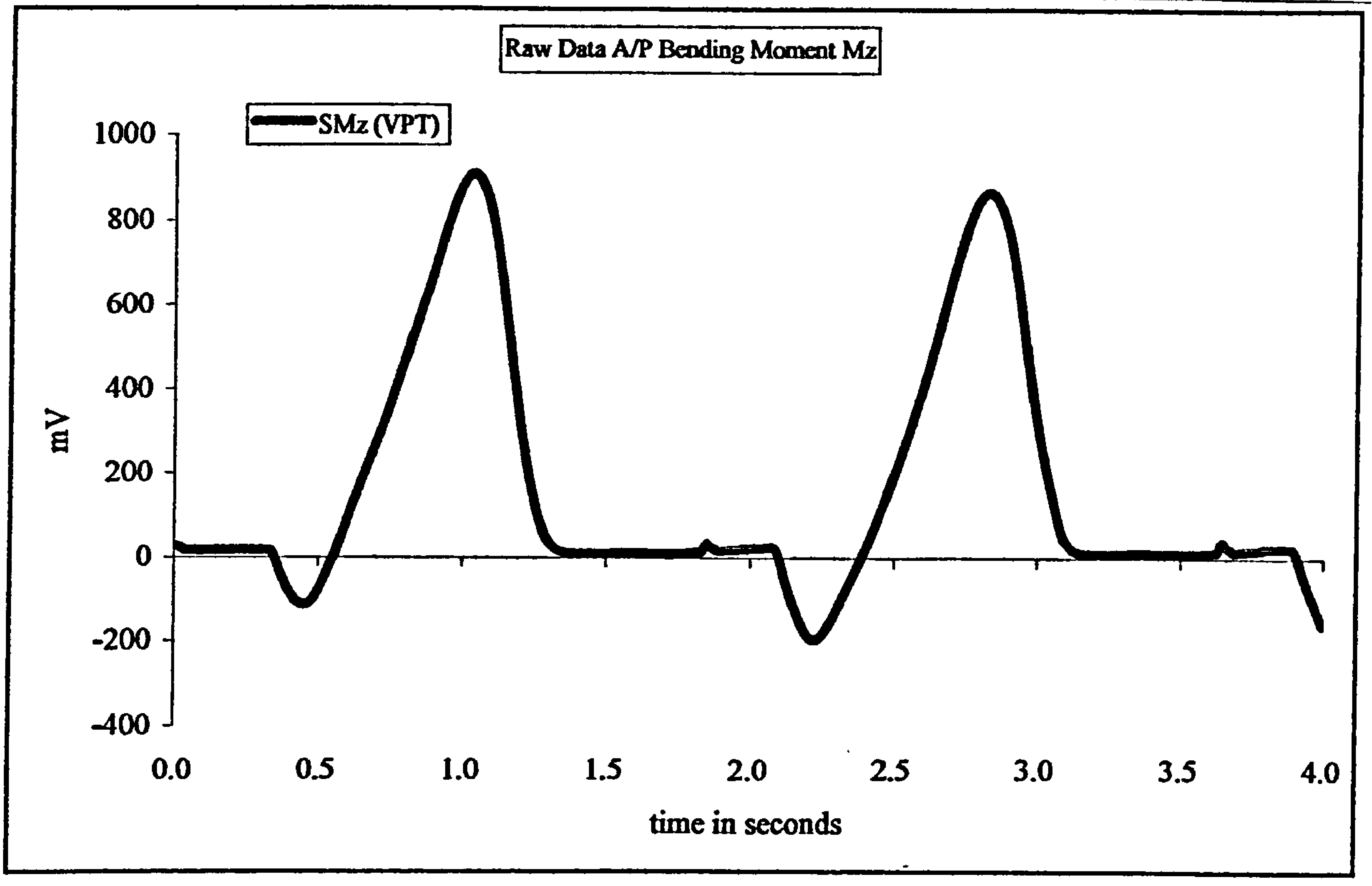


Figure VII.22b: From trial n°3 with a sampling frequency of 800 Hz for the VPT, the A/P bending moment Mz, simultaneously recorded from the two pylon transducers (VPT and SPT) is shown after applying the corresponding calibration matrix to each pylon transducer. The results are in N.m versus a base of time in seconds.



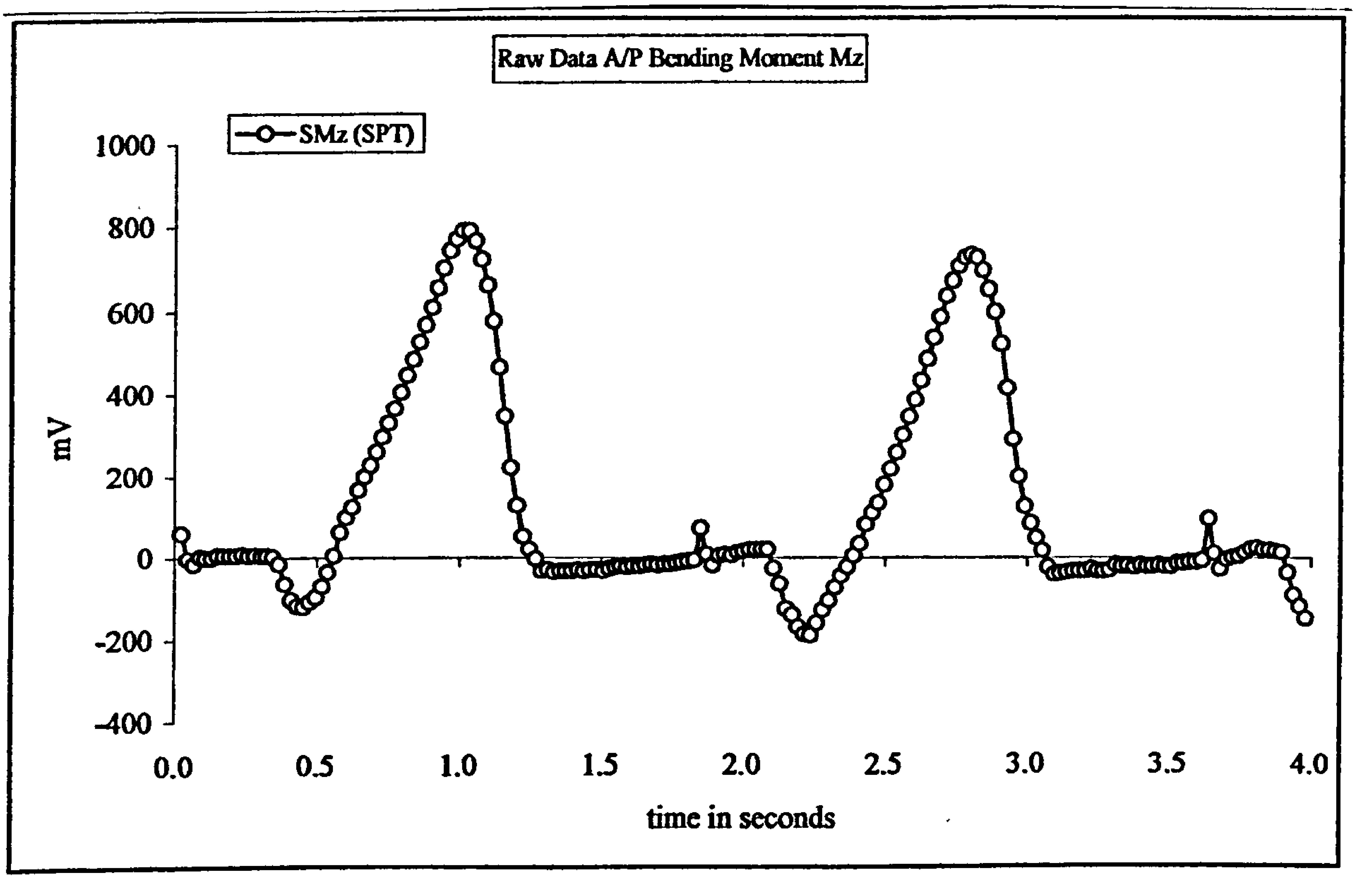


Figure VII.22a: From trial n°3 with a sampling frequency of 800 Hz for the VPT, raw data of the A/P bending moment Mz, simultaneously recorded from the two pylon transducers (VPT, top and SPT, bottom) are shown. The results are in mV versus a base of time in seconds.

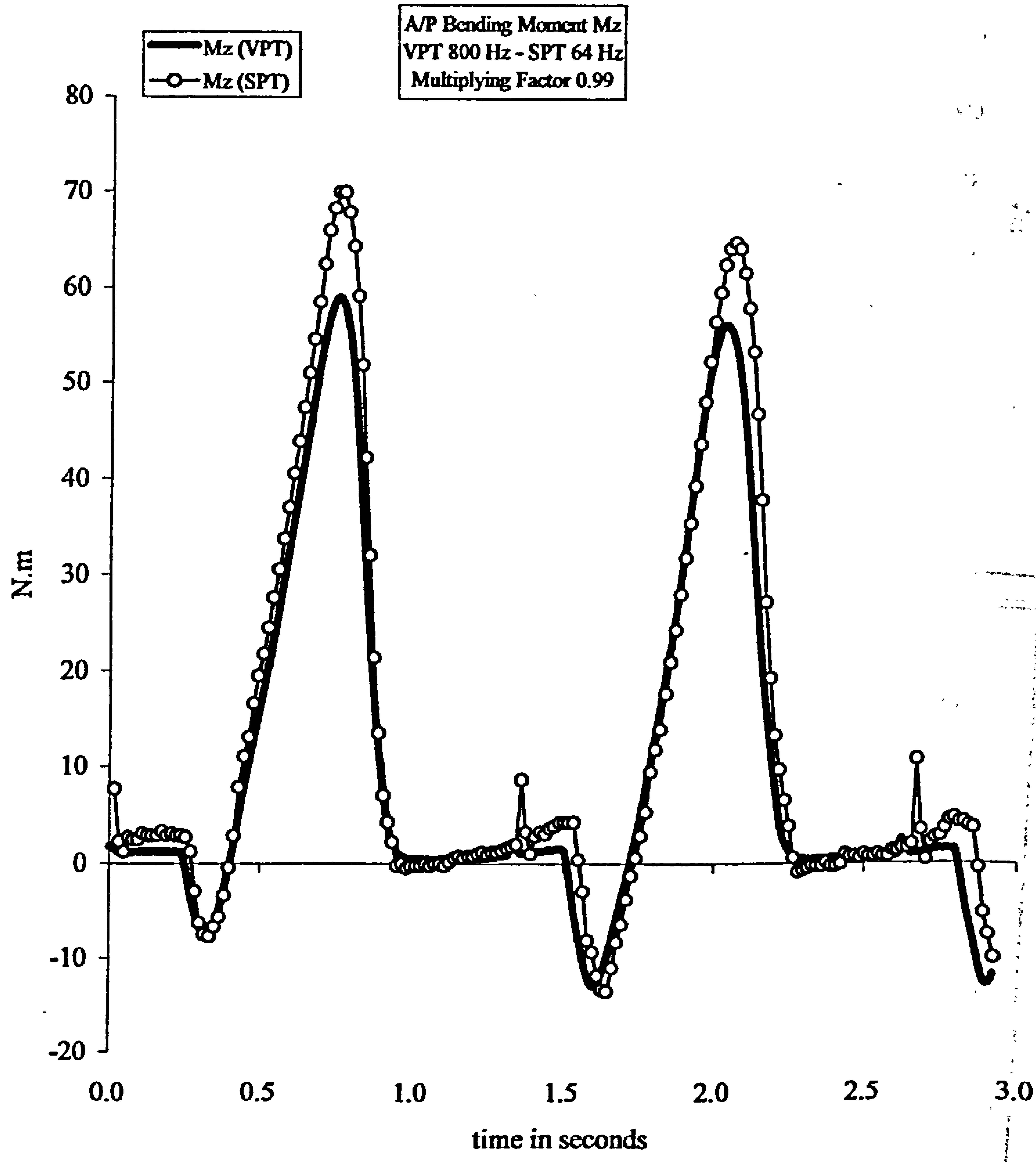


Figure VII.22c: From trial n°3 with a sampling frequency of 800 Hz for the VPT, the A/P bending moment Mz, simultaneously recorded from the two pylon transducers (VPT and SPT) is shown after applying the corresponding calibration matrix to each pylon transducer. The correcting factor of 0.99, established in section 7.8.1 for the axial load Fy, was applied to the new Villiers Pylon Transducer (VPT). The results are in N.m versus a base of time in seconds.

11.VII.7.4 THE TRIAL N°4 IN WHICH THE NEW VILLIERS PYLON TRANSDUCER IS RECORDED WITH THE DATA ACQUISITION SYSTEM PREVIOUSLY USED FOR THE STRATHCLYDE PYLON TRANSDUCER.

The main purpose of this test was to eliminate the portable data acquisition system to ensure that it did not interfere between the new Villiers Pylon Transducer and the exhibited results.

Unfortunately for connecting reasons, it was not possible to record the Strathclyde Pylon Transducer through the portable data acquisition system. This test was thus performed with only one pylon, the VPT. To process data, the way of doing was the following: the VPT was recorded using the Strathclyde amplifiers and Acquire data acquisition programme having the following characteristics:

	Gain Setting	Bridge Voltage
Fx	1000	7.5
Fy	2000	8
Fz	1000	7.5
Mx	200	7.5
My	500	7.5
Mz	200	7.5

Table VII.19: The gain setting and bridge voltage used for each channel when the trail n°3 was undertaken.

The bridge voltages were exactly the same as those used with the portable data acquisition system, thus, no transformation was necessary. The first file was thus raw data in Acquire computer units, it was necessary to convert them in millivolts (see the term in brackets in the following equation, in table VII.20). Then a transformation in raw data having the same gain was indispensable to allow the use of the calibration matrix described in section 8.7.

The gain setting and bridge voltage used with the portable data recorder were shown in section 7.3.2

The transformation was done as follows:

Fx	[(Raw Data Acquire – 2000) * 2.442]*10^{-3} * 1546
Fy	(Raw Data Acquire – 2000) * 2.442
Fz	[(Raw Data Acquire – 2000) * 2.442]* 714.28 10^{-3} * 3215
Mx	[(Raw Data Acquire – 2000) * 2.442]*2 10^{-2} * 174
My	[(Raw Data Acquire – 2000) * 2.442]*5 10^{-2} * 493
Mz	[(Raw Data Acquire – 2000) * 2.442]*2 10^{-2} * 59

Table VII.20: The equations used to transform Acquire raw data in portable recorder raw data to be able to use the VPT calibration matrix.

It is therefore possible now to show raw data (in mV versus time) and processed data using the VPT calibration matrix (in N or N.m versus time). It is thus possible to compare the results with those previously established.

The schedule of the following pages is as follows:

Figures VII.23a and b: A/P Shear Force Fx: respectively raw data and processed data with the correcting factors established in section 7.8.1. Figures VII.24a to VII.28b: same arrangement as figure VII.23.

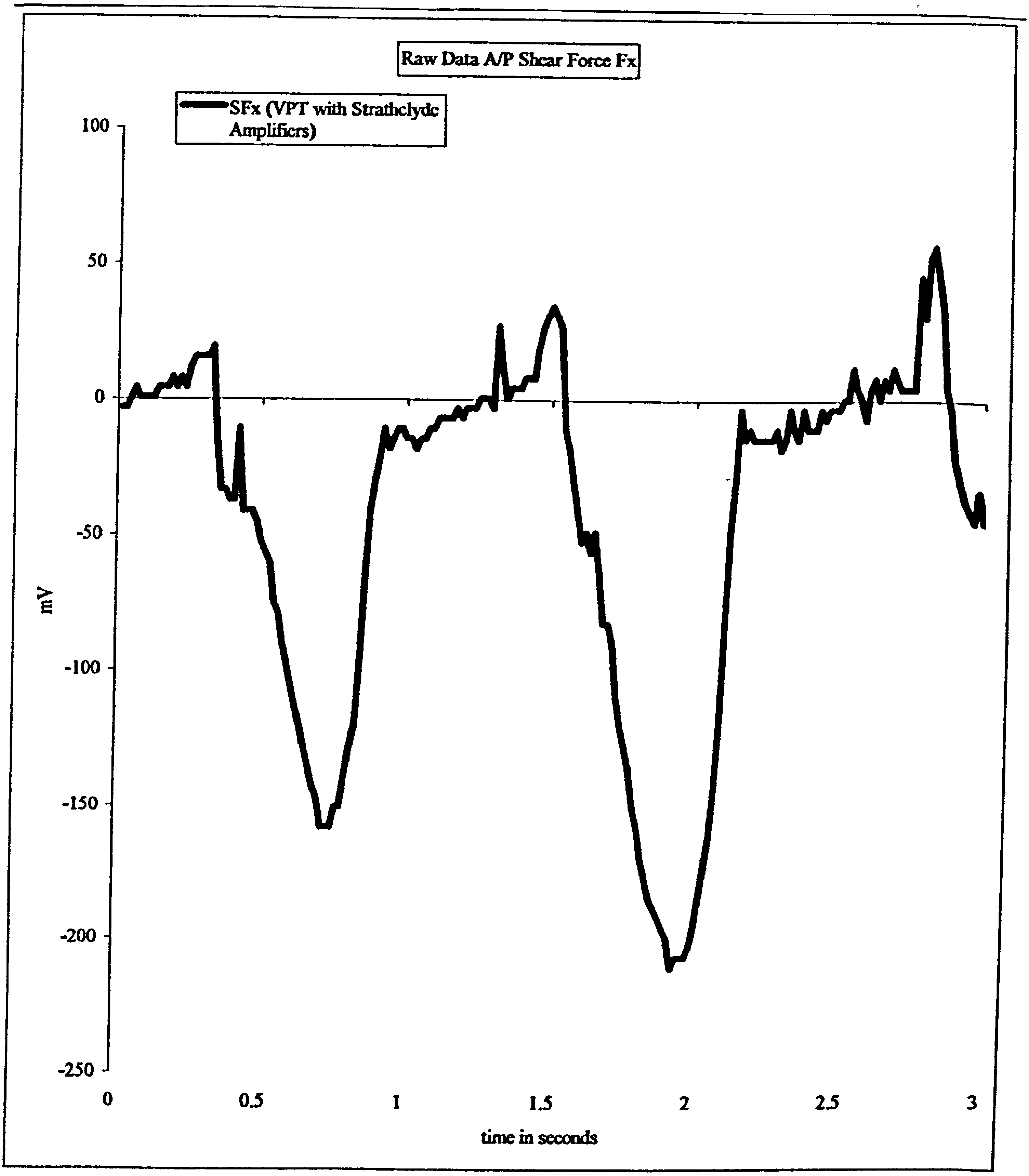


Figure VII.23a: Raw data of the A/P Shear Force Fx recorded from the Villiers Pylon Transducer using the Strathclyde set of amplifiers. The shape and the magnitude are equivalent as those recorded with the portable data acquisition system (see figures 7.20a and VII.17a)

Globally, when the Strathclyde amplifiers were used, the results showed the same pattern with the same magnitude in the six channels as there were when the portable data acquisition system was used. Therefore, the portable data acquisition system and the manner to process data are accurate for the requirements and purposes established in chapter 1.

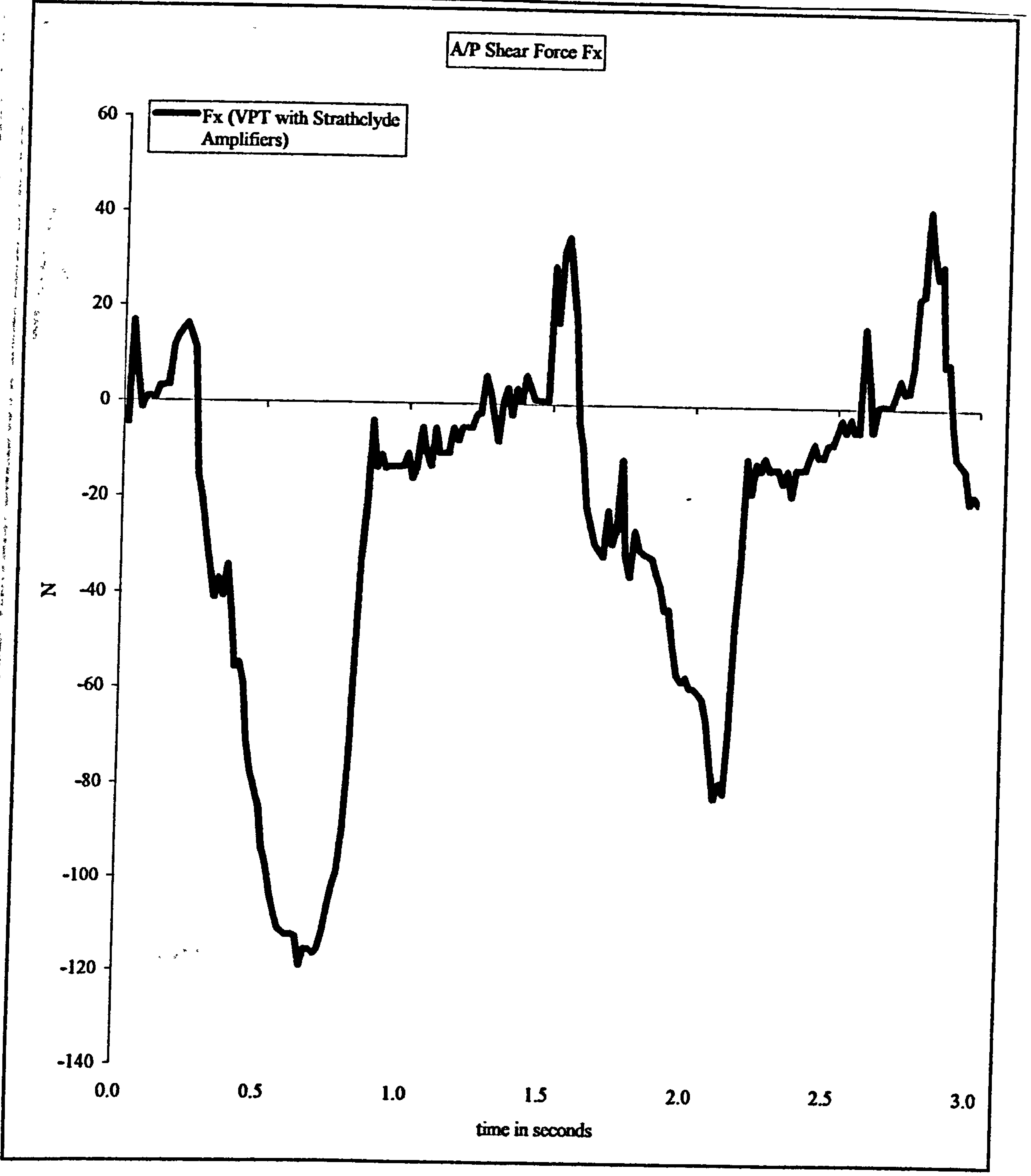


Figure VII.23b: Processed data of the A/P Shear Force Fx recorded from the Villiers Pylon Transducer using the Strathclyde set of amplifiers. The correcting factors are used. The shape and the magnitude are equivalent as those recorded with the portable data acquisition system (see figures 7.20a and VII.17c)

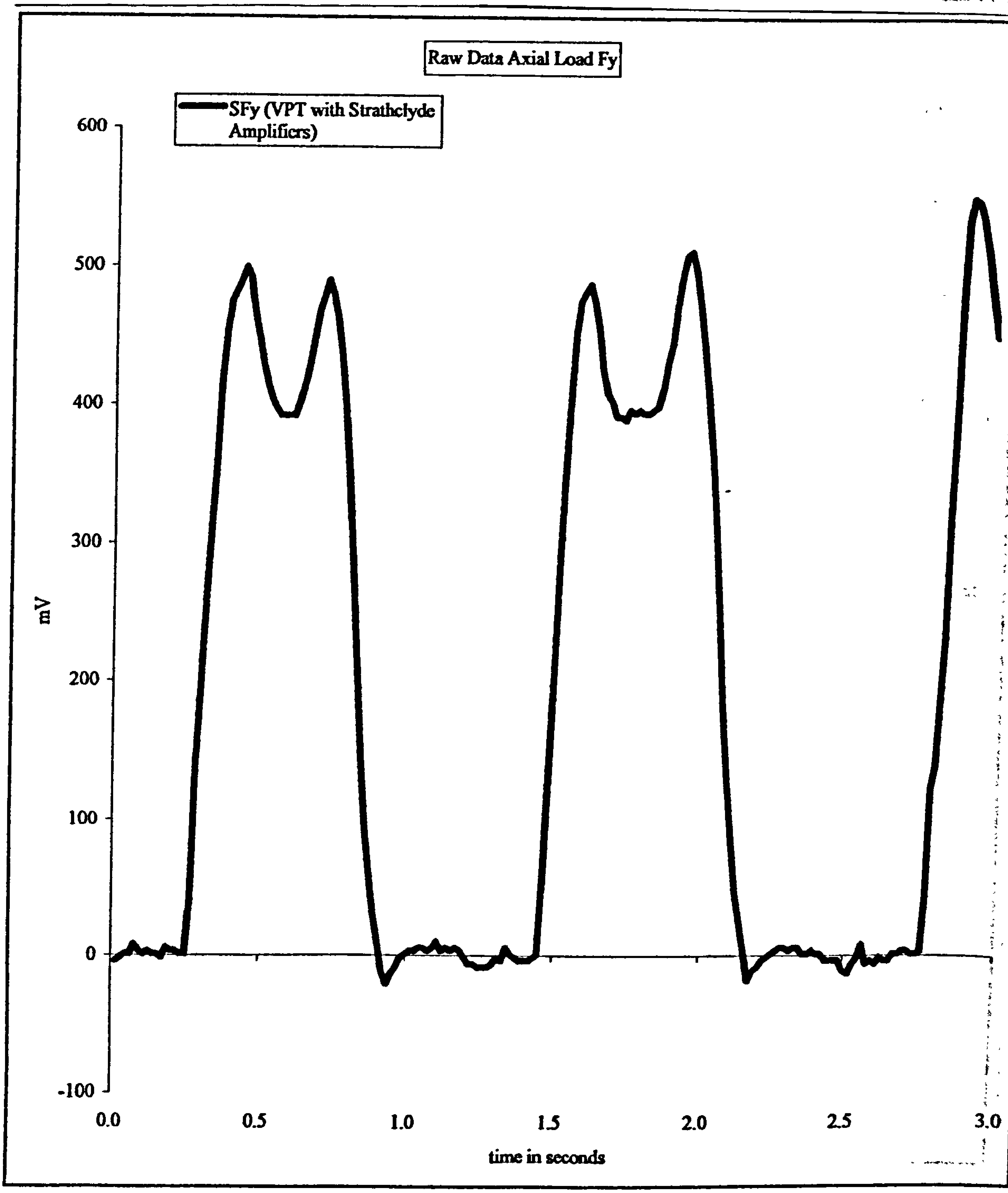


Figure VII.24a: Raw data of the axial load Fy recorded from the Villiers Pylon Transducer using the Strathclyde set of amplifiers. The shape and the magnitude are equivalent as those recorded with the portable data acquisition system (see figures 7.20b and VII.18a)

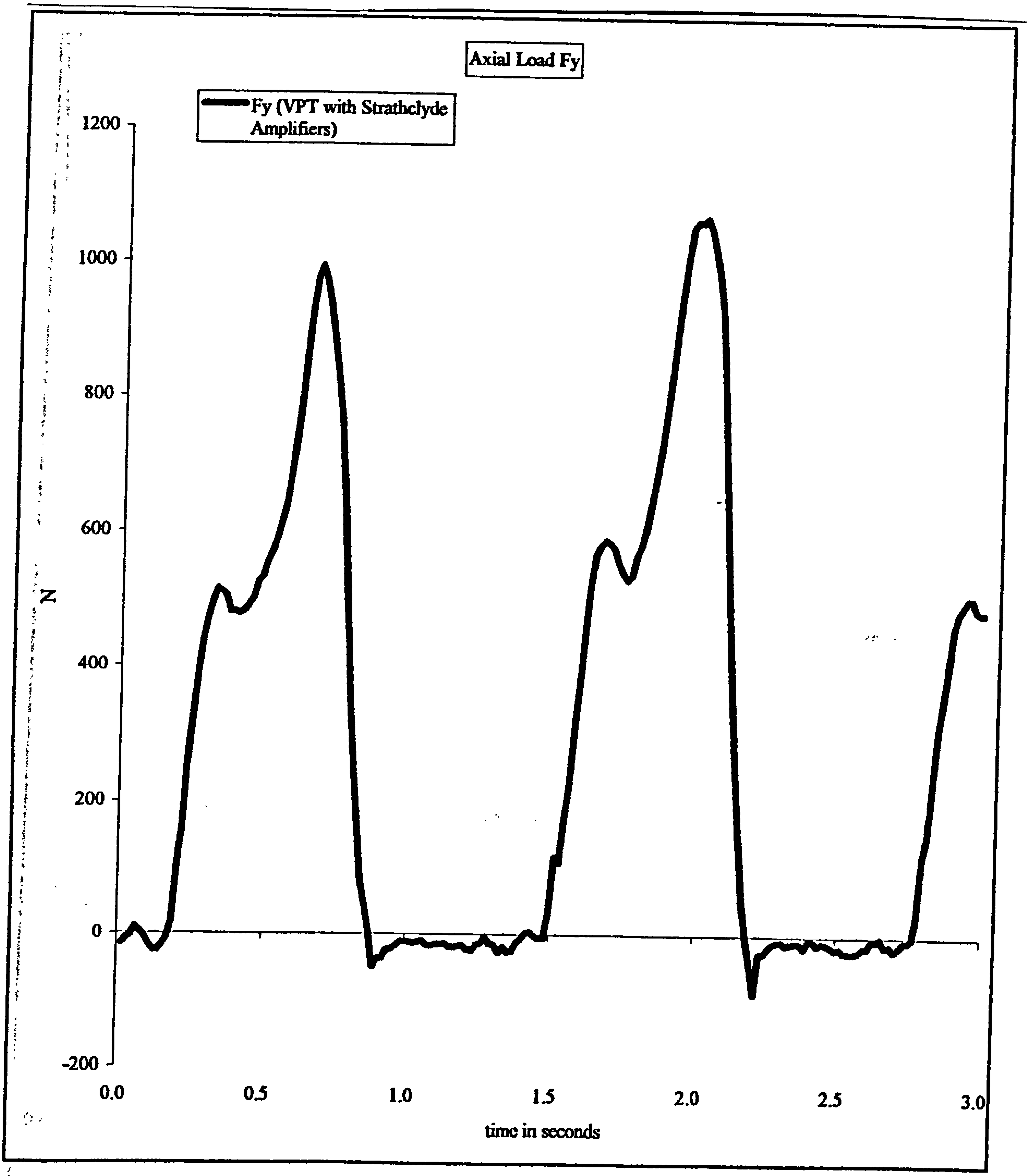


Figure VII.24b: Processed data of the axial load Fy recorded from the Villiers Pylon Transducer using the Strathclyde set of amplifiers. The correcting factors are used. The shape and the magnitude are equivalent as those recorded with the portable data acquisition system (see figures 7.20b and VII.18c)

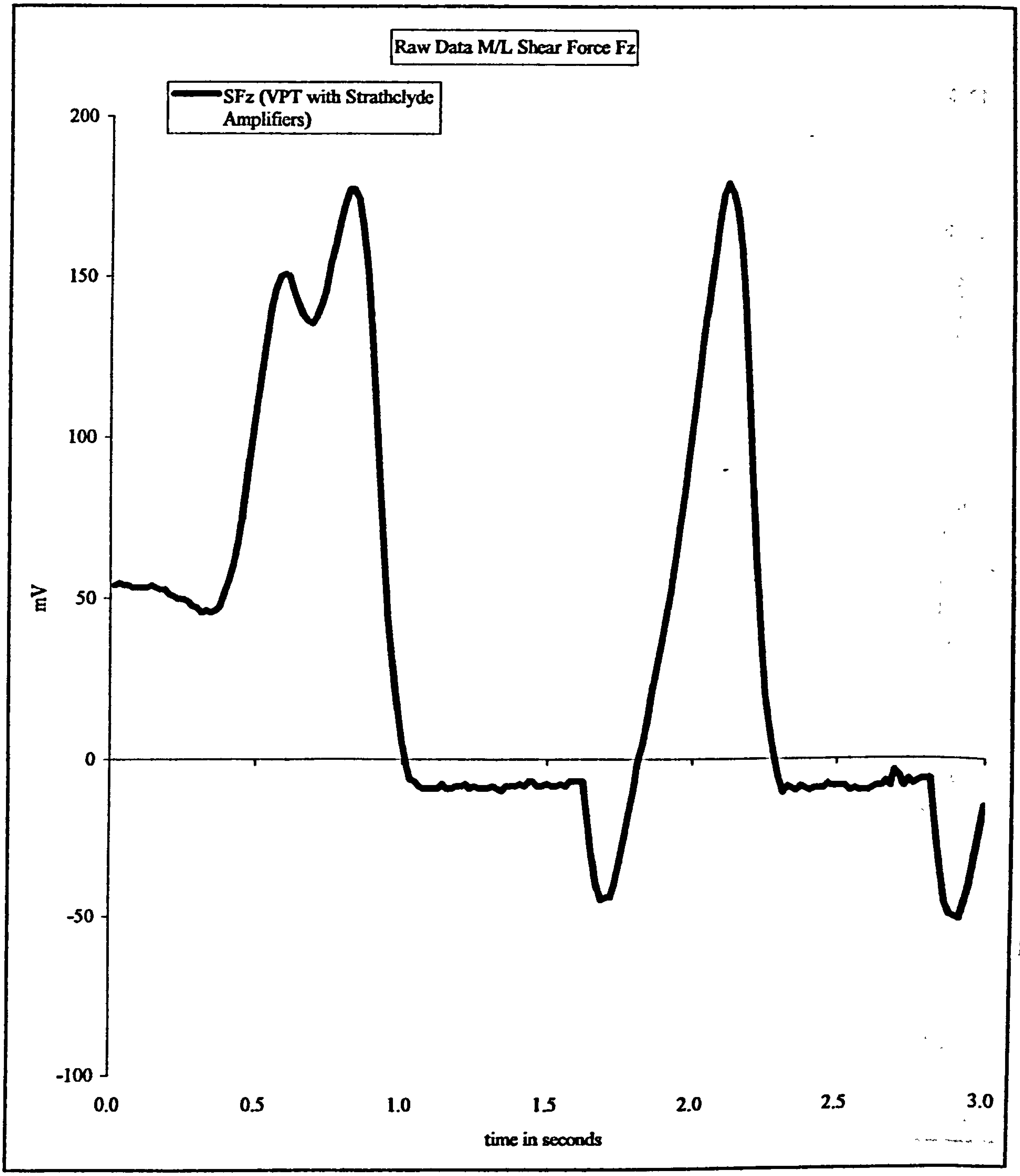


Figure VII.25a: Raw data of the M/L shear force Fz recorded from the Villiers Pylon Transducer using the Strathclyde set of amplifiers. The shape and the magnitude are equivalent as those recorded with the portable data acquisition system (see figures 7.20c and VII.19a)

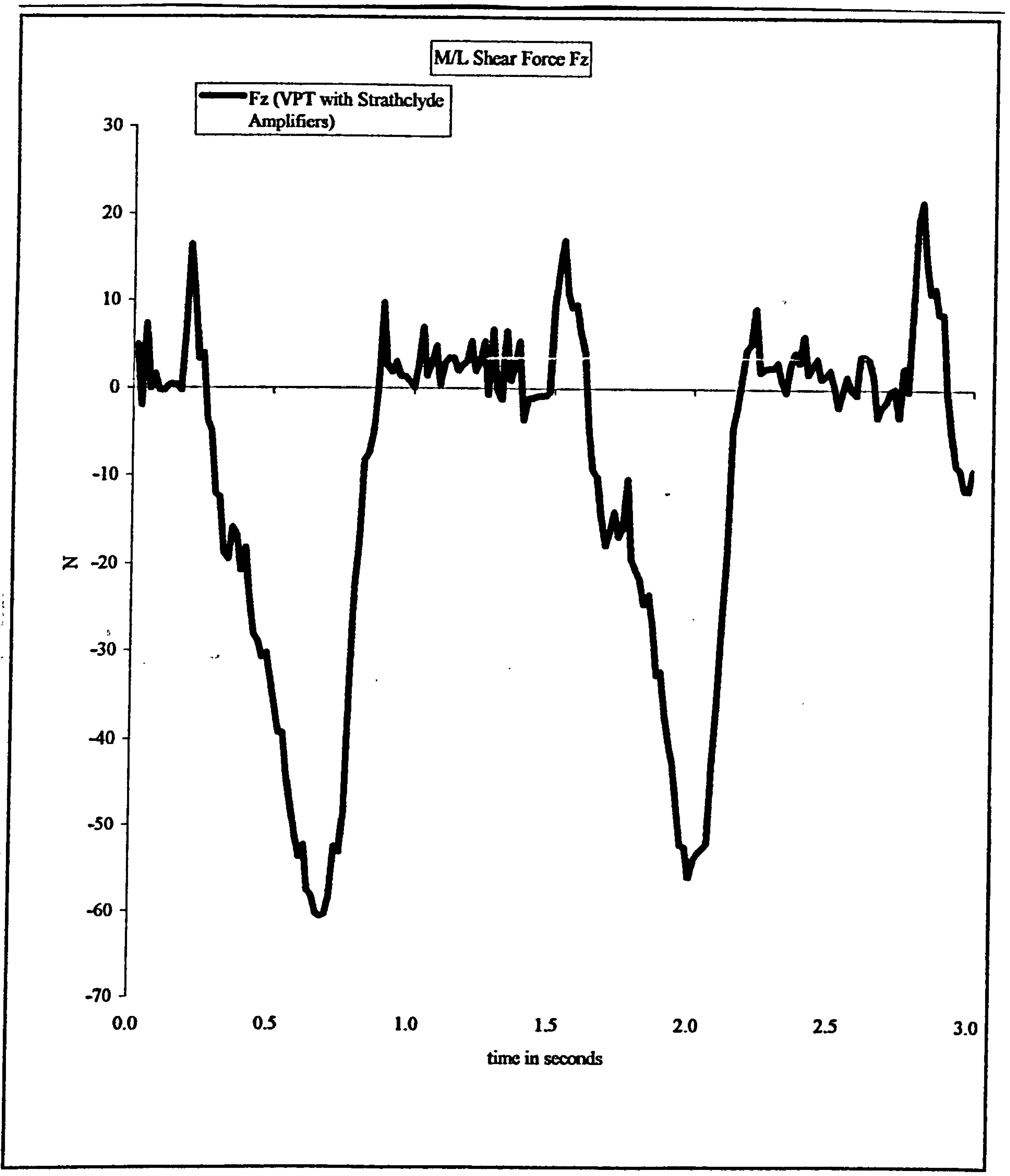


Figure VII.25b: Processed data of the M/L shear force Fz recorded from the Villiers Pylon Transducer using the Strathclyde set of amplifiers. The correcting factors are used. The shape and the magnitude are equivalent as those recorded with the portable data acquisition system (see figures 7.20c and VII.19c)

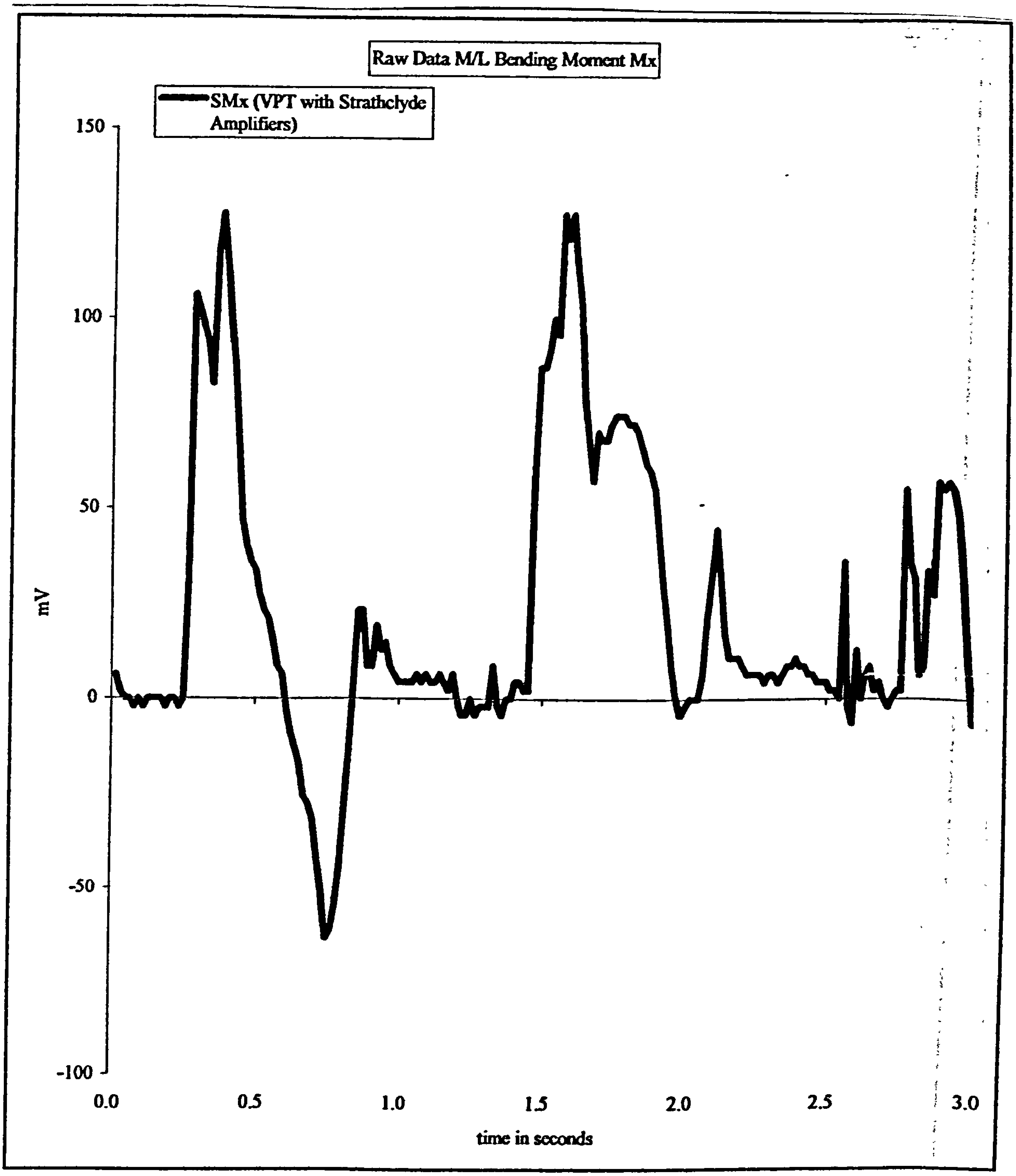


Figure VII.26a: Raw data of the M/L bending moment Mx recorded from the Villiers Pylon Transducer using the Strathclyde set of amplifiers. The shape and the magnitude are equivalent as those recorded with the portable data acquisition system (see figures 7.21a and VII.20a)

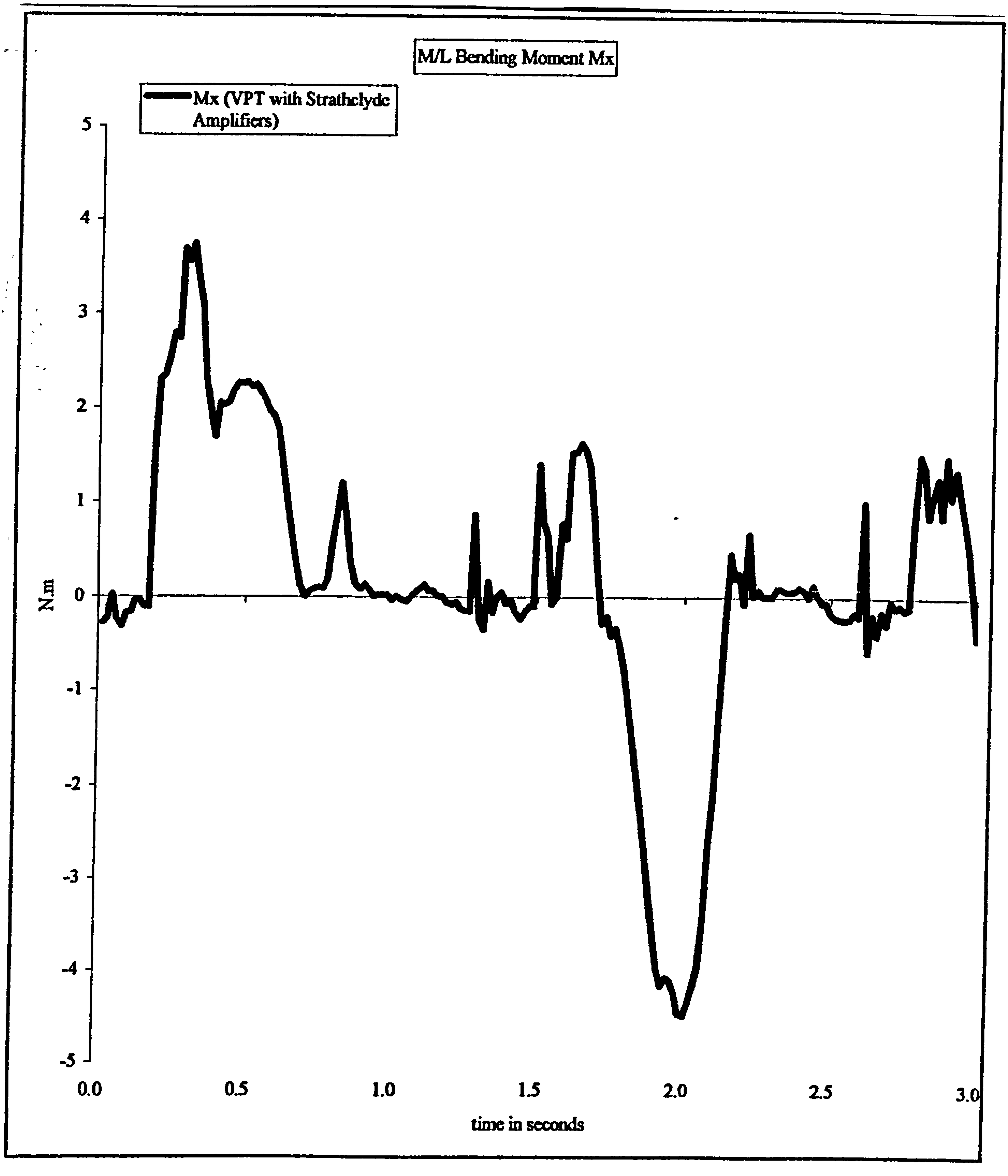


Figure VII.26b: Processed data of the M/L bending moment Mx recorded from the Villiers Pylon Transducer using the Strathclyde set of amplifiers. The correcting factors are used. The shape and the magnitude are equivalent as those recorded with the portable data acquisition system (see figures 7.21a and VII.20c).

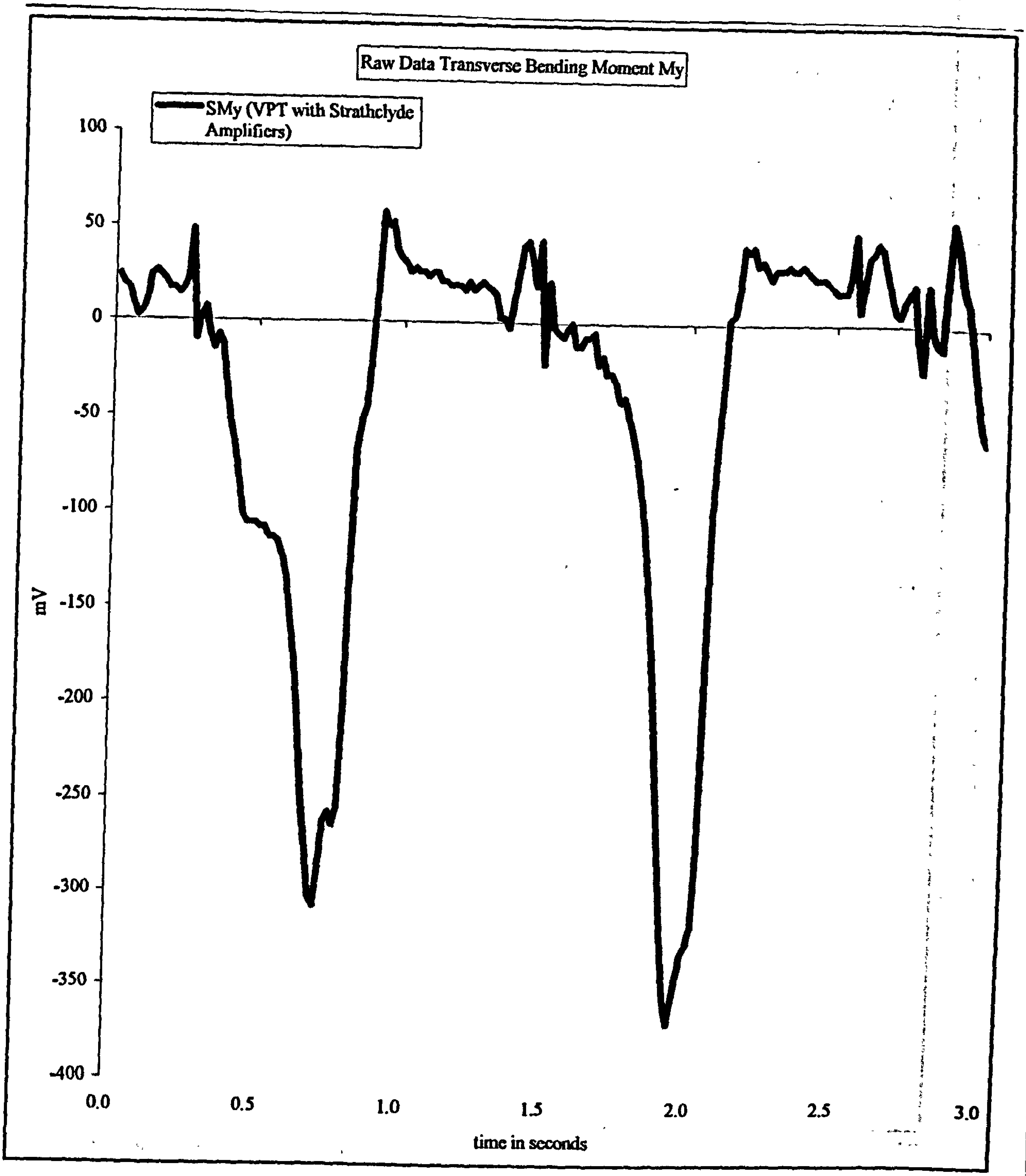


Figure VII.27a: Raw data of the transverse torque My recorded from the Villiers Pylon Transducer using the Strathclyde set of amplifiers. The shape and the magnitude are equivalent as those recorded with the portable data acquisition system (see figures 7.21b and VII.21a)

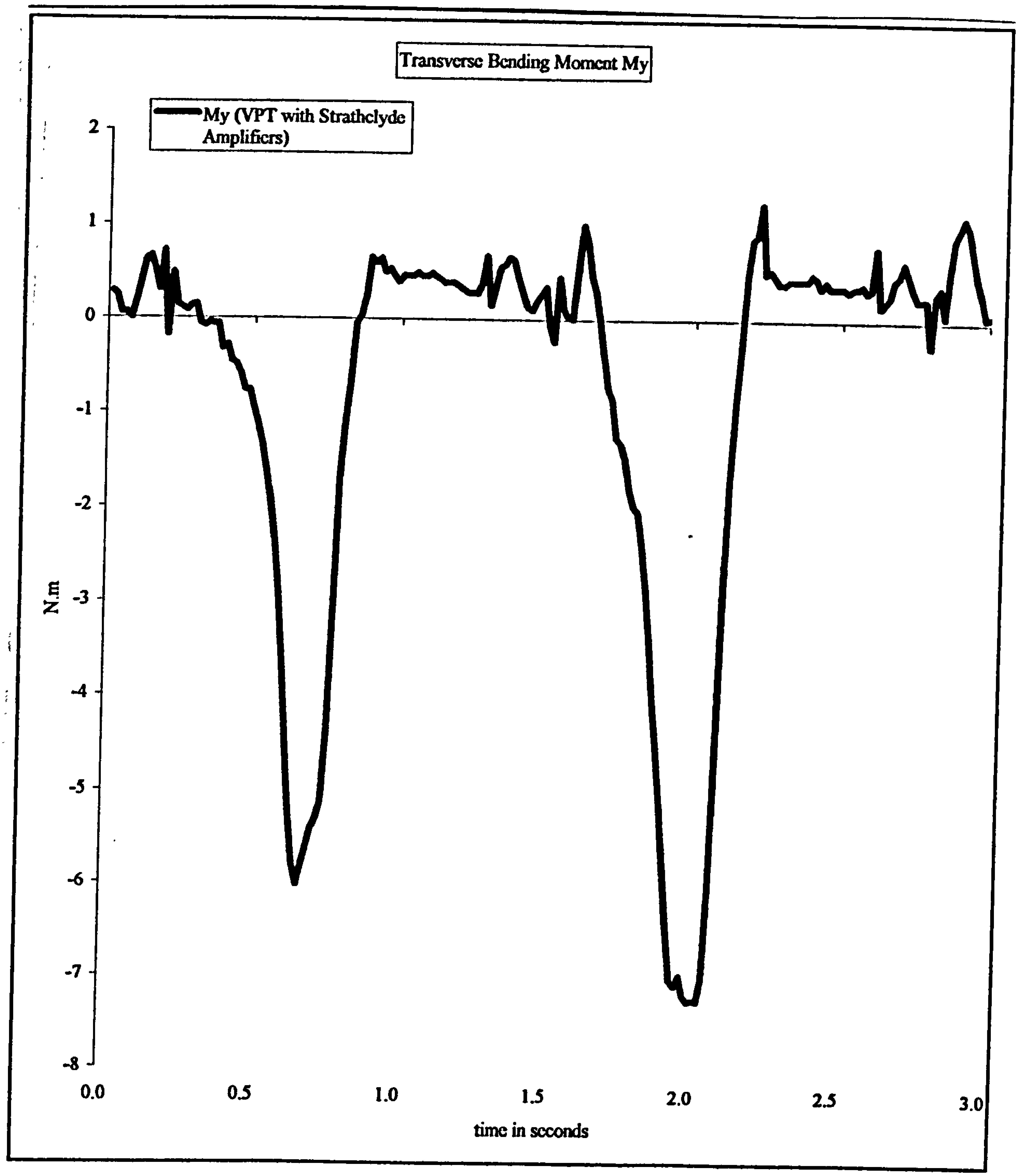


Figure VII.27b: Processed data of the transverse torque My recorded from the Villiers Pylon Transducer using the Strathclyde set of amplifiers. The correcting factors are used. The shape and the magnitude are equivalent as those recorded with the portable data acquisition system (see figures 7.21b and VII.21c).

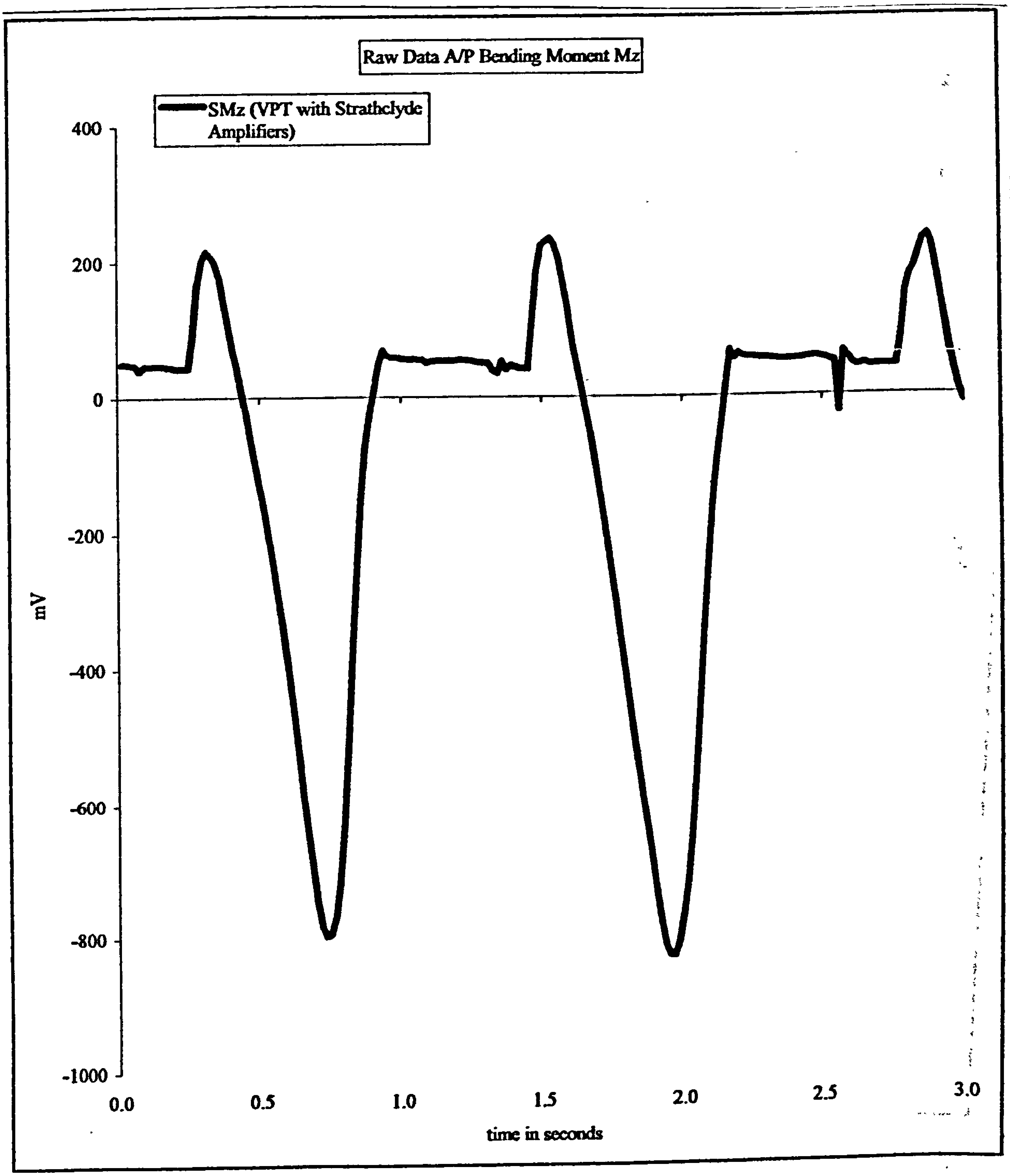


Figure VII.28a: Raw data of the A/P bending moment Mz recorded from the Villiers Pylon Transducer using the Strathclyde set of amplifiers. The shape and the magnitude are equivalent as those recorded with the portable data acquisition system (see figures 7.21c and VII.22a)

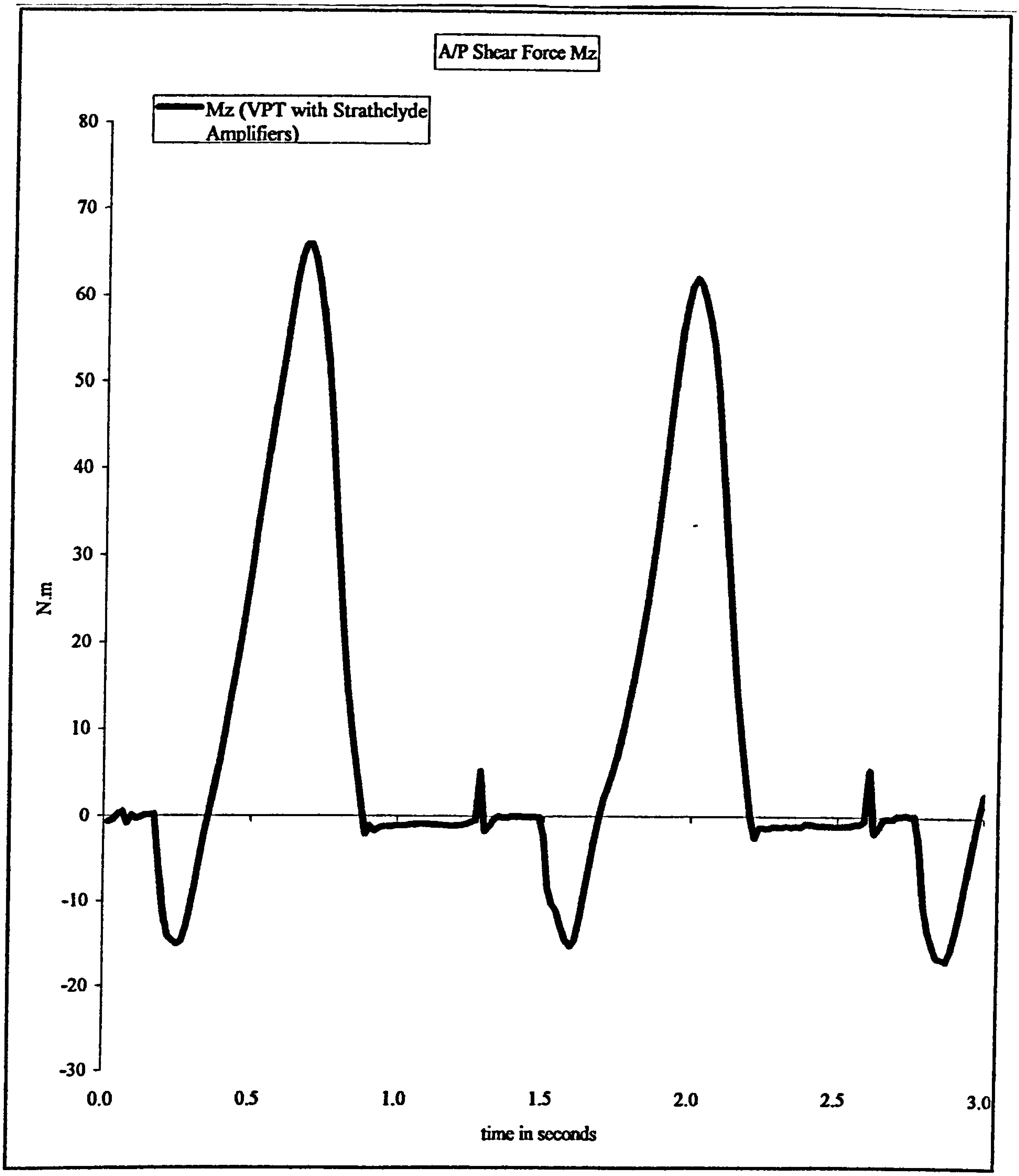


Figure VII.28b: Processed data of the A/P bending moment Mz recorded from the Villiers Pylon Transducer using the Strathclyde set of amplifiers. The correcting factors are used. The shape and the magnitude are equivalent as those recorded with the portable data acquisition system (see figures 7.21c and VII.22c).

	1	2
1	Macro-sheet opening eight files (FX.TXT to CaLe.TXT) from Myodata recordi	COMMENTS
2	*Myodata gains must be equal to 1 with raw data in volts. Sampling rate = 64 Hz*	
3	The macro-command is opening a file in both volts and millivolts	
4	Creating a temporary raw data full six transducer's channels + 2 canes graph fo	
5	Creating a *.DAT file to use it with GAIT.EXE in which results are millivots +	
6	having digits looking like Acquire	
7	Creating a definitive work-out file after using the calibration matrix and correc	
8	This macro must be used with two sticks or canes	
9		
10	Fz raw data are divided by 1.4 (*714.28 instead of 1000)	
11		
12	=OUVRIR("C:\MYODATA\FX.TXT")	Opening Fx.TXT file
13	=SELECTIONNER("C1")	All transfer files must be open with tabulation
14	=REDISTRIBUER()	and CTR/L (default value) as rows' crossing
15	=SELECTIONNER("C1")	
16	=COPIER()	
17	=NOUVEAU.DOCUMENT(1)	Opening the first EXCEL file
18	=SELECTIONNER("L1C2")	
19	=COLLER()	Transferring Fx.TXT file
20	=REORGANISER(3)	
21	=ACTIVER("FX.TXT")	
22	=ENREGISTRER()	Recording Fx.TXT file
23	=FERMER(FAUX)	Closing Fx.TXT file
24		Files are closed as and when required
25		for memory space saving
26	=OUVRIR("C:\MYODATA\FY.TXT")	Opening Fy TXT file
27	=SELECTIONNER("C1")	
28	=REDISTRIBUER()	
29	=SELECTIONNER("C1")	
30	=COPIER()	
31	=ACTIVER.SUIV()	
32	=SELECTIONNER("L1C3")	
33	=COLLER()	Transferring Fy TXT file
34	=REORGANISER(3)	
35	=ACTIVER("FY.TXT")	
36	=ENREGISTRER()	Recording Fy TXT file
37	=FERMER(FAUX)	Closing Fy TXT file
38		
39		
40	=OUVRIR("C:\MYODATA\FZ.TXT")	Opening Fz.TXT file
41	=SELECTIONNER("C1")	
42	=REDISTRIBUER()	
43	=SELECTIONNER("C1")	
44	=COPIER()	
45	=ACTIVER.SUIV()	
46	=SELECTIONNER("L1C4")	
47	=COLLER()	Transferring Fz.TXT file
48	=REORGANISER(3)	
49	=ACTIVER("FZ.TXT")	
50	=ENREGISTRER()	Recording Fz.TXT file
51	=FERMER(FAUX)	Closing Fz.TXT file
52		
53		
54	=OUVRIR("C:\MYODATA\MX.TXT")	Opening Mx.TXT file
55	=SELECTIONNER("C1")	
56	=REDISTRIBUER()	
57	=SELECTIONNER("C1")	
58	=COPIER()	
59	=ACTIVER.SUIV()	
60	=SELECTIONNER("L1C5")	
61	=COLLER()	Transferring Mx.TXT file
62	=REORGANISER(3)	
63	=ACTIVER("MX.TXT")	
64	=ENREGISTRER()	Recording Mx.TXT file
65	=FERMER(FAUX)	Closing Mx.TXT file
66		
67		
68	=OUVRIR("C:\MYODATA\MY.TXT")	Opening My TXT file
69	=SELECTIONNER("C1")	
70	=REDISTRIBUER()	
71	=SELECTIONNER("C1")	
72	=COPIER()	
73	=ACTIVER.SUIV()	
74	=SELECTIONNER("L1C6")	
75	=COLLER()	Transferring My TXT file
76	=REORGANISER(3)	
77	=ACTIVER("MY.TXT")	
78	=ENREGISTRER()	Recording My TXT file
79	=FERMER(FAUX)	Closing My TXT file
80		
81		
82	=OUVRIR("C:\MYODATA\MZ.TXT")	Opening Mz.TXT file
83	=SELECTIONNER("C1")	

11.VIII COMPLETE RESULTS CONCERNING THE TESTS UNDERTAKEN WITH PATIENTS AND THE FOLLOWING METHOD USED TO EXPRESS THE RESULTS

11.VIII.1 The Excel® macro-sheet used to process data during the tests performed (see section 8.2.3)

This macro-sheet, written for Excel 4®, is named MYOGAIT2.XLM. It could be used through any version of Excel® above the version 4. This macro must be used with two sticks or canes (see row n°8, page 517A). Each command is expressed in one row in block letters, in column 1. There are 575 rows and the file is performed in 35 seconds with a 486 DX 4x100 personal computer having 8 Mb as RAM. Each row is numbered. The file begins in the facing page. The macro-sheet is written in French. However, some English explanations are provided in the column 2.

	1	2
84	=REDISTRIBUER()	
85	=SELECTIONNER("C1")	
86	=COPIER()	
87	=ACTIVER.SUIV()	
88	=SELECTIONNER("L1C7")	
89	=COLLER()	Transfering Mz.TXT file
90	=REORGANISER(3)	
91	=ACTIVER("MZ.TXT")	
92	=ENREGISTRER()	Recording Mz.TXT file
93	=FERMER(FAUX)	Closing Mz.TXT file
94		
95	=OUVRIR("C:\MYODATA\CARI.TXT")	Opening Cari.TXT file
96	=SELECTIONNER("C1")	
97	=REDISTRIBUER()	It is for the channel N°7
98	=SELECTIONNER("C1")	
99	=COPIER()	
100	=ACTIVER.SUIV()	
101	=SELECTIONNER("L1C8")	
102	=COLLER()	Transfering Cari.TXT file
103	=REORGANISER(3)	
104	=ACTIVER("CARI.TXT")	
105	=ENREGISTRER()	Recording Cari.TXT file
106	=FERMER(FAUX)	Closing Cari.TXT file
107		
108	=OUVRIR("C:\MYODATA\CALE.TXT")	Opening Cale.TXT file
109	=SELECTIONNER("C1")	
110	=REDISTRIBUER()	It is for the channel N°8
111	=SELECTIONNER("C1")	
112	=COPIER()	
113	=ACTIVER.SUIV()	
114	=SELECTIONNER("L1C9")	
115	=COLLER()	Transfering Cale.TXT file on column N°9
116	=REORGANISER(3)	
117	=ACTIVER("CALE.TXT")	
118	=ENREGISTRER()	Recording Cale.TXT file
119	=FERMER(FAUX)	Closing Cale.TXT file
120		
121	=REORGANISER(3)	
122		
123	=SELECTIONNER("L1C1")	
124	=FORMULE(0)	Creating the time code for a file with
125	=SELECTIONNER("L2C1")	a maximum of 6000 rows (EXCEL maximum)
126	=FORMULE(0.015625)	
127	=SELECTIONNER("L3C1")	The time base is for a sampling rate
128	=FORMULE(0.03125)	of 64 Hz.
129	=SELECTIONNER("L1C1:L3C1")	The user must say OK at the dialog box
130	=RECOPIE.INCREMENT("LC:L(6000)C")	"Sélection Trop Grande"
131	=FORMAT.NOMBRE("00.0")	Time code has the tenth of second as unit
132	=ECRAN(FAUX)	
133	=ECRAN(VRAI)	Screen is updated
134		
135	=SELECTIONNER("L1C2")	
136	=MODIFIER.SELECTION(4)	
137	=DEFINIR.NOM("fin11pro";CELLULE.ACTIVE())	
138	=SELECTIONNER("L1C3")	Gives a relative name at the end of each
139	=MODIFIER.SELECTION(4)	column.
140	=DEFINIR.NOM("fin21pro";CELLULE.ACTIVE())	This macro could be used whatever length
141	=SELECTIONNER("L1C4")	data have.
142	=MODIFIER.SELECTION(4)	
143	=DEFINIR.NOM("fin31pro";CELLULE.ACTIVE())	
144	=SELECTIONNER("L1C5")	
145	=MODIFIER.SELECTION(4)	
146	=DEFINIR.NOM("fin41pro";CELLULE.ACTIVE())	
147	=SELECTIONNER("L1C6")	
148	=MODIFIER.SELECTION(4)	
149	=DEFINIR.NOM("fin51pro";CELLULE.ACTIVE())	
150	=SELECTIONNER("L1C7")	
151	=MODIFIER.SELECTION(4)	
152	=DEFINIR.NOM("fin61pro";CELLULE.ACTIVE())	
153	=SELECTIONNER("L1C8")	
154	=MODIFIER.SELECTION(4)	The last cell from column eight is called
155	=DEFINIR.NOM("fin71pro";CELLULE.ACTIVE())	"fin71pro".
156	=SELECTIONNER("L1C9")	
157	=MODIFIER.SELECTION(4)	The last cell from column nine (left cane)
158	=DEFINIR.NOM("fin81pro";CELLULE.ACTIVE())	is called "fin81pro".
159		
160	=SELECTIONNER("fin11pro")	
161	=SELECTIONNER("LC(-1)")	
162	=DEFINIR.NOM("fin01pro";CELLULE.ACTIVE())	The time code column last cell is named "fin01pro"
163	=SELECTIONNER("fin01pro")	
164	=SELECTIONNER("fin01pro:L6000C9")	Maximum 6000 rows (EXCEL limit)
165	=EFFACER(1)	i.e. 93.75 seconds.
166		All cells over "fin01pro" are cleared

	1	2
167		
168	=SELECTIONNER("L1")	
169	=INSERER()	Starting the set up of the sheet
170	=SELECTIONNER("L1C2")	Creating the sheet's legend · SFx, SFy, SFz,
171	=FORMULE("SFx")	SMx, SMy, SMz, SCane1, SCane2.
172	=SELECTIONNER("L1C3")	S stands for signal.
173	=FORMULE("SFy")	
174	=SELECTIONNER("L1C4")	
175	=FORMULE("SFz")	
176	=SELECTIONNER("L1C5")	
177	=FORMULE("SMx")	
178	=SELECTIONNER("L1C6")	
179	=FORMULE("SMy")	
180	=SELECTIONNER("L1C7")	
181	=FORMULE("SMz")	
182	=SELECTIONNER("L1C8")	
183	=FORMULE("SCane1")	The legend is "SCane1" showing that the patient is using
184	=SELECTIONNER("L1C9")	the first right cane
185	=FORMULE("SCane2")	The legend is "SCane2" showing that the patient is using
186	=SELECTIONNER("L1C1:fin81pro")	the second left cane
187	=FORMAT.POLICE("Times New Roman";11)	
188	=SELECTIONNER("L1C2:L1C9")	
189	=FORMAT.POLICE("Times New Roman";12;VRAI)	
190	=POSITION(3)	
191	=SELECTIONNER("L2C2:fin81pro")	
192	=FORMAT.NOMBRE("standard")	
193	=ECRAN(FAUX)	
194	=ECRAN(VRAI)	Screen is updated
195		
196	=SELECTIONNER("L1C1:fin81pro")	
197	=COPIER()	
198	=NOUVEAU.DOCUMENT(1)	Creating a new temporary file
199	=SELECTIONNER("L1C1")	
200	=COLLAGE.SPECIAL(1;1;FAUX;FAUX)	Paste digits and values
201		
202	=SELECTIONNER("C3")	
203	=INSERER()	Creating a new column
204		
205	=SELECTIONNER("L1C3")	
206	=FORMULE("SFx mV")	This new column is named "SFx mV"
207		
208	=SELECTIONNER("L2C2")	
209	=MODIFIER.SELECTION(4)	
210	=DEFINIR.NOM("fin12pro";CELLULE.ACTIVE())	Giving a new name "fin12pro" to the last cell of column n°2
211	=SELECTIONNER("fin12pro")	
212	=SELECTIONNER("LC(1)")	
213	=DEFINIR.NOM("fin1pro";CELLULE.ACTIVE())	Giving the name of "fin1pro" to the last cell
214	=SELECTIONNER("fin1pro")	of column N°3
215		
216	=SELECTIONNER("LC(-2)")	
217	=DEFINIR.NOM("fin0pro";CELLULE.ACTIVE())	
218	=SELECTIONNER("fin0pro")	
219		
220	=SELECTIONNER("L2C3")	Putting the volts values in millivolts
221	=FORMULE("=LC(-1)*1000")	Multiplying by 1000
222	=SELECTIONNER("L3C3")	
223	=FORMULE("=LC(-1)*1000")	
224	=SELECTIONNER("L4C3")	
225	=FORMULE("=LC(-1)*1000")	
226	=SELECTIONNER("L2C3:L4C3")	
227	=RECOPIE.INCREMENT("LC:fin1pro";FAUX)	
228		
229	=SELECTIONNER("C5")	
230	=INSERER()	Creating a new column
231		
232	=SELECTIONNER("L1C5")	
233	=FORMULE("SFy mV")	This new column is named "SFy mV"
234		
235	=SELECTIONNER("L2C4")	
236	=MODIFIER.SELECTION(4)	
237	=DEFINIR.NOM("fin22pro";CELLULE.ACTIVE())	Giving a new name to the last cell of column n°4
238	=SELECTIONNER("fin22pro")	
239	=SELECTIONNER("LC(1)")	
240	=DEFINIR.NOM("fin2pro";CELLULE.ACTIVE())	Giving the name of "fin2pro" to the last cell
241	=SELECTIONNER("fin2pro")	of column N°5
242		
243	=SELECTIONNER("L2C5")	
244	=FORMULE("=LC(-1)*1000")	Putting the volts values in millivolts
245	=SELECTIONNER("L3C5")	Multiplying by 1000
246	=FORMULE("=LC(-1)*1000")	
247	=SELECTIONNER("L4C5")	
248	=FORMULE("=LC(-1)*1000")	
249	=SELECTIONNER("L2C5:L4C5")	

	1	2
250	=RECOPIE.INCREMENT("LC:fin2pro";FAUX)	Expanding to the end of the column
251		
252	=SELECTIONNER("C7")	
253	=INSERER()	Creating a new column
254		
255	=SELECTIONNER("L1C7")	
256	=FORMULE("SFz mV")	This new column is named "SFz mV"
257		
258	=SELECTIONNER("L2C6")	
259	=MODIFIER.SELECTION(4)	
260	=DEFINIR.NOM("fin32pro";CELLULE.ACTIVE())	Giving a new name to the last cell of column n°6
261	=SELECTIONNER("fin32pro")	
262	=SELECTIONNER("LC(1)")	
263	=DEFINIR.NOM("fin3pro";CELLULE.ACTIVE())	Giving the name of "fin3pro" to the last cell
264	=SELECTIONNER("fin3pro")	of column N°7
265		
266	=SELECTIONNER("L2C7")	
267	=FORMULE("=LC(-1)*714.28")	Putting the volts values in millivolts
268	=SELECTIONNER("L3C7")	Multiplying by 714.28
269	=FORMULE("=LC(-1)*714.28")	The correcting factor of this particular channel
270	=SELECTIONNER("L4C7")	is to divide it by 1.4
271	=FORMULE("=LC(-1)*714.28")	
272	=SELECTIONNER("L2C7:L4C7")	
273	=RECOPIE.INCREMENT("LC:fin3pro";FAUX)	Expanding to the end of the column
274	=FORMAT.NOMBRE("0.0")	Only one decimal digit, because numbers were multiplied
275		by 714.28 instead of 1000
276	=SELECTIONNER("C9")	
277	=INSERER()	Creating a new column
278		
279	=SELECTIONNER("L1C9")	
280	=FORMULE("SMx mV")	This new column is named "SMx mV"
281		
282	=SELECTIONNER("L2C8")	
283	=MODIFIER.SELECTION(4)	
284	=DEFINIR.NOM("fin42pro";CELLULE.ACTIVE())	Giving a new name to the last cell of column n°8
285	=SELECTIONNER("fin42pro")	
286	=SELECTIONNER("LC(1)")	
287	=DEFINIR.NOM("fin4pro";CELLULE.ACTIVE())	Giving the name of "fin4pro" to the last cell
288	=SELECTIONNER("fin4pro")	of column N°9
289		
290	=SELECTIONNER("L2C9")	
291	=FORMULE("=LC(-1)*1000")	Putting the volts values in millivolts
292	=SELECTIONNER("L3C9")	Multiplying by 1000
293	=FORMULE("=LC(-1)*1000")	
294	=SELECTIONNER("L4C9")	
295	=FORMULE("=LC(-1)*1000")	
296	=SELECTIONNER("L2C9:L4C9")	
297	=RECOPIE.INCREMENT("LC:fin4pro";FAUX)	Expanding to the end of the column
298		
299	=SELECTIONNER("C11")	
300	=INSERER()	Creating a new column
301		
302	=SELECTIONNER("L1C11")	
303	=FORMULE("SMy mV")	This new column is named "SMy mV"
304		
305	=SELECTIONNER("L2C10")	
306	=MODIFIER.SELECTION(4)	
307	=DEFINIR.NOM("fin52pro";CELLULE.ACTIVE())	Giving a new name to the last cell of column n°10
308	=SELECTIONNER("fin52pro")	
309	=SELECTIONNER("LC(1)")	
310	=DEFINIR.NOM("fin5pro";CELLULE.ACTIVE())	Giving the name of "fin5pro" to the last cell
311	=SELECTIONNER("fin5pro")	of column N°11
312		
313	=SELECTIONNER("L2C11")	
314	=FORMULE("=LC(-1)*1000")	Putting the volts values in millivolts
315	=SELECTIONNER("L3C11")	Multiplying by 1000
316	=FORMULE("=LC(-1)*1000")	
317	=SELECTIONNER("L4C11")	
318	=FORMULE("=LC(-1)*1000")	
319	=SELECTIONNER("L2C11:L4C11")	
320	=RECOPIE.INCREMENT("LC:fin5pro";FAUX)	Expanding to the end of the column
321		
322	=SELECTIONNER("C13")	
323	=INSERER()	Creating a new column
324		
325	=SELECTIONNER("L1C13")	
326	=FORMULE("SMz mV")	The new column is named "SMz mV"
327		
328	=SELECTIONNER("L2C12")	
329	=MODIFIER.SELECTION(4)	
330	=DEFINIR.NOM("fin62pro";CELLULE.ACTIVE())	Giving a new name to the last cell of column n°12
331	=SELECTIONNER("fin62pro")	
332	=SELECTIONNER("LC(1)")	

	1	2
333	=DEFINIR.NOM("fin6pro";CELLULE.ACTIVE())	Giving the name of "fin6pro" to the last cell
334	=SELECTIONNER("fin6pro")	of column N°13
335		
336	=SELECTIONNER("L2C13")	
337	=FORMULE("=LC(-1)*1000")	Putting the volts values in millivolts
338	=SELECTIONNER("L3C13")	Multiplying by 1000
339	=FORMULE("=LC(-1)*1000")	
340	=SELECTIONNER("L4C13")	
341	=FORMULE("=LC(-1)*1000")	
342	=SELECTIONNER("L2C13:L4C13")	
343	=RECOPIE.INCREMENT("LC:fin6pro";FAUX)	Expanding to the end of the column
344		
345	=SELECTIONNER("C15")	
346	=INSERER()	Creating a new column
347		
348	=SELECTIONNER("L1C15")	
349	=FORMULE("SCane1 mV")	The last new column is named "SCane1 mV"
350		
351	=SELECTIONNER("L2C14")	
352	=MODIFIER.SELECTION(4)	
353	=DEFINIR.NOM("fin72pro";CELLULE.ACTIVE())	
354	=SELECTIONNER("fin72pro")	
355	=SELECTIONNER("LC(1)")	Giving a new name to the last cell of column n°14
356	=DEFINIR.NOM("fin7pro";CELLULE.ACTIVE())	
357	=SELECTIONNER("fin7pro")	
358		Giving the name of "fin7pro" to the last cell
359	=SELECTIONNER("L2C15")	of column N°15
360	=FORMULE("=LC(-1)*1000")	
361	=SELECTIONNER("L3C15")	
362	=FORMULE("=LC(-1)*1000")	Putting the volts values in millivolts
363	=SELECTIONNER("L4C15")	Multiplying by 1000
364	=FORMULE("=LC(-1)*1000")	
365	=SELECTIONNER("L2C15:L4C15")	
366	=RECOPIE.INCREMENT("LC:fin7pro";FAUX)	-
367		
368	=SELECTIONNER("L1C17")	Expanding to the end of the column
369	=FORMULE("SCane2 mV")	
370		
371	=SELECTIONNER("L2C16")	The last new column is named "SCane2 mV"
372	=MODIFIER.SELECTION(4)	
373	=DEFINIR.NOM("fin82pro";CELLULE.ACTIVE())	
374	=SELECTIONNER("fin82pro")	
375	=SELECTIONNER("LC(1)")	
376	=DEFINIR.NOM("fin8pro";CELLULE.ACTIVE())	
377	=SELECTIONNER("fin8pro")	Giving a new name to the last cell of column n°14
378		
379	=SELECTIONNER("L2C17")	
380	=FORMULE("=LC(-1)*1000")	Giving the name of "fin8pro" to the last cell
381	=SELECTIONNER("L3C17")	of column N°17
382	=FORMULE("=LC(-1)*1000")	
383	=SELECTIONNER("L4C17")	
384	=FORMULE("=LC(-1)*1000")	Putting the volts values in millivolts
385	=SELECTIONNER("L2C17:L4C17")	Multiplying by 1000
386	=RECOPIE.INCREMENT("LC:fin8pro";FAUX)	
387		
388	=SELECTIONNER("L1")	
389	=FORMAT.POLICE("Times New Roman";12;VRAI)	
390	=POSITION(3)	
391		Expanding to the end of the column
392	=ECRAN(FAUX)	
393	=ECRAN(VRAI)	
394		
395	=SELECTIONNER("L1C1:fin8pro")	
396	=ENREGISTRER.SOUS?()	
397		Screen is updated
398	=SELECTIONNER("C1;C3;C5;C7;C9;C11;C13;C15;C17")	
399	=COPIER()	Recording this file where data are both in volts
400	=NOUVEAU.DOCUMENT(1)	and millivolts for checking
401	=SELECTIONNER("L1C1")	
402	=COLLER()	Selecting the eight millivolts columns
403	=ENREGISTRER.SOUS?()	plus the time code column
404		Opening a new sheet
405		
406	=NOUVEAU.DOCUMENT(2;3)	
407	=SELECTIONNER("S1")	Recording this new file where data are
408	=COURBES(2;VRAI)	in millivolts (time + 8 columns)
409	=SELECTIONNER("S1")	
410	=MOTIFS(0;2;3;2;2;;;;FAUX)	Opening a raw data graph for checking
411	=FORMAT.GRAPH.PRINC(6)	
412	=SELECTIONNER("Axe1")	
413	=ECHELLE(-1000;2000;VRAI;VRAI;0;FAUX;FAUX;FAUX)	
414	=SELECTIONNER("Axe2")	
415	=MOTIFS(0;1;3;2;1;1;2)	

	1	2
416	=SELECTIONNER("Axe2")	
417	=ECHELLE(VRAI;VRAI;1)	Scale is -500 to 2000 millivolts
418	=AJOUTER.TEXTE(2)	It is easy to change it
419	=FORMULE("=""mV""")	
420	=AJOUTER.TEXTE(3)	
421	=FORMULE("=""time in seconds""")	
422	=AJOUTER.TEXTE(1)	
423	=FORMULE("=""All Channels""")	
424	=LEGENDE(VRAI)	
425	=FORMAT.LEGENDE(3)	
426	=SELECTIONNER("Graphique")	
427	=FORMAT.POLICE(0;1;FAUX;"Times New Roman";10;FAUX;FAUX;FAUX;F	
428	=SELECTIONNER("Graphique")	
429	=MOTIFS(1)	
430	=SELECTIONNER("Titre")	
431	=FORMAT.POLICE(0;1;FAUX;"Times New Roman";14;VRAI;FAUX;FAUX;FA	
432	=SELECTIONNER("Titre")	
433	=MOTIFS(1)	
434	=MISE.EN.PAGE("&N";"&J";1;1;1;1;3;VRAI;VRAI;2;9;100;1)	
435	=APERCU.IMPRESSION()	The chart is given in full screen fo checking
436		
437	=FICHIER.FERMER(FAUX)	The chart is closed without recording
438	=ECRAN(FAUX)	
439	=ECRAN(VRAI)	Screen is updated
440		
441	=SELECTIONNER("C2:C7")	
442	=COPIER()	
443	=NOUVEAU.DOCUMENT(1)	Opening a new file for using it in DOS session
444	=SELECTIONNER("L1C1")	especially with GAIT.EXE programme
445	=COLLER()	
446	=SELECTIONNER("L1")	
447	=EDITION.SUPPRIMER(3)	
448	=SELECTIONNER("C2")	
449	=INSERER()	
450	=SELECTIONNER("L1C1")	Cutting the first line where names are
451	=MODIFIER.SELECTION(4)	
452	=DEFINIR.NOM("fin13pro";CELLULE.ACTIVE())	
453	=SELECTIONNER("fin13pro")	Inserting a new column
454	=SELECTIONNER("LC(1)")	
455	=DEFINIR.NOM("fin111pro";CELLULE.ACTIVE())	
456	=SELECTIONNER("fin111pro")	
457	=SELECTIONNER("L1C2")	
458	=FORMULE("=LC(-1)+2000")	Naming the end of this new column
459	=SELECTIONNER("L2C2")	"fin111pro"
460	=FORMULE("=LC(-1)+2000")	Checking the name of the cell
461	=SELECTIONNER("L3C2")	
462	=FORMULE("=LC(-1)+2000")	Values are "SFx + 2000"
463	=SELECTIONNER("L1C2:L3C2")	
464	=RECOPIE.INCREMENT("LC:fin111pro";FAUX)	
465		
466	=SELECTIONNER("C4")	
467	=INSERER()	
468	=SELECTIONNER("L1C3")	Expanding values to the end of the column
469	=MODIFIER.SELECTION(4)	
470	=DEFINIR.NOM("fin23pro";CELLULE.ACTIVE())	
471	=SELECTIONNER("fin23pro")	Inserting a new column
472	=SELECTIONNER("LC(1)")	
473	=DEFINIR.NOM("fin211pro";CELLULE.ACTIVE())	
474	=SELECTIONNER("fin211pro")	
475	=SELECTIONNER("L1C4")	
476	=FORMULE("=LC(-1)+2000")	Naming the end of this new column
477	=SELECTIONNER("L2C4")	"fin211pro"
478	=FORMULE("=LC(-1)+2000")	Checking the name of the cell
479	=SELECTIONNER("L3C4")	
480	=FORMULE("=LC(-1)+2000")	Values are "SFy + 2000"
481	=SELECTIONNER("L1C4:L3C4")	
482	=RECOPIE.INCREMENT("LC:fin211pro";FAUX)	
483		
484	=SELECTIONNER("C6")	
485	=INSERER()	
486	=SELECTIONNER("L1C5")	Expanding values to the end of the column
487	=MODIFIER.SELECTION(4)	
488	=DEFINIR.NOM("fin33pro";CELLULE.ACTIVE())	
489	=SELECTIONNER("fin33pro")	Inserting a new column
490	=SELECTIONNER("LC(1)")	
491	=DEFINIR.NOM("fin311pro";CELLULE.ACTIVE())	
492	=SELECTIONNER("fin311pro")	
493	=SELECTIONNER("L1C6")	
494	=FORMULE("=LC(-1)+2000")	Naming the end of this new column
495	=SELECTIONNER("L2C6")	"fin311pro"
496	=FORMULE("=LC(-1)+2000")	Checking the name of the cell
497	=SELECTIONNER("L3C6")	
498	=FORMULE("=LC(-1)+2000")	Values are "SFz + 2000"

	1	2
499	=SELECTIONNER("L1C6:L3C6")	
500	=RECOPIE.INCREMENT("LC:fin311pro";FAUX)	
501		
502	=SELECTIONNER("C8")	
503	=INSERER()	
504	=SELECTIONNER("L1C7")	Expanding values to the end of the column
505	=MODIFIER.SELECTION(4)	
506	=DEFINIR.NOM("fin43pro";CELLULE.ACTIVE())	
507	=SELECTIONNER("fin43pro")	Inserting a new column
508	=SELECTIONNER("LC(1)")	
509	=DEFINIR.NOM("fin411pro";CELLULE.ACTIVE())	
510	=SELECTIONNER("fin411pro")	
511	=SELECTIONNER("L1C8")	
512	=FORMULE("=LC(-1)+2000")	Naming the end of this new column
513	=SELECTIONNER("L2C8")	"fin411pro"
514	=FORMULE("=LC(-1)+2000")	Checking the name of the cell
515	=SELECTIONNER("L3C8")	
516	=FORMULE("=LC(-1)+2000")	Values are "SMx + 2000"
517	=SELECTIONNER("L1C8:L3C8")	
518	=RECOPIE.INCREMENT("LC:fin411pro";FAUX)	
519		
520	=SELECTIONNER("C10")	
521	=INSERER()	
522	=SELECTIONNER("L1C9")	Expanding values to the end of the column
523	=MODIFIER.SELECTION(4)	
524	=DEFINIR.NOM("fin53pro";CELLULE.ACTIVE())	
525	=SELECTIONNER("fin53pro")	Inserting a new column
526	=SELECTIONNER("LC(1)")	
527	=DEFINIR.NOM("fin511pro";CELLULE.ACTIVE())	
528	=SELECTIONNER("fin511pro")	
529	=SELECTIONNER("L1C10")	
530	=FORMULE("=LC(-1)+2000")	Naming the end of this new column
531	=SELECTIONNER("L2C10")	"fin411pro"
532	=FORMULE("=LC(-1)+2000")	Checking the name of the cell
533	=SELECTIONNER("L3C10")	
534	=FORMULE("=LC(-1)+2000")	Values are "SMy + 2000"
535	=SELECTIONNER("L1C10:L3C10")	
536	=RECOPIE.INCREMENT("LC:fin511pro";FAUX)	
537		
538	=SELECTIONNER("L1C11")	
539	=MODIFIER.SELECTION(4)	
540	=DEFINIR.NOM("fin63pro";CELLULE.ACTIVE())	Expanding values to the end of the column
541	=SELECTIONNER("fin63pro")	
542	=SELECTIONNER("LC(1)")	
543	=DEFINIR.NOM("fin611pro";CELLULE.ACTIVE())	
544	=SELECTIONNER("fin611pro")	
545	=SELECTIONNER("L1C12")	
546	=FORMULE("=LC(-1)+2000")	Naming the end of this new column
547	=SELECTIONNER("L2C12")	"fin411pro"
548	=FORMULE("=LC(-1)+2000")	Checking the name of the cell
549	=SELECTIONNER("L3C12")	
550	=FORMULE("=LC(-1)+2000")	Values are "SMz + 2000"
551	=SELECTIONNER("L1C12:L3C12")	
552	=RECOPIE.INCREMENT("LC:fin611pro";FAUX)	
553		
554	=SELECTIONNER("C2;C4;C6;C8;C10;C12")	
555	=COPIER()	
556	=NOUVEAU.DOCUMENT(1)	
557	=SELECTIONNER("L1C1")	Expanding values to the end of the column
558	=COLLER()	
559	=FORMAT.NOMBRE("0000.00")	Recording this new file (*.DAT) using it with
560	=ENREGISTRER.SOUS?(;21)	DOS programme. Data are separeted by a
561	=FICHIER.FERMER(FAUX)	semicolon. Closing the file.
562	=ECRAN(FAUX)	
563	=ECRAN(VRAI)	Screen is updated
564	=FICHIER.FERMER(FAUX)	
565		
566	=SELECTIONNER("C2:C9")	
567	=COPIER()	Opening Excel model file called CALIMAT1.XLT (T for Template)
568	=OUVRIR("C:\EXCEL\PHDPERSO\CALIMAT2.XLT")	using the calibration matrix and correcting factors with six graphs.
569	=SELECTIONNER("L1C2")	One graph by channel. Axial force Fy is mixed withe two ones
570	=COLLER()	
571		
572	=ENREGISTRER.SOUS?()	Recording the work-out file with an Excel extension * XLS
573		
574	=ARRETER()	
575	=RETOUR()	End of the macro - sheet

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
1		SFx	SFy	SFz	SMx	SMy	SMz	SCaRi	SCaLe			Fx	Fy	Fz	Mx	My	Mz	Cane Right	Cane Left			
2	0.02										0.02	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95			
3	0.03										0.03	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95		MAX Fx	0.00
4	0.05										0.05	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95		MIN	0.00
5	0.06										0.06	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95		MEDIANE	0.00
6	0.08										0.08	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95			
7	0.09										0.09	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95		MAX Fy	0.00
8	0.11										0.11	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95		MIN	0.00
9	0.13										0.13	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95		MEDIANE	0.00
10	0.14										0.14	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95			
11	0.16										0.16	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95		MAX Fz	0.00
12	0.17										0.17	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95		MIN	0.00
13	0.19										0.19	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95		MEDIANE	0.00
14	0.20										0.20	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95			
15	0.22										0.22	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95		MAX Mx	0.00
16	0.23										0.23	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95		MIN	0.00
17	0.25										0.25	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95		MEDIANE	0.00
18	0.27										0.27	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95			
19	0.28										0.28	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95		MAX My	0.00
20	0.30										0.30	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95		MIN	0.00
21	0.31										0.31	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95		MEDIANE	0.00
22	0.33										0.33	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95			
23	0.34										0.34	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95		MAX Mz	0.00
24	0.36										0.36	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95		MIN	0.00
25	0.38										0.38	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95		MEDIANE	0.00
26	0.39										0.39	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95			
27	0.41										0.41	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95		MAX CaRi	68.38
28	0.42										0.42	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95		MIN	68.38
29	0.44										0.44	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95		MEDIANE	68.38
30	0.45										0.45	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95			
31	0.47										0.47	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95		MAX CaLe	45.95
32	0.48										0.48	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95		MIN	45.95
33	0.50										0.50	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95		MEDIANE	45.95
34	0.52										0.52	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95			
35	0.53										0.53	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95			
36	0.55										0.55	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95			
37	0.56										0.56	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95			
38	0.58										0.58	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95			
39	0.59										0.59	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95			
40	0.61										0.61	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95			
41	0.63										0.63	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95			
42	0.64										0.64	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95			
43	0.66										0.66	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95			
44	0.67										0.67	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95			
45	0.69										0.69	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95			
46	0.70										0.70	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95			
47	0.72										0.72	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95			
48	0.73										0.73	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95			
49	0.75										0.75	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95			
50	0.77										0.77	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95			
51	0.78										0.78	0.0	0.0	0.00	0.00	0.00	0.00	68.38	45.95			

Figure VII.1: The first page of the template file CALIMAT2.XLT. See facing page for more explanations

11.VIII.2 The first page of the template file named CALIMAT2.XLT

The first page of the template file used with the macro-sheet described in 12.VIII.1, is shown in the facing page. the first column corresponds to a base of time adjusted for a sampling rate of 64 Hz. The letter S stands for signal that is raw data (column 2 to 9). The columns 12 to 19 corresponds to processed data. The calibration matrix described in section 8.7 and the correcting factors described in section 7.8 are applied. Concerning the walking assistive devices (columns 18 and 19), 68.38 and 45.95 corresponds to the offset values of the two devices. These values are used in the template file because it was not possible to adjust the offset when the data acquisition system is programmed. The columns 21 and 22 show automatically the maximum positive, the minimum (maximum negative) and the median for the eight channels.

SUBJECTS' CODE	Age	Gender	Delay from Amput. in months	Stump Length in mm	B. Mass B. Height	Side	Type of Socket	Walking Assistive Devices Used	Terrain	Comments
TTR6	65	M	4	65	59 176	R	ARS	2 S 2 C 1 S 1 C	tiled corridor ramp outside	before Safe II Foot
TTL2	74	F	4	135	69 162	L	GS GS ARS	2 S 2 C 1 S 1 C	vinyl floor	new socket before discharge
TTL11	75	M	3	90	60 168 62 67	L	GS ARS	2 S 2 S / 2 C 2 S / 2 C	vinyl floor ramp outside tiled corridor ramp	socket too large cross stroll.
TTL14	59	M	3	45	49.3 174	L	GS ARS	2 S	vinyl floor tiled corridor	small stump
TTL7	74	M	2.5	45	78 172	L	GS ARS	2 S 2 S / 2 C	vinyl floor	short stump pain & weakness lower pain
TTR1	75	M	3.5		71 171	R	GS	2 S / 2 C	tiled corridor	socket in varus new GS
TTL21	77	F	3.5	80	58 160	L	GS	2S	vinyl floor	day before ARS
TTR22	67	M	4		97 167	R	GS ARS	2S 1S 2S	vinyl floor	video.
TTL16	67	M	5	95	69 176	L	ARS	2S 1S1C	vinyl floor stair	permanent knee bending
TTR23	86	F	3	95	54.2 161	R	ARS	1S1C	vinyl floor stair	in 1997 : bilateral transtibial
TTR5	47	M	2.5	160	74.4 188	R	GS	2S 1C 2S/2C 1S/1C		2S since 2 days
TTL15	46	M	3	160	73.8 175	L	GS	1S Right 0S	vinyl floor tiled corridor	no pain
TTL12	74	M	5	95	69 167	L	GS ARS	2S	vinyl floor stair	painful patient

Table VIII.3a: The directory concerning the 30 transtibial patients, see explanation in section 11.VIII.3: in page facing (11-422

11.VIII.3 The characteristics of the subjects tested

The directory of the 30 transtibial patients is shown in table VIII.3, see section 8.3 for explanation concerning the subjects' code.

The directory of the 10 transfemoral patients is shown in table VIII.4.

The main characteristics of each patient are shown. Some of them could have a weight variation due to a special diet during the stay-in at the Rehabilitation Unit.

The column of comments indicates

- some characteristics of the socket worn;
- new surgery between tests;
- the daily activity score when it is special;
- some comment concerning the pain and the muscle strength of the patient.

SUBJECTS' CODE	Age	Gender	Delay from Amput. in months	Stump Length in mm	B. Mass B. Height	Side	Type of Socket	Walking Assistive Devices Used	Terrain	Comments
TTR20	48	M	4	95	54 170	R	ARS	2S / 2C 1S Left Side	vinyl floor trial n°1 trial n°2 flat + utside ramp	 new surgery of the stump
TTR24	58	M	1.5	110	53 180	R	GS	2S 2S	flat + utside ramp	2nd test is the opposite Patient died few days later
TTR18	83	M	2.5	145	73 172	R	ARS	2S	vinyl floor	pain in front of the stump
TTR3	41	M	1.5	140	54 173	R	GS ARS	2 C / 2S	vinyl floor stair	before discharge
TTR25	51	M	8	125	83 176	R	ARS	2S / 2C	vinyl floor stair	knee bending AK in 1997
TTL10	75	F	6	100	42 155	L	ARS	2S / 2C 1S / 1C	vinyl floor	± pain
TTL26	75	M	3	95	82 185	L	GS	2S 1S / 1C	vinyl floor	socket too big day before ARS
TTL27	65	M	1	105	62 169	L	GS	2S 1S / 1C	vinyl floor	TM amputee large wound silicon boot
TTL15	63	M	7	80	73 165	L	ARS	1S / 1C 2C	vinyl floor	bad opposite foot
TTR17	50	M	8	170	81 185	R	ARS	2S / 2C	vinyl floor	bad opposite foot left knee arthrodesis
TTR4	62	M	2	160	72.3 190	R	GS GS ARS	2 S 2 S / 2 C	vinyl floor	 on/off shoe sole just before discharge
TTR13	65	F	5	85	85 168	R	GS ARS	2 S	vinyl floor	arthrosis pain on he opposite knee
TTL28	62	F	2 y.	125	67 160	L	ARS	1 S Right	vinyl floor tiled corridor	
TTL8	49	M	2	200	70 178	L	GS GS ARS	2 S 2 S / 2C	vinyl floor staircase	 new socket
TTL9	88	M	3	60	44.8 158	L	ARS	2S / 2 C	vinyl floor tiled corridor	oldest patient just before discharge

Table VIII.3b: The directory concerning the 30 transtibial patients, see explanation in section 11.VIII.3, page 11-422.

SUBJECTS' CODE	Age	Gender	Delay from Amput. in months	Stump Length in mm	B. Mass B. Height	Side	Type of Socket	Walking Assistive Devices Used	Terrain	Comments
TFR7	54 55	M	3	275	53 170 54	R	ARS-Q OB SA K ARS LOCKED	2S / 2C 1C / 1S	vinyl floor tiled corridor	sockect sine one week Silicon Soft-Socket New opposite by-pass
TFR1	68	M	4	215	60 165	R	ARS-Q LOCKED	2S	vinyl floor	
TFL9	40	F	4	335	42 170 46 49	L	ARS-Q OB SA K	2S 2C 1C	vinyl floor outside ramp id.	
TFR6	67	M	9	310	79 175	R	ARS OB SA K	2S 1C / 1S	vinyl floor stair	
TFR8	66	M	3	360	69.4 177	R	ARS-Q LOCKED	2S 1C / 1S	vinyl floor stair	
TFL10	62	M	2.5	350	68 175	L	ARS-Q LOCKED	2S	vinyl floor	low activity level
TFL5	76	M	2	340	60 168	L	ARS-Q LOCKED	2S - 2C	vinyl floor	middle activity level
TFL2	52	M	9	320	48 162	L	ARS-Q OB SA K	2 S	vinyl floor	low activity level
TFL4	68	M	1	295	90 172	L	GS LOCKED	2 S	vinyl floor	very low activity level
TFL3	46	M	1.5	300	60 170	L	GS LOCKED ARS-Q LOCKED	2S 2S / 2C	vinyl floor vinyl floor tiled corridor	2 S since 2 days low activity level new socket since 2 days

Table X.4: The 10 transfemoral patients directory

Table VIII.3c: The ten transfemoral patients directory

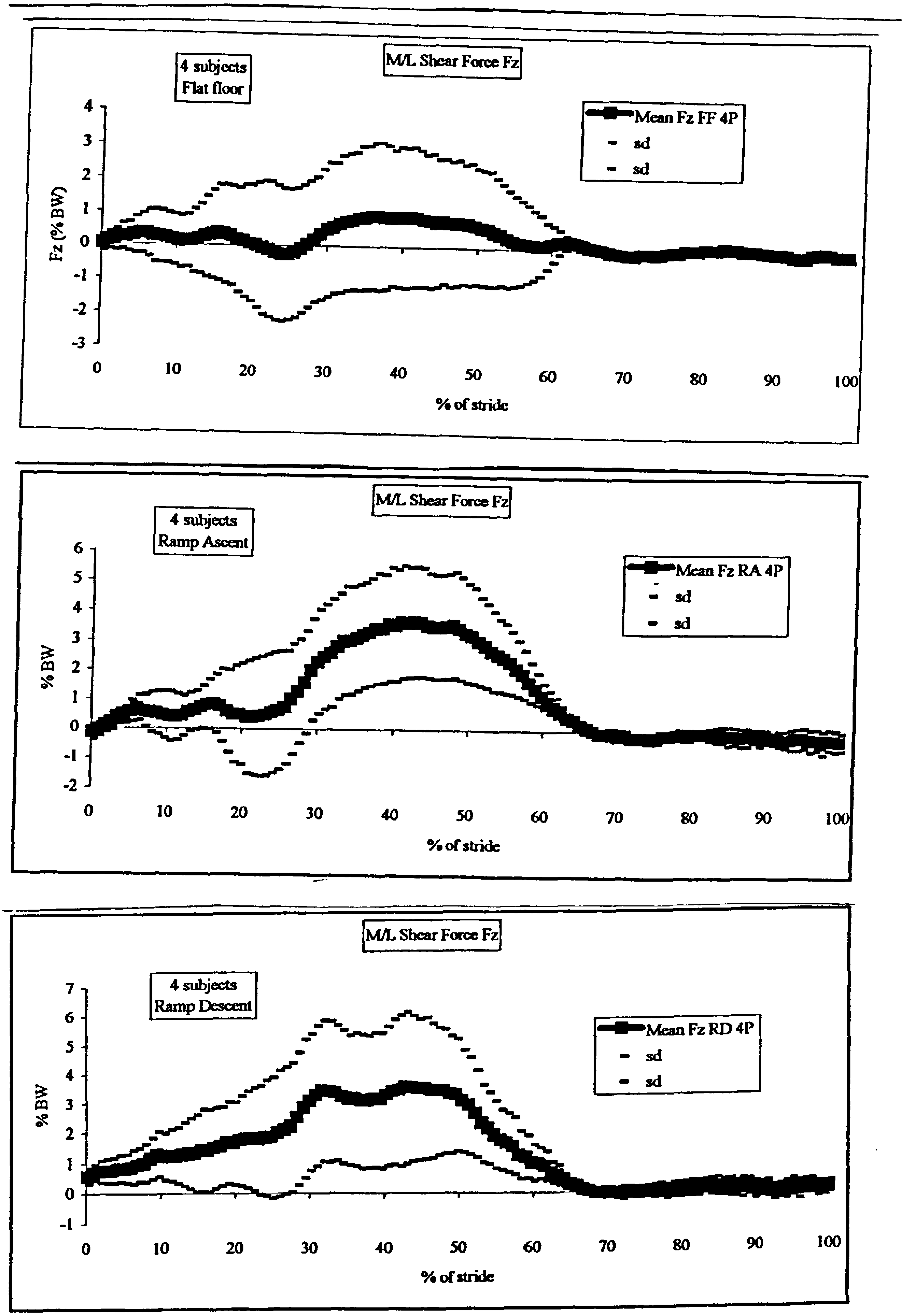


Figure VIII.2: Mean M/L shear Force Fz of 4 patients, using two sticks, in % of BW versus % of stride: above, flat floor; middle, ramp ascent; bottom, ramp descent.

11.VIII.4 The results for ramp ascent and descent from 4 transtibial patients in the medio lateral and transverse planes

Figure VIII.1 shows the side view of the ramp used to test four transtibial amputees: TTL11, TTR24, TTR20 and TTR6. The ramp is in front of the Rehabilitation Unit. It is used for the ambulances. It is partially covered by a roof. The slope is 5.2 %, 22.7 metres long. The floor is tar with small pebbles (see section 8.6).

Figure VIII.2 shows the medio lateral shear force Fz (% BW vs. % stride, ± SD) during flat floor trial, then ramp ascent and ramp descent. The results are the average of 5 strides recorded from 4 patients. The patients were using two sticks. However, the traces from the sticks are not shown because of the lack of information concerning the walking of amputees without sticks or canes in such a slope. Any comparison is thus impossible. Figure VIII.3 shows the same M/L shear force Fz recorded on flat floor (FF), ramp ascent (RA), ramp descent (RD) and plotted simultaneously on the same graph. The traces exhibit a lower value (maximum 1 % BW) in flat floor than in ramp ascent or descent (maximum 3.5 % BW). This confirms that the stress on the residual limb is increasing when a patient walks outside the Rehabilitation Unit. This is why only few patients were able to do so and therefore, the population tested (only 4 patients) was smaller than the other series.

Figure VIII.4 shows the media lateral bending moment Mx (N.m/kg vs. % of stride, ± SD). Figure VIII.5 shows the same channel simultaneously plotted when it has been recorded in three terrains such as: flat floor, ramp ascent and descent. The results, through a large standard deviation, show an important inter-patient variation. However, the values corresponding to the ramp ascent trials were widely more important (maximum multiplied by three, in both positive and negative directions) than those recorded during the other trials. Here also, it can be deducted that a ground with a slope introduces more stress on the residual limb than a flat floor.

Figure VIII.6 shows the transverse torque My (N.m/kg vs. % of stride, ± SD), with the same arrangement as figures VIII.2 and VIII.4. Figure VIII.7 is identical as figure VIII.5 showing the transverse torque channel My. Here also, as in M/L bending moment, the ramp ascent introduces a large amount in torque (maximum of-0.025 N.m/kg, i.e., 1.75 N.m for a body mass of 70Kg) relative to the other trials. However, the value of such a channel is small relative to the other channels and to the values reported in the literature. It could be the use of the walking assistive devices which decrease the amount of the transverse torque. However, no more information could be provided from the present research.

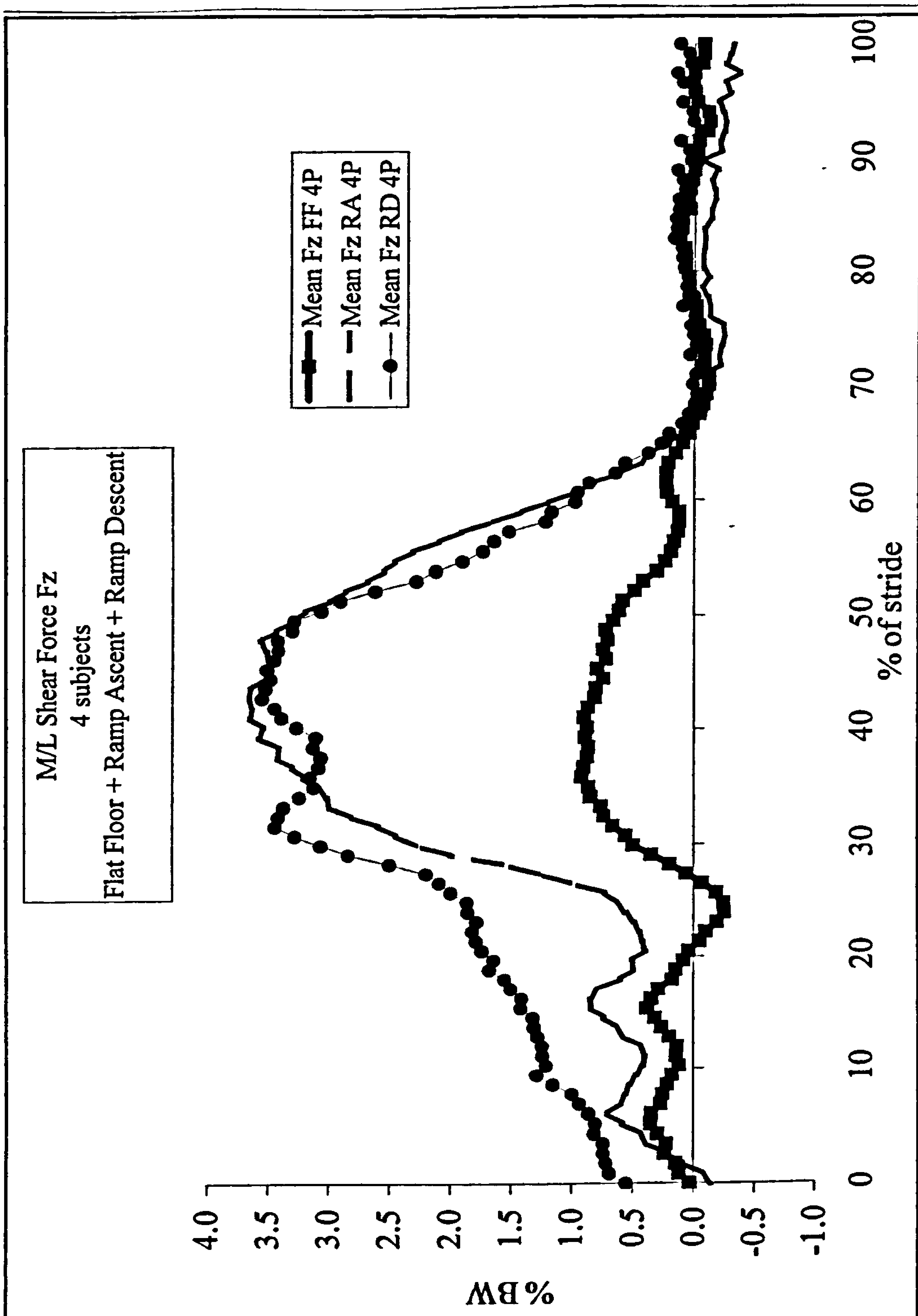


Figure VIII.3: M/L shear force Fz (% BW versus % stride) on three ground floors such as: flat floor, ramp ascent and descent.

Figure VIII.1: The side view of the Rehabilitation Unit with the ramp used to test 4 patients in ramp ascent and descent (slope 5.2 %, partially outside, the floor is made of tar with pebbles).

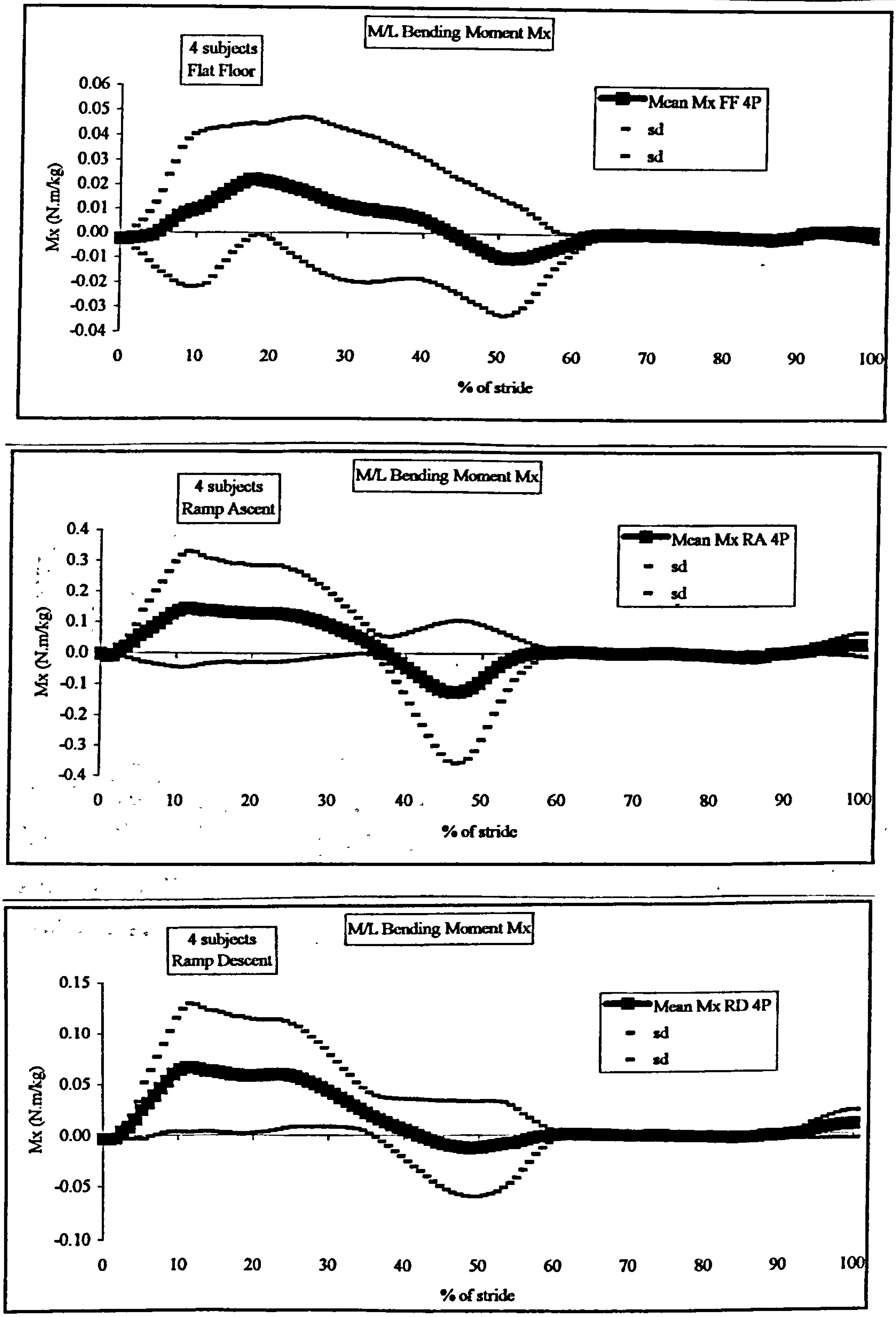


Figure VIII.4: Mean M/L bending moment Mx of 4 patients, using two sticks, in N.m/kg versus % of stride: above, flat floor; middle, ramp ascent; bottom, ramp descent.

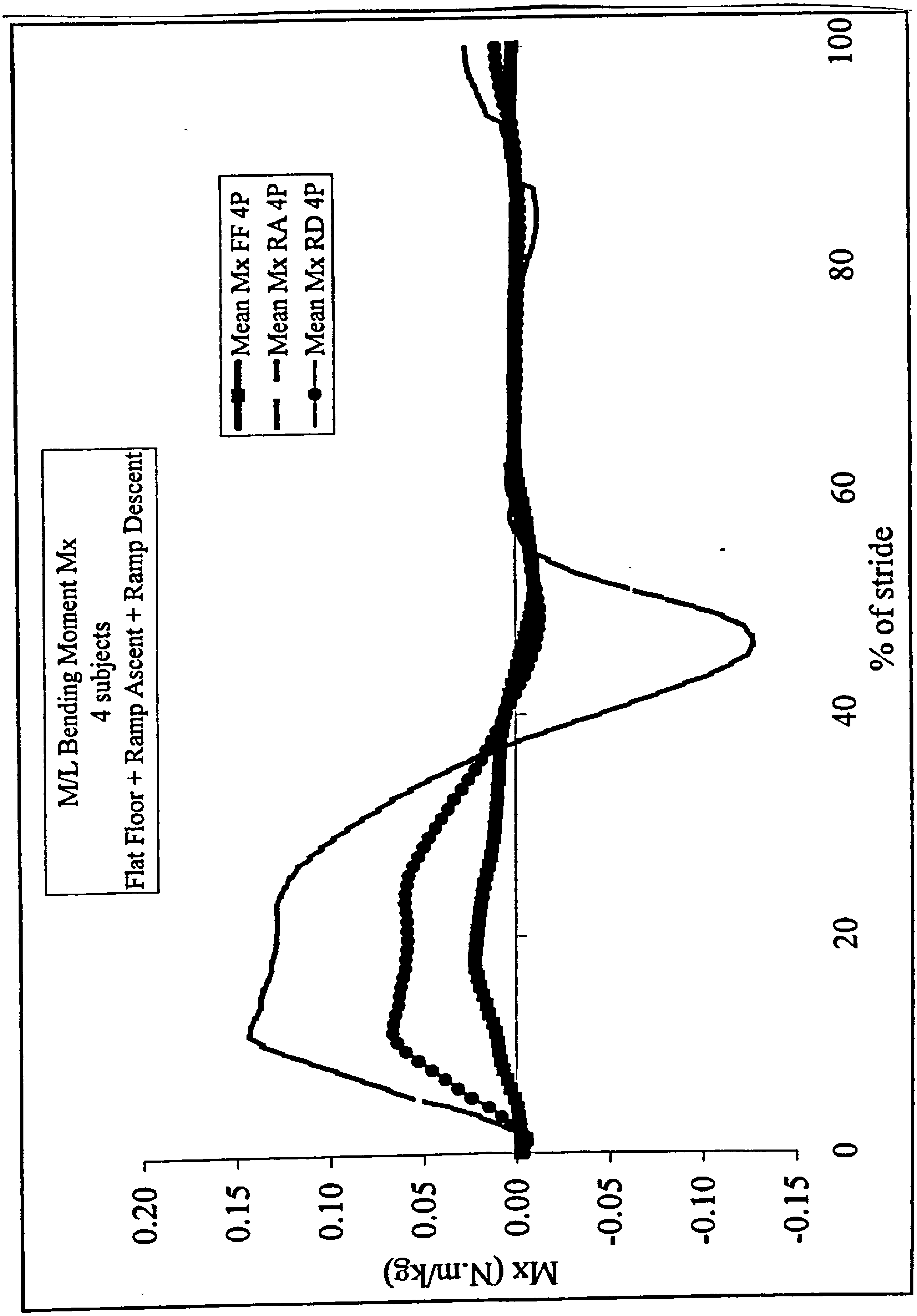


Figure VIII.5: M/L bending moment Mx (N.m/kg versus % stride) on three ground floors such as; flat floor, ramp ascent and descent.

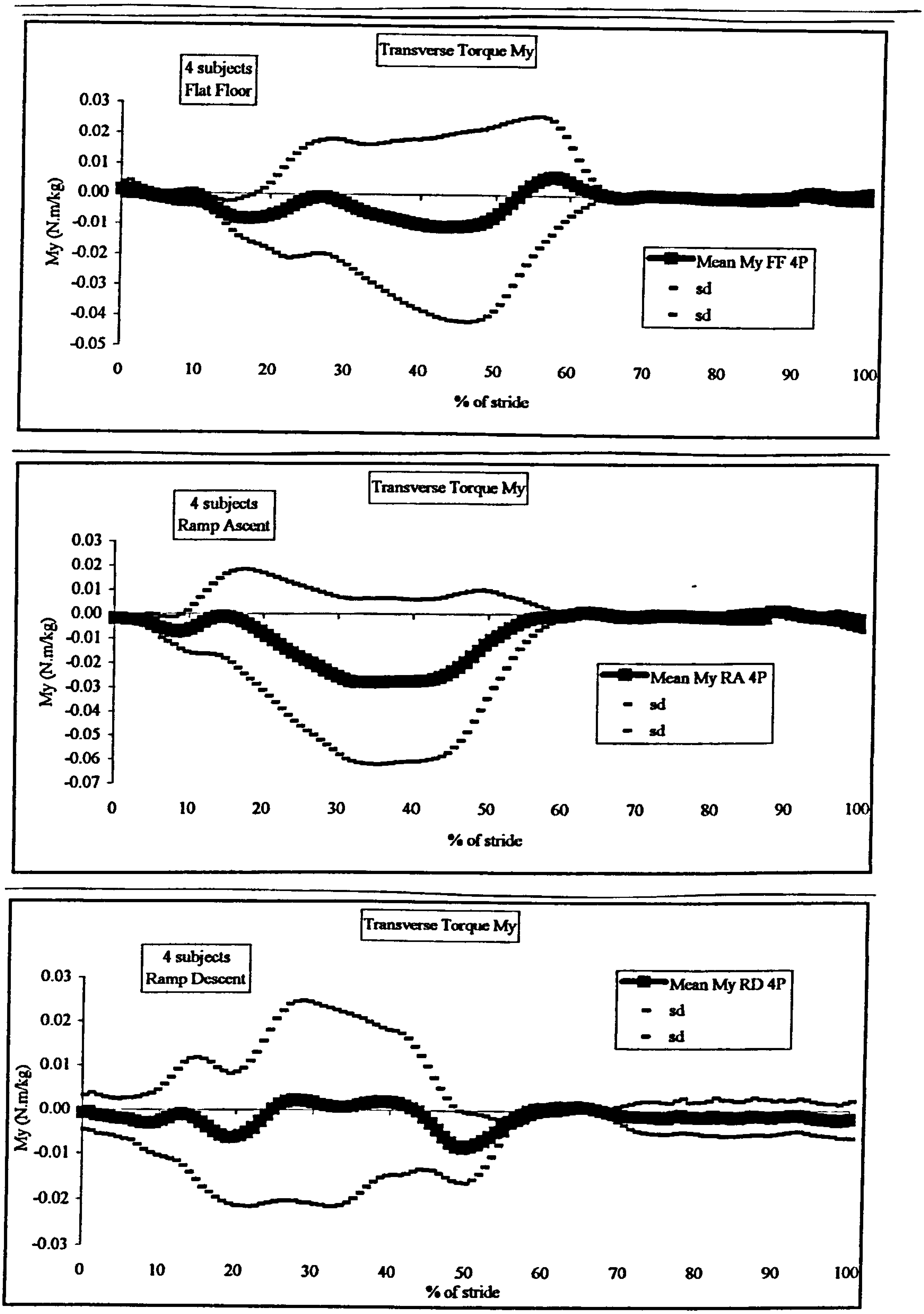


Figure VIII.6: Mean transverse torque My of 4 patients, using two sticks, in N.m/kg versus % of stride: above, flat floor; middle, ramp ascent; bottom, ramp descent.

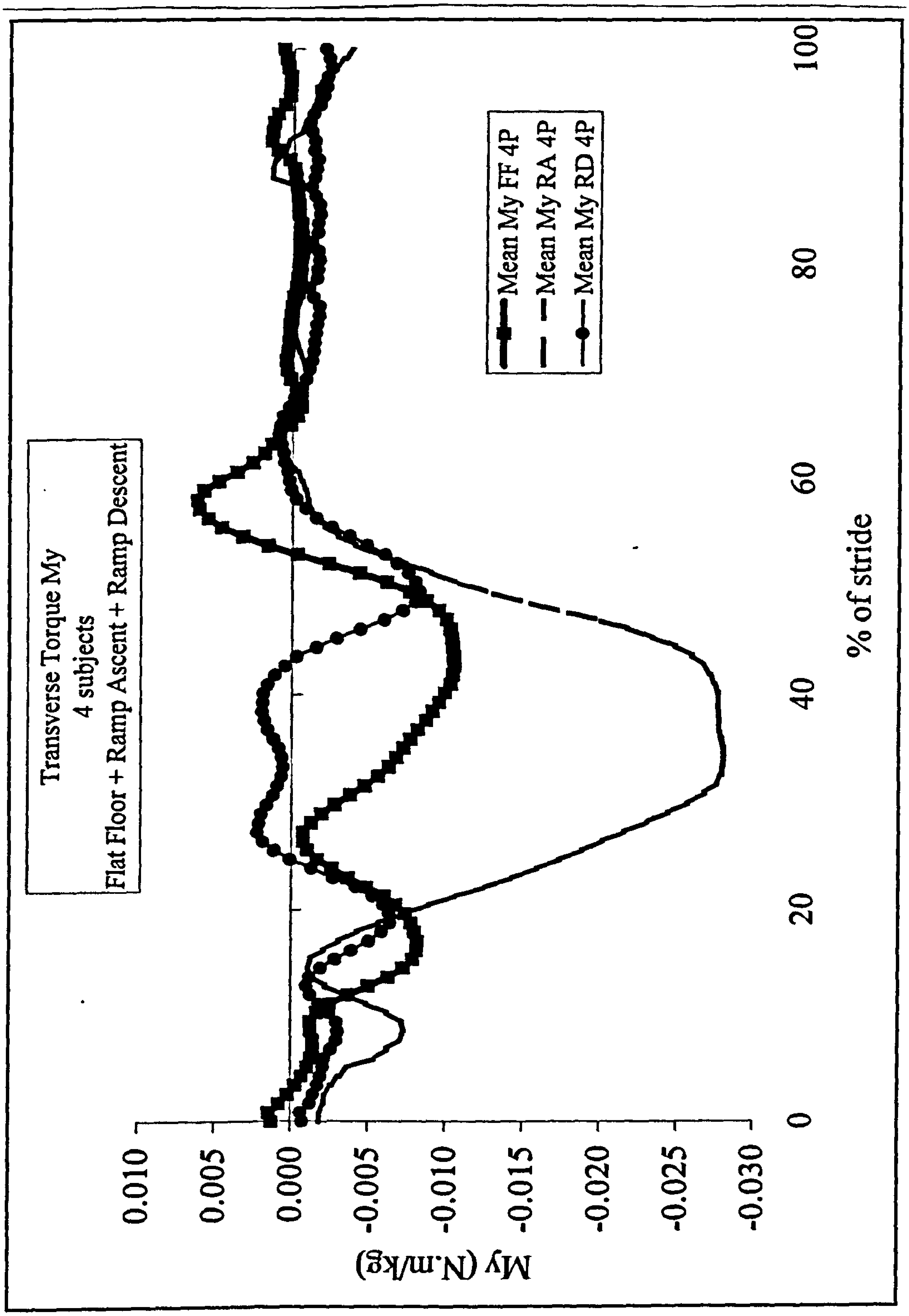


Figure VIII.7: Transverse torque My (N.m/kg versus % of stride) on three ground floors such as: flat floor, ramp ascent and descent.

2 STICKS VS. 2 CANES	Patient TTR1 GS - RIGHT BK **2 sticks**				Patient TTR1 GS - RIGHT BK **2 canes**			
	mean	SD	% of B.W.	N or Nm.kg^{-1}	mean	SD	% of B.W.	N or Nm.kg^{-1}
Maximum Gait Rate in s.stride^{-1}	1.61	0.06			1.57	0.07		
Maximum Axial Load (Fy) N	613	26		8.63	612	34		8.61
% of Axial Load vs. Body Mass	85 %				85 %			
Maximum Fx Shear negative N	-147	4.42	20.47	2.071	-138	6.74	19.19	1.942
Maximum Fx Shear positive N	19.5	6.71	2.71	0.275	45.3	3.46	6.27	0.638
Maximum Mz plantarflexion negative N.m	-5.41	0.54	0.75	0.072	-5.73	0.46	0.79	0.082
Maximum Mz dorsiflexion positive N.m	48.5	1.46	6.75	0.682	52.7	1.84	7.34	0.742
Maximum Load on both sticks or canes N	201	18		2.943	147	10.2		2.071
% of Sticks Load vs. Body Mass	28 %				20 %			
Maximum Load on Right Stick or Cane N	80	7	11.14	1.126	70	5.5	9.75	0.985
Maximum Load on Left Stick or Cane N	129	13	17.96	1.816	77	10.5	10.72	1.084
time from HS to the following TO = prosthesis stance phase (PSP)	1.39		0.04		1.11		0.05	
time from SS (CS) to the following SO (CO) = sticks or canes stance phase (SSP or CSP)	1.34		0.04		1.26		0.04	
time from SO (CO) to the following SS (CS) = sticks or canes swing phase (SSwP or CSwP)	0.27		0.04		0.31		0.04	
time from TO to the following SS (CS)	1.07		0.03		0.81		0.02	
time from TO the following SO (CO)	0.27		0.05		0.45		0.04	
time-interval between SS (CS) and HS	0.34		0.04		0.29		0.04	
time between Max Fy and Max Sticks or Canes = time - interval between axial load & sticks or canes push-up	0.54		0.02		0.51		0.04	
time between Max Mz +, Fx - and Max Sticks or Canes = time - interval between dorsiflexion + posterior shear and sticks or canes push-up	0.31		0.06		0.23		0.07	

Table VIII.5a: The results concerning the transtibial patient TTR1 using two sticks then two canes.

2 STICKS VS. 2 CANES	Patient TTL2 ARS - LEFT BK **2 sticks**				Patient TTL2 ARS - LEFT BK **2 canes**			
	mean	SD	% of B.W.	N or $Nm.kg^{-1}$	mean	SD	% of B.W.	N or $Nm.kg^{-1}$
Maximum Gait Rate in $s.stride^{-1}$	1.69	0.11			2.27	0.07		
Maximum Axial Load (Fy) N	571	33		8.05	547	32		7.71
% of Axial Load vs. Body Mass	82 %				78 %			
Maximum Fx Shear negative N	-121	7.53	17.46	1.71	-125	5.72	17.97	1.76
Maximum Fx Shear positive N	22.1	2.49	3.17	0.31	25.9	2	3.72	0.36
Maximum Mz plantarflexion negative N.m	-5.87	2.49	0.84	0.08	-6.18	0.47	0.88	0.09
Maximum Mz dorsiflexion positive N.m	41.8	1.77	6.01	0.59	37	1.86	5.31	0.52
Maximum Load on both sticks or canes N	188	12.47		2.65	183	11.65		2.58
% of Sticks Load vs. Body Mass	27 %				26 %			
Maximum Load on Right Stick or Cane N	97.32	12.44	13.99	1.37	107	9.31	15.38	1.51
Maximum Load on Left Stick or Cane N	90.82	12.71	13.05	1.28	76	8.6	10.92	1.07
time from HS to the following TO = prosthesis stance phase (PSP)	1.18		0.11		1.74		0.09	
time from SS (CS) to the following SO (CO) = sticks or canes stance phase (SSP or CSP)	1.36		0.08		1.90		0.23	
time from SO (CO) to the following SS (CS) = sticks or canes swing phase (SSwP or CSwP)	0.33		0.03		0.37		0.04	
time from TO to the following SS (CS)	0.67		0.08		0.16		0.08	
time from SO (CO) to the following TO					0.24		0.07	
time from TO the following SO (CO)	0.36		0.04					
time-interval between SS (CS) and HS					0.35		0.06	
time-interval between HS and SS (CS)	0.16		0.06					
time between Max Fy and Max Sticks or Canes = time - interval between axial load & sticks or canes push-up	0.03		0.04		0.08		0.02	
time between Max Mz +, Fx - and Max Sticks or Canes = time - interval between dorsiflexion + posterior shear and sticks or canes push-up	0.02		0.01		0.09		0.01	

Table VIII.5b: The results concerning the transtibial patient TTL2 using two sticks then two canes.

2 STICKS VS. 2 CANES	Patient TTR3 ARS - RIGHT BK **2 sticks**				Patient TTR3 ARS - RIGHT BK **2 canes**			
	mean	SD	% of B.W.	N or $Nm.kg^{-1}$	mean	SD	% of B.W.	N or $Nm.kg^{-1}$
Maximum Gait Rate in $s.stride^{-1}$	1.79	0.08			1.87	0.07		
Maximum Axial Load (Fy) N	268	24.12		4.96	325	14.15		6.01
% of Axial Load vs. Body Mass	49 %				59 %			
Maximum Fx Shear negative N	-90.1	5.18	15.68	1.66	-96	6.73	16.71	1.77
Maximum Fx Shear positive N	11.2	4.15	1.95	0.21	16.3	2.63	2.84	0.30
Maximum Mz plantarflexion negative N.m	-3.7	0.69	0.64	0.07	-4.16	0.53	0.72	0.08
Maximum Mz dorsiflexion positive N.m	25.65	1.83	4.47	0.47	32.6	1.48	5.67	0.60
Maximum Load on both sticks or canes N	315	16.84		5.83	230	9.67		4.26
% of Sticks or Canes Load vs. Body Mass	57 %				42 %			
Maximum Load on Right Stick or Cane N	117	7.8	20.36	2.16	103	8.4	17.93	1.91
Maximum Load on Left Stick or Cane N	198	13	34.47	3.66	127	9.7	22.11	2.35
time from HS to the following TO = prosthesis stance phase (PSP)	1.22		0.08		1.27		0.09	
time from SS (CS) to the following SO (CO) = sticks or canes stance phase (SSP or CSP)	1.48		0.06		1.49		0.08	
time from SO (CO) to the following SS (CS) = sticks or canes swing phase (SSwP or CSwP)	0.31		0.05		0.37		0.04	
time from TO to the following SS (CS)	1.04		0.06		1.13		0.09	
time from TO the following SO (CO)	0.44		0.05		0.36		0.03	
time-interval between SS (CS) and HS	0.20		0.04		0.13		0.02	
time between Max Fy and Max Sticks or Canes = time - interval between axial load & sticks or canes push-up	0.52		0.12		0.38		0.03	
time between Max Mz +, Fx - and Max Sticks or Canes = time - interval between dorsiflexion + posterior shear and sticks or canes push-up	0.04		0.04		0.06		0.03	

Table VIII.5c: The results concerning the transtibial patient TTR3 using two sticks then two canes.

2 STICKS VS. 2 CANES	Patient TTR4 ARS - RIGHT BK **2 sticks**				Patient TTR4 ARS - RIGHT BK **2 canes**			
	mean	SD	% of B.W.	N or Nm.kg^{-1}	mean	SD	% of B.W.	N or Nm.kg^{-1}
Maximum Gait Rate in s.stride^{-1}	1.52	0.02			1.47	0.004		
Maximum Axial Load (Fy) N	408	24.13		5.64	522	27.47		7.21
% of Axial Load vs. Body Mass	55 %				70 %			
Maximum Fx Shear negative N	-129	24.2	17.72	1.79	-157	8.89	21.56	2.17
Maximum Fx Shear positive N	22.7	3.32	3.11	0.31	34.9	5.75	4.79	0.48
Maximum Mz plantarflexion negative N.m	-3.37	1.04	0.46	0.04	-6.12	0.44	0.84	0.08
Maximum Mz dorsiflexion positive N.m	39.8	3.37	5.46	0.55	47.2	2.96	6.48	0.65
Maximum Load on both sticks or canes N	319	23.86		4.41	184	20.47		2.54
% of Sticks or Canes Load vs. Body Mass	43 %				25 %			
Maximum Load on Right Stick or Cane N	137	15.67	18.82	1.91	101	14.43	13.87	1.39
Maximum Load on Left Stick or Cane N	181	16.28	24.86	2.51	83.7	10.61	11.49	1.14
time from HS to the following TO = prosthesis stance phase (PSP)	0.92		0.03		0.9		0.01	
time from SS (CS) to the following SO (CO) = sticks or canes stance phase (SSP or CSP)	1.26		0.04		1.02		0.03	
time from SO (CO) to the following SS (CS) = sticks or canes swing phase (SSwP or CSwP)	0.25		0.04		0.45		0.06	
time from TO to the following SS (CS)	0.77		0.04		0.66		0.02	
time from TO the following SO (CO)	0.49		0.04		0.36		0.04	
time-interval between SS (CS) and HS	0.15		0.03		0.25		0.03	
time between Max Fy and Max Sticks or Canes = time - interval between axial load & sticks or canes push-up	0.42		0.04		0.46		0.04	
time between Max Mz +, Fx - and Max Sticks or Canes = time - interval between dorsiflexion + posterior shear and sticks or canes push-up	0.04		0.01		0.08		0.12	

Table VIII.5d: The results concerning the transtibial patient TTR4 using two sticks then two canes.

2 STICKS VS. 2 CANES	Patient TTR5 GS - RIGHT BK **2 sticks**				Patient TTR5 GS - RIGHT BK **2 canes**			
	mean	SD	% of B.W.	N or $Nm.kg^{-1}$	mean	SD	% of B.W.	N or $Nm.kg^{-1}$
Maximum Gait Rate in $s.stride^{-1}$	1.98	0.03			2.11	0.05		
Maximum Axial Load (Fy) N	188	11.5		2.44	348	23		4.51
% of Axial Load vs. Body Mass	25 %				46 %			
Maximum Fx Shear negative N	-62.7	4.81	8.27	0.81	-123	9.92	16.34	1.61
Maximum Fx Shear positive N	21.8	2.21	2.88	0.28	29.4	2.41	3.88	0.38
Maximum Mz plantarflexion negative N.m	2.02	0.36	0.26	0.02	-3.97	0.19	0.52	0.05
Maximum Mz dorsiflexion positive N.m	22.6	1.28	2.99	0.29	39.5	1.67	5.21	0.51
Maximum Load on both sticks or canes N	543	15.2		7.03	350	20.46		4.53
% of Sticks or Canes Load vs. Body Mass	72 %				46 %			
Maximum Load on Right Stick or Cane N	195	12.8	25.68	2.53	148	10.5	19.6	1.92
Maximum Load on Left Stick or Cane N	347	9.91	45.69	4.50	201	22.2	26.6	2.61
time from HS to the following TO = prosthetic stance phase (PSP)	1.20		0.04		1.34		0.04	
time from SS (CS) to the following SO (CO) = sticks or canes stance phase (SSP or CSP)	1.69		0.04		1.86		0.08	
time from SO (CO) to the following SS (CS) = sticks or canes swing phase (SSwP or CSwP)	0.29		0.03		0.25		0.04	
time from SS to the following TO	1.05		0.05		1.28		0.04	
time from TO the following SO	0.64		0.02		0.62		0.04	
time-interval between HS and SS	0.13		0.04		0.09		0.03	
time between Max Fy and Max Sticks = time - interval between axial load & sticks or canes push-up	0.35		0.02		0.45		0.09	
time between Max Mz +, Fx - and Max Sticks = time - interval between dorsiflexion + posterior shear and sticks or canes push-up	0.14		0.02		0.04		0.02	

Table VIII.5e: The results concerning the transtibial patient TTR5 using two sticks then two canes.

2 STICKS VS. 2 CANES	Patient TTL7 ARS - LEFT BK **2 sticks**				Patient TTL7 ARS - LEFT BK **2 canes**			
	mean	SD	% of B.W.	N or $Nm.kg^{-1}$	mean	SD	% of B.W.	N or $Nm.kg^{-1}$
Maximum Gait Rate in $s.stride^{-1}$	1.66	0.08			1.65	0.08		
Maximum Axial Load (Fy) N	673	37.12		8.62	666	31		8.29
% of Axial Load vs. Body Mass	85 %				84 %			
Maximum Fx Shear negative N	-172	9.33	21.82	2.17	-185	9.39	23.47	2.31
Maximum Fx Shear positive N	38.3	2.47	4.86	0.48	40	3.02	5.13	0.51
Maximum Mz plantarflexion negative N.m	-6.26	0.72	0.79	0.08	-6.21	0.53	0.78	0.07
Maximum Mz dorsiflexion positive N.m	58.9	2.07	7.47	0.74	58	2.06	7.41	0.72
Maximum Load on both sticks or canes N	154	15.09		1.95	155	15.77		1.92
% of Sticks or Canes Load vs. Body Mass	20 %				19 %			
Maximum Load on Right Stick or Cane N	79.2	13.92	10.04	1.00	79	13	10.03	0.98
Maximum Load on Left Stick or Cane N	75.3	12.03	9.55	0.95	75	11.7	9.57	0.94
time from HS to the following TO = prosthetic stance phase (PSP)	1.17		0.06		1.17		0.06	
time from SS (CS) to the following SO (CO) = sticks or canes stance phase (SSP or CSP)	1.21		0.05		1.22		0.04	
time from SO (CO) to the following SS (CS) = sticks or canes swing phase (SSwP or CSwP)	0.45		0.14		0.43		0.08	
time from SS to the following TO	0.83		0.04		0.83		0.03	
time from TO the following SO	0.38		0.04		0.38		0.04	
time-interval between HS and SS	0.33		0.05		0.34		0.05	
time between Max Fy and Max Sticks = time - interval between axial load & sticks or canes push-up	0.28		0.14		0.25		0.14	
time between Max Mz +, Fx - and Max Sticks = time - interval between dorsiflexion + posterior shear and sticks or canes push-up	0.05		0.03		0.05		0.03	

Table VIII.5f: The results concerning the transtibial patient TTL7 using two sticks then two canes.

2 STICKS VS. 2 CANES	Patient TTL8 GS - LEFT BK **2 sticks**				Patient TTL8 GS - LEFT BK **2 canes**			
	mean	SD	% of B.W.	N or Nm.kg^{-1}	mean	SD	% of B.W.	N or Nm.kg^{-1}
Maximum Gait Rate in s.stride^{-1}	1.80	0.06			1.71	0.05		
Maximum Axial Load (Fy) N	594	28.11		8.51	637	24.12		9.12
% of Axial Load vs. Body Mass	83 %				89 %			
Maximum Fx Shear negative N	-65.5	10.5	9.26	0.94	-65.1	6.39	9.21	0.93
Maximum Fx Shear positive N	57.8	7.57	8.17	0.83	80.1	6.43	11.3	1.15
Maximum Mz plantarflexion negative N.m	-10.9	0.59	1.54	0.16	-10.3	0.75	1.45	0.14
Maximum Mz dorsiflexion positive N.m	37.71	4.04	5.33	0.54	45.4	2.45	6.41	0.65
Maximum Load on both sticks or canes N	151	29.12		0.89	145	20.13		2.08
% of Sticks Load vs. Body Mass	21 %				20 %			
Maximum Load on Right Stick or Cane N	97.6	17.07	13.79	1.39	80.7	11.08	11.4	1.15
Maximum Load on Left Stick or Cane N	61.9	20.91	8.75	0.89	64.9	13.97	9.17	0.93
time from HS to the following TO = prosthesis stance phase (PSP)	1.28		0.09		1.33		0.05	
time from SS (CS) to the following SO (CO) = sticks or canes stance phase (SSP or CSP)	1.46		0.07		1.24		0.08	
time from SO (CO) to the following SS (CS) = sticks or canes swing phase (SSwP or CSwP)	0.44		0.09		0.47		0.06	
time from TO to the following SS (CS)	0.90		0.08		0.82		0.04	
time from TO the following SO (CO)	0.56		0.12		0.42		0.06	
time-interval between HS and SS (CS)	0.30		0.10		0.53		0.05	
time between Max Fy and Max Sticks or Canes = time - interval between axial load & sticks or canes push-up	0.63		0.02		0.21		0.07	
time between Max Mz +, Fx - and Max Sticks or Canes = time - interval between dorsiflexion + posterior shear and sticks or canes push-up	0.06		0.03		0.10		0.05	

Table VIII.5g: The results concerning the transtibial patient TTL8 using two sticks then two canes.

2 STICKS VS. 2 CANES	Patient TTL9 ARS - LEFT BK **2 sticks**				Patient TTL9 ARS - LEFT BK **2 canes**			
	mean	SD	% of B.W.	N or $Nm.kg^{-1}$	mean	SD	% of B.W.	N or $Nm.kg^{-1}$
Maximum Gait Rate in $s.stride^{-1}$	2.02	0.12			1.96	0.11		
Maximum Axial Load (Fy) N	357	20		7.97	394	35		8.79
% of Axial Load vs. Body Mass	78 %				87 %			
Maximum Fx Shear negative N	-64.2	4.9	14.07	1.45	-72.3	13	15.84	1.61
Maximum Fx Shear positive N	13.6	2.1	2.98	0.30	8.84	1.88	1.94	0.19
Maximum Mz plantarflexion negative N.m	-1.22	0.31	0.26	0.03	-1.97	0.2	0.43	0.04
Maximum Mz dorsiflexion positive N.m	24.3	0.68	5.32	0.54	27.5	0.96	6.02	0.61
Maximum Load on both sticks or canes N	227	22		5.06	161	10.2		3.59
% of Sticks Load vs. Body Mass	50 %				36 %			
Maximum Load on Right Stick or Cane N	91.1	6.3	19.97	2.03	88.7	7.1	19.44	1.96
Maximum Load on Left Stick or Cane N	136	18	29.81	3.03	74.5	6.7	16.33	1.63
time from HS to the following TO = prosthesis stance phase (PSP)	1.41		0.21		1.37		0.09	
time from SS (CS) to the following SO (CO) = sticks or canes stance phase (SSP or CSP)	1.60		0.05		1.56		0.09	
time from SO (CO) to the following SS (CS) = sticks or canes swing phase (SSwP or CSwP)	0.42		0.11		0.40		0.11	
time from TO to the following SS (CS)	1.47		0.18		1.29		0.11	
time from TO the following SO (CO)	0.13		0.06		0.27		0.13	
time-interval between SS (CS) and HS	0.02		0.06		0.08		0.11	
time between Max Fy and Max Sticks or Canes = time - interval between axial load & sticks or canes push-up	0.07		0.01		0.09		0.03	
time between Max Mz +, Fx - and Max Sticks or Canes = time - interval between dorsiflexion + posterior shear and sticks or canes push-up	0.094		0.02		0.12		0.03	

Table VIII.5h: The results concerning the transtibial patient TTL9 using two sticks then two canes.

Tables VIII.7a to VIII.7i show the results of the nine transtibial amputees of the series 3. The patients were fitted with a provisional Plaster of Paris gypsum socket for the first test; then they wore a definitive acrylic resin socket for the second test. All used two forearm sticks as walking assistive devices. The standard deviations are shown to be used for a statistical analysis. Five subjects were common with those of the series 2 (TTL2, TTR3, TTR4, TTL7, TTL8).

GYPSUM VS. ACRYLIC SOCKET 2 STICKS	Patient TTL11 GS - LEFT BK **2 sticks**				Patient TTL11 ARS - LEFT BK **2 sticks**			
	mean	SD	% of B.W.	N or $Nm.kg^{-1}$	mean	SD	% of B.W.	N or $Nm.kg^{-1}$
Maximum Gait Rate in $s.stride^{-1}$	2.59	0.44			1.65	0.09		
Maximum Axial Load (Fy) N	529	30.13		8.81	702	9.32		11.7
% of Axial Load vs. Body Mass	87 %				104 %			
Maximum Fx Shear negative in N	-131	7.73	21.46	2.18	-133	8.63	19.71	2.21
Maximum Fx Shear positive in N	9.4	2.7	1.54	0.15	30.8	3.1	4.56	0.51
Maximum Mz plantarflexion negative in N.m	0.74	0.55	0.12	0.01	-4.81	0.9	0.71	0.08
Maximum Mz dorsiflexion positive in N.m	46.7	2.28	7.65	0.77	58.9	1.28	8.72	0.98
Maximum Load on both sticks in N	154	14.5		2.56	46.6	5.3		0.67
% of Sticks Load vs. Body Mass	25 %				7 %			
Maximum Load on Right Stick in N	69	9.9	11.31	1.15	33.9	5.3	5.02	0.565
Maximum Load on Left Stick in N	80	14.5	13.11	1.33	12.7	2.8	1.88	0.18
time from HS to the following TO = prosthetic stance phase (PSP)	2.1		0.21		1.19		0.03	
time from SS to the following SO = sticks stance phase (SSP)	2.2		0.07		1.17		0.11	
time from SO to the following SS = sticks swing phase (SSwP)	0.39		0.12		0.48		0.07	
time from TO to the following SS	0.11		0.08		0.04		0.02	
time from SO to the following TO	0.32		0.07		0.63		0.18	
time from TO the following SO	0.88		0.22		1.02			
time-lag between SS and HS	0.54		0.15		0.39		0.04	
time between Max Fy and Max Sticks = time - lag between axial load & sticks push-up	0.02		0.008		0.45		0.05	
time between Max Mz +, Fx - and Max Sticks = time - lag between dorsiflexion + posterior shear and sticks push-up	0.05		0.03		0.01		0.01	

Table VIII.7a: The results concerning the transtibial patient TTL11 fitted with a Plaster of Paris socket then an acrylic resin socket.

GYPSUM VS. ACRYLIC SOCKET 2 STICKS	Patient TTL2 GS - LEFT BK **2 sticks**				Patient TTL2 ARS - LEFT BK **2 sticks**			
	mean	SD	% of B.W.	N or $Nm.kg^{-1}$	mean	SD	% of B.W.	N or $Nm.kg^{-1}$
Gait Rate in $s.stride^{-1}$	2.29	0.04			1.69	0.11		
Axial Load (Fy) in N	541	34		7.58	571	33		8.05
% of Axial Load vs. Body Mass	77 %				82 %			
Maximum Fx Shear negative in N	-102	6.94	14.58	1.43	-121	7.53	17.46	1.71
Maximum Fx Shear positive in N	27.6	2.74	3.94	0.38	22.1	2.49	3.17	0.31
Maximum Mz plantarflexion negative in N.m	-5.94	0.45	0.84	0.08	-5.87	2.49	0.84	0.08
Maximum Mz dorsiflexion positive in N.m	32.8	1.52	4.68	0.46	41.8	1.77	6.01	0.59
Maximum Load on both sticks in N	195	17.37		2.73	188	12.47		2.65
% of Sticks Load vs. Body Mass	28 %				27 %			
Maximum Load on Right Stick in N	117	5.41	16.77	1.64	97.32	12.44	13.99	1.37
Maximum Load on Left Stick in N	77	15.33	11.07	1.08	90.82	12.71	13.05	1.28
time from HS to the following TO = prosthetic stance phase (PSP)	1.89	0.06			1.18	0.11		
time from SS to the following SO = sticks stance phase (SSP)	1.89	0.10			1.36	0.08		
time from SO to the following SS = sticks swing phase (SSwP)	0.40	0.04			0.33	0.03		
time from TO to the following SS	0.15	0.05			0.67	0.08		
time from SO to the following TO	0.24	0.05						
time from TO the following SO					0.36	0.04		
time-lag between SS and HS	0.23	0.05						
time-lag between HS and SS					0.16	0.06		
time between Max Fy and Max Sticks = time - lag between axial load & sticks push-up	0.03	0.02			0.03	0.04		
time between Max Mz +, Fx - and Max Sticks = time - lag between dorsiflexion + posterior shear and sticks push-up	0.05	0.03			0.02	0.01		

Table VIII.7b: The results concerning the transtibial patient TTLL2 fitted with a Plaster of Paris socket then an acrylic resin socket.

GYPSUM VS. ACRYLIC SOCKET 2 STICKS	Patient TTR3 GS - RIGHT BK **2 sticks**				Patient TTR3 ARS - RIGHT BK **2 sticks**			
	mean	SD	% of B.W.	N or $Nm.kg^{-1}$	mean	SD	% of B.W.	N or $Nm.kg^{-1}$
Gait Rate in $s.stride^{-1}$ from HS to the following HS	2.05	0.05			1.79	0.08		
Axial Load (Fy) in N	219	16.4		3.91	268	24		4.96
% of Axial Load vs. Body Mass	40 %				49 %			
Maximum Fx Shear negative in N	-62.1	11.30	11.26	1.11	-90.1	5.18	17.01	1.668
Maximum Fx Shear positive in N	14.9	4.09	2.56	0.26	11.2	4.15	2.11	0.207
Maximum Mz plantarflexion negative in N.m	-3.33	0.57	0.61	0.05	-3.7	0.69	0.69	0.071
Maximum Mz dorsiflexion positive in N.m	19.7	1.44	3.58	0.35	25.6	1.83	4.83	0.471
Maximum Load on both sticks in N	349	13.24		6.22	315	16.01		5.833
% of Sticks Load vs. Body Mass	63 %				57 %			
Maximum Load on Right Stick in N	121	7.44	22.02	2.16	117	7.8	22.08	2.166
Maximum Load on Left Stick in N	228	11.83	41.45	4.06	198	13	37.37	3.666
time from HS to the following TO = prosthesis stance phase (PSP)	1.43		0.05		1.22		0.08	
time from SS to the following SO = sticks stance phase (SSP)	1.64		0.07		1.48		0.06	
time from SO to the following SS = sticks swing phase (SSwP)	0.42		0.06		0.31		0.05	
time from SS to the following TO	1.26		0.04		1.04		0.06	
time from TO the following SO	0.38		0.07		0.44		0.05	
time-lag between HS and SS	0.18		0.03		0.2		0.04	
time between Max Fy and Max Sticks = time - lag between axial load & sticks push-up	0.19		0.18		0.52		0.12	
time between Max Mz +, Fx - and Max Sticks = time - lag between dorsiflexion + posterior shear and sticks push-up	0.06		0.02		0.04		0.04	

Table VIII.7c: The results concerning the transtibial patient TTR3 fitted with a Plaster of Paris socket then an acrylic resin socket.

GYPSUM VS. ACRYLIC SOCKET 2 STICKS	Patient TTR4 GS - RIGHT BK **2 sticks**				Patient TTR4 ARS - RIGHT BK **2 sticks**			
	mean	SD	% of B.W.	N or $Nm.kg^{-1}$	mean	SD	% of B.W.	N or $Nm.kg^{-1}$
Gait Rate in $s.stride^{-1}$	1.88	0.08			1.52	0.02		
Axial Load (Fy) in N	334	25.84		4.47	408	24		5.64
% of Axial Load vs. Body Mass	46 %				55 %			
Maximum Fx Shear negative in N	-78.1	13.58	10.67	1.04	-130	24.2	17.85	1.792
Maximum Fx Shear positive in N	22.6	6.78	3.09	0.31	22.8	3.3	3.13	0.314
Maximum Mz plantarflexion negative in N.m	-3.09	0.97	0.42	0.04	-3.37	1.04	0.46	0.046
Maximum Mz dorsiflexion positive in N.m	23.12	2.18	3.16	0.31	39.8	3.3	5.46	0.551
Maximum Load on both sticks in N	425	21.84		58.04	319	23		4.412
% of Sticks Load vs. Body Mass	58 %				43 %			
Maximum Load on Right Stick in N	174	12.79	23.85	2.34	137	15.6	18.82	1.908
Maximum Load on Left Stick in N	250	16.66	34.18	3.35	181	16	24.86	2.503
time from HS to the following TO = prosthesis stance phase (PSP)	1.11		0.08		0.92		0.03	
time from SS to the following SO = sticks stance phase (SSP)	1.68		0.13		1.26		0.04	
time from SO to the following SS = sticks swing phase (SSwP)	0.20		0.09		0.25		0.04	
time from TO to the following SS	0.98		0.06		0.77		0.04	
time from TO the following SO	0.64		0.06		0.49		0.04	
time-lag between HS and SS	0.11		0.05		0.15		0.03	
time between Max Fy and Max Sticks = time - lag between axial load & sticks push-up	0.28		0.13		0.42		0.04	
time between Max Mz +, Fx - and Max Sticks = time - lag between dorsiflexion + posterior shear and sticks push-up	0.11		0.12		0.04		0.01	

Table VIII.7d: The results concerning the transtibial patient TTLR4 fitted with a Plaster of Paris socket then an acrylic resin socket.

GYPSUM VS. ACRYLIC SOCKET 2 STICKS	Patient TTL12 GS - LEFT BK **2 sticks**				Patient TTL12 ARS - LEFT BK **2 sticks**			
	mean	SD	% of B.W.	N or $Nm.kg^{-1}$	mean	SD	% of B.W.	N or $Nm.kg^{-1}$
Gait Rate in $s.stride^{-1}$	2.11	0.28			2.69	0.18		
Axial Load (Fy) in N	425	22.78		5.96	536	25.60		7.56
% of Axial Load vs. Body Mass	61 %				77 %			
Maximum Fx Shear negative in N	-61.5	10.78	8.78	0.86	-70.4	7.66	10.13	0.99
Maximum Fx Shear positive in N	33.6	8.37	4.80	0.47	24.9	3.71	3.57	0.35
Maximum Mz plantarflexion negative in N.m	-4.43	1.02	0.63	0.06	-3.44	0.68	0.49	0.05
Maximum Mz dorsiflexion positive in N.m	18.3	1.45	2.62	0.25	34.5	3.95	4.96	0.48
Maximum Load on both sticks in N	276	18.05		3.87	274	25.50		3.87
% of Sticks Load vs. Body Mass	39 %				39 %			
Maximum Load on Right Stick in N	126	7.11	18.11	1.77	123	13.48	17.71	1.73
Maximum Load on Left Stick in N	150	13.32	21.46	2.11	152	12.13	21.94	2.15
time from HS to the following TO = prosthesis stance phase (PSP)	1.57	0.24			2.06	0.4		
time from SS to the following SO = sticks stance phase (SSP)	1.64	0.21			2.03	0.13		
time from SO to the following SS = sticks swing phase (SSwP)	0.47	0.07			0.66	0.81		
time from TO to the following SS	0.36	0.12			0.11	0.06		
time from SO to the following TO					0.52	0.14		
time from TO the following SO	0.21	0.19						
time-lag between SS and HS 2 strides	0.22	0.23			0.62 6 strides	0.05		
time-lag between HS and SS 4 strides	0.17	0.17						
time between Max Fy and Max Sticks = time - lag between axial load & sticks push-up	0.07	0.11			0.13	0.02		
time between Max Mz +, Fx - and Max Sticks = time - lag between dorsiflexion + posterior shear and sticks push-up	0.04	0.03			0.15	0.03		

Table VIII.7e: The results concerning the transtibial patient TTL12 fitted with a Plaster of Paris socket then an acrylic resin socket.

GYPSUM VS. ACRYLIC SOCKET 2 STICKS	Patient TTR13 GS - RIGHT BK **2 sticks**				Patient TTR13 ARS - RIGHT BK **2 sticks**			
	mean	SD	% of B.W.	N or $Nm.kg^{-1}$	mean	SD	% of B.W.	N or $Nm.kg^{-1}$
Gait Rate in $s.stride^{-1}$	2.33	0.32			1.83	0.09		
Axial Load (Fy) in N	449	30		5.282	489	33		5.753
% of Axial Load vs. Body Mass	51 %				55 %			
Maximum Fx Shear negative in N	-111	7.1	12.90	1.30	-155	15.3	18.01	1.18
Maximum Fx Shear positive in N	16.9	5.1	1.96	0.19	17.2	5.07	1.99	0.20
Maximum Mz plantarflexion negative in N.m	-5.22	0.47	0.61	0.06	-5.61	1.14	0.65	0.06
Maximum Mz dorsiflexion positive in N.m	32.8	2.71	3.81	0.38	36.4	2.5	4.23	0.43
Maximum Load on both sticks in N	501	27		5.89	463	24.6		5.44
% of Sticks Load vs. Body Mass	57 %				52 %			
Maximum Load on Right Stick in N	173	8	20.11	2.035	145	11.5	16.85	1.705
Maximum Load on Left Stick in N	328	22	38.12	3.858	310	39	36.03	3.647
time from HS to the following TO = prosthetic stance phase (PSP)	1.6		0.3		1.22		0.09	
time from SS to the following SO = sticks stance phase (SSP)	2.03		0.12		1.49		0.04	
time from SO to the following SS = sticks swing phase (SSwP)	0.3		0.18		0.34		0.08	
time from TO to the following SS	1.22		0.33		0.85		0.04	
time from SO to the following TO								
time from TO the following SO	0.81		0.18		0.64		0.01	
time-lag between SS and HS								
time-lag between HS and SS	0.4		0.07		0.38		0.07	
time between Max Fy and Max Sticks = time - lag between axial load & sticks push-up	0.3		0.02		0.41		0.03	
time between Max Mz +, Fx - and Max Sticks = time - lag between dorsiflexion + posterior shear and sticks push-up	0.09		0.01		0.16		0.09	

Table VIII.7f: The results concerning the transtibial patient TTLR13 fitted with a Plaster of Paris socket then an acrylic resin socket.

GYPSUM VS. ACRYLIC SOCKET 2 STICKS	Patient TTL7 GS - LEFT BK **2 sticks**				Patient TTL7 ARS - LEFT BK **2 sticks**			
	mean	SD	% of B.W.	N or Nm.kg^{-1}	mean	SD	% of B.W.	N or Nm.kg^{-1}
Gait Rate in s.stride^{-1}	2.87	0.13			1.66	0.08		
Axial Load (Fy) in N	251	16		3.21	673	37		8.62
% of Axial Load vs. Body Mass	32 %				85 %			
Maximum Fx Shear negative in N	-106	7.12	13.45	1.36	-172	9.3	21.97	2.18
Maximum Fx Shear positive in N	3.04	2.21	0.38	0.04	38	2.8	4.85	0.48
Maximum Mz plantarflexion negative in N.m	-0.62	0.44	0.07	0.01	-6.2	0.7	0.79	0.08
Maximum Mz dorsiflexion positive in N.m	23.76	1.02	3.01	0.30	58.9	2.07	7.52	0.74
Maximum Load on both sticks in N	445	16		5.70	154	15		1.95
% of Sticks Load vs. Body Mass	58 %				20 %			
Maximum Load on Right Stick in N	202	7	25.64	2.59	79	13	10.09	1.00
Maximum Load on Left Stick in N	243	13	30.84	3.11	75	12	9.58	0.95
time from HS to the following TO = prosthetic stance phase (PSP)	2.2		0.14		1.17		0.06	
time from SS to the following SO = sticks stance phase (SSP)	2.59		0.14		1.21		0.05	
time from SO to the following SS = sticks swing phase (SSwP)	0.28		0.08		0.45		0.14	
time from TO to the following SS	2.12		0.04		0.83		0.04	
time from SO to the following TO								
time from TO the following SO	0.47		0.03		0.38		0.04	
time-lag between SS and HS								
time-lag between HS and SS	0.6		0.11		0.33		0.05	
time between Max Fy and Max Sticks = time - lag between axial load & sticks push-up	0.2		0.10		0.28		0.14	
time between Max Mz +, Fx - and Max Sticks = time - lag between dorsiflexion + posterior shear and sticks push-up	0.11		0.04		0.05		0.03	

Table VIII.7g: The results concerning the transtibial patient TTL7 fitted with a Plaster of Paris socket then an acrylic resin socket.

GYPSUM VS. ACRYLIC SOCKET 2 STICKS	Patient TTL8 GS - LEFT BK **2 sticks**				Patient TTL8 ARS - LEFT BK **2 sticks**			
	mean	SD	% of B.W.	N or $Nm.kg^{-1}$	mean	SD	% of B.W.	N or $Nm.kg^{-1}$
Gait Rate in $s.stride^{-1}$	1.81	0.06			1.68	0.13		
Axial Load (Fy) in N	594	28		8.5	535	40		7.7
% of Axial Load vs. Body Mass	82 %				75 %			
Maximum Fx Shear negative in N	-65.5	10.5	9.31	0.938	-70	4.4	9.95	1.002
Maximum Fx Shear positive in N	57.8	7.6	8.21	0.828	46	8.5	6.53	0.659
Maximum Mz plantarflexion negative in N.m	-10.9	0.6	1.54	0.157	-11.3	0.9	1.61	0.161
Maximum Mz dorsiflexion positive in N.m	37.7	4	5.36	0.54	39.5	2.5	5.61	0.56
Maximum Load on both sticks in N	160	29		2.28	289	27		4.14
% of Sticks Load vs. Body Mass	22 %				40 %			
Maximum Load on Right Stick in N	98	17	13.93	1.41	147	20	20.89	2.11
Maximum Load on Left Stick in N	62	21	8.81	0.89	142	13	20.18	2.03
time from HS to the following TO = prosthetic stance phase (PSP)	1.3		0.09		1.15		0.05	
time from SS to the following SO = sticks stance phase (SSP)	1.37		0.07		1.45		0.05	
time from SO to the following SS = sticks swing phase (SSwP)	0.44		0.09		0.19		0.05	
time from TO to the following SS	0.85		0.08		0.86		0.05	
time from SO to the following TO								
time from TO the following SO	0.52		0.12		0.59		0.02	
time-lag between SS and HS								
time-lag between HS and SS	0.6		0.12		0.26		0.04	
time between Max Fy and Max Sticks = time - lag between axial load & sticks push-up	0.2		0.02		0.18		0.07	
time between Max Mz +, Fx - and Max Sticks = time - lag between dorsiflexion + posterior shear and sticks push-up	0.06		0.03		0.09		0.05	

Table VIII.7h: The results concerning the transtibial patient TTLL8 fitted with a Plaster of Paris socket then an acrylic resin socket.

GYPSUM VS. ACRYLIC SOCKET 2 STICKS	Patient TTL14 GS - LEFT BK 2 sticks				Patient TTL14 ARS - LEFT BK 2 sticks			
	mean	SD	% of B.W.	N or Nm.kg^{-1}	mean	SD	% of B.W.	N or Nm.kg^{-1}
Gait Rate in s.stride^{-1}	2.21	0.17			1.97	0.15		
Axial Load (Fy) in N	142	17		2.88	292	37		5.92
% of Axial Load vs. Body Mass	28 %				58 %			
Maximum Fx Shear negative in N	-41.1	5.42	8.21	0.83	-63.9	6.6	12.77	1.27
Maximum Fx Shear positive in N	4.81	2.31	0.96	0.10	12.3	2.2	2.46	0.25
Maximum Mz plantarflexion negative in N.m	-1.27	0.26	0.25	0.02	-3	0.4	0.59	0.06
Maximum Mz dorsiflexion positive in N.m	11.1	1.25	2.21	0.22	23.8	3.2	4.75	0.48
Maximum Load on both sticks in N	358	10		7.26	259	16		5.18
% of Sticks Load vs. Body Mass	71 %				51 %			
Maximum Load on Right Stick in N	154	7	30.78	3.12	113	10	22.58	2.29
Maximum Load on Left Stick in N	205	7	40.97	4.16	145	9	28.98	2.90
time from HS to the following TO = prosthetic stance phase (PSP)	1.29		0.20		1.41		0.15	
time from SS to the following SO = sticks stance phase (SSP)	1.82		0.17		1.69		0.11	
time from SO to the following SS = sticks swing phase (SSwP)	0.39		0.08		0.28		0.06	
time from TO to the following SS	1.39		0.21		1.42		0.19	
time from TO the following SO	0.51		0.13		0.27		0.09	
time-lag between SS and HS	0.31		0.15		0.11		0.08	
time between Max Fy and Max Sticks = time - lag between axial load & sticks push-up	0		0		0.1		0.04	
time between Max Mz +, Fx - and Max Sticks = time - lag between dorsiflexion + posterior shear and sticks push-up	0.05		0.02		0.01		0.04	

Table VIII.7i: The results concerning the transtibial patient TTL14 fitted with a Plaster of Paris socket then an acrylic resin socket.

11.VIII.6 The normal probability plot used for a common statistical analysis of the results.

As example, table VIII.8 shows a regression analysis of one stride of the patient TTL9 using 2 sticks then 2 canes. The slope x_1 is close to 1 (1.08) but the r-square (0.93) does not exhibit a perfect linearity. Despite it was the same test, the two different walking devices had obviously changed the gait pattern of the patient. Figure VIII.8 shows the normal probability plot calculated from table VIII.8 by the spreadsheet: the trace is enough straight to consider that forces and moments were normally distributed (Weiss, 1995) (see section 8.4.3).

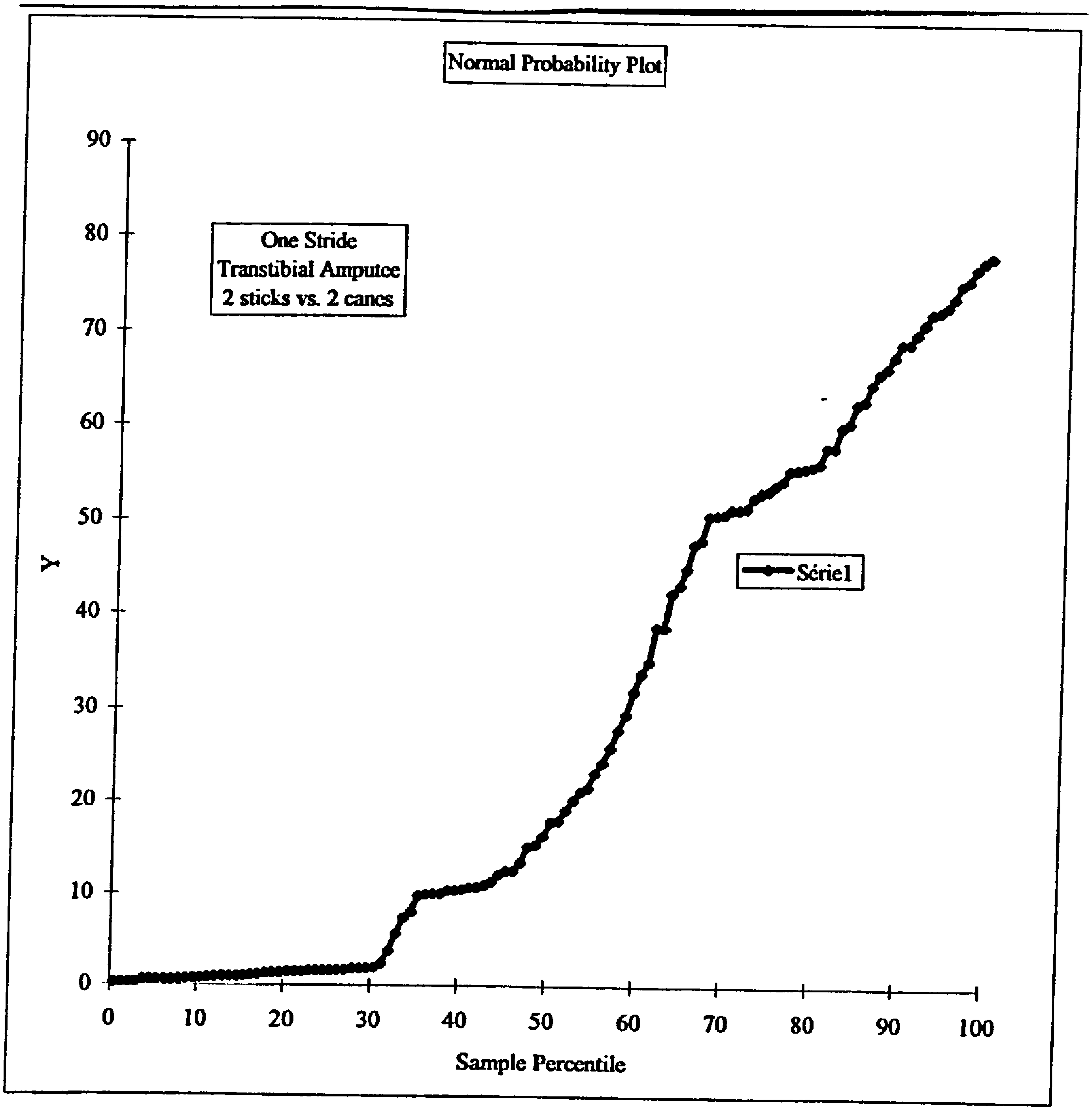


Figure VIII.8: The normal probability plot from table VIII.8

5.1	7.4	55.1	53.4	58.9	50.7
5.8	7.3	54.8	58.8	56.8	48.0
6.3	7.0	53.3	64.3	54.5	45.7
8.8	7.2	51.5	69.4	52.3	43.0
9.0	7.2	50.3	73.9	49.7	39.7
9.4	7.7	49.5	77.4	47.0	37.0
9.4	8.0	49.6	78.7	44.0	34.0
8.9	8.6	50.4	78.6	41.3	31.3
9.4	9.2	52.0	77.5	37.6	30.6
9.7	9.6	54.7	76.0	33.9	30.2
9.7	10.1	56.8	74.8	30.9	30.9
9.9	10.5	59.4	74.4	26.8	26.8
10.3	10.6	61.5	74.4	23.3	23.3
11.1	11.0	63.6	75.3	20.2	20.2
11.6	11.1	65.4	76.4	17.0	17.0
12.5	11.7	66.6	77.7	14.3	14.3
14.1	12.2	68.0	79.0	11.5	11.5
15.3	12.7	69.1	80.0	9.0	8.8
16.8	13.5	70.1	80.6	7.0	5.6
18.1	14.9	71.3	81.1	4.6	3.2
19.3	17.3	72.1	81.5	2.7	1.4
20.6	20.3	73.0	82.0	1.3	0.9
22.2	23.4	74.4	82.4	0.3	-0.4
24.9	26.2	76.1	83.1	0.1	-0.4
28.4	29.4	77.3	83.9	0.0	-0.4
32.7	32.7	76.9	84.8	-0.1	0.0
37.6	35.8	74.9	73.1	-0.2	0.0
42.1	39.4	71.5	67.5	-0.3	-0.2
46.5	43.5	68.0	62.3	-0.4	0.0
50.2	47.9	64.9	57.9	-0.6	-0.4
52.8	54.4	61.9	53.9	-0.7	-0.4

Regression Statistics

Multiple R	0.965580136
R Square	0.932344998
Adjusted R Square	0.931771651
Standard Error	7.90976948
Observations	120

Analysis of Variance

	df	*Sum of Squares*	*Mean Square*
Regression	1	101738.7501	101738.7501
Residual	118	7382.605481	62.56445323
Total	119	109121.3556	
		F	*Significance F*
		1626.143039	7.37434E-71

	Coefficients	*Standard Error*	*t Statistic*
Intercept	-1.293831488	1.026837464	-1.260015859
x1	1.088985697	0.027004914	40.3254639
	P-value	*Lower 95%*	*Upper 95%*
	0.210129028	-3.327247014	0.739584037
	3.05089E-71	1.035508673	1.142462722

TableVIII.8: The regression analysis of the axial load Fy from one stride (heel strike to the following heel strike) of the subject TTL9. The values are shown side by side for room reason: first column 2 sticks, second column, 2 canes, etc.

11.VIII.7 The traces in medio-lateral shear force Fx and bending moment Mx, with transverse torque My for transtibial amputees

As example, three transtibial patients have been chosen to show the results in the other planes than anterio-posterior (M/L shear force and bending moment; transverse torque). The choice of the subjects was made to show representative traces found in the population tested.

Figure VIII.9 (next page) shows the traces recorded from the subject TTR17, using two sticks. Because of his body mass (81 kg), the maximum recorded were the following:

	M/L Shear Force (N)	M/L Bending Moment (N.m)	Transverse Torque (N.m)
Maximum +	18	6	7
Maximum -	-64	-4	-8

It seems that the use of walking assistive devices such as sticks decreased the maximum values of the M/L bending moment and the transverse torque relative to the mean values found in literature.

Figure VIII.10 shows the same traces recorded from the subject TTL8 using two sticks. Having a body mass of 70 kg, the maximum were as follows:

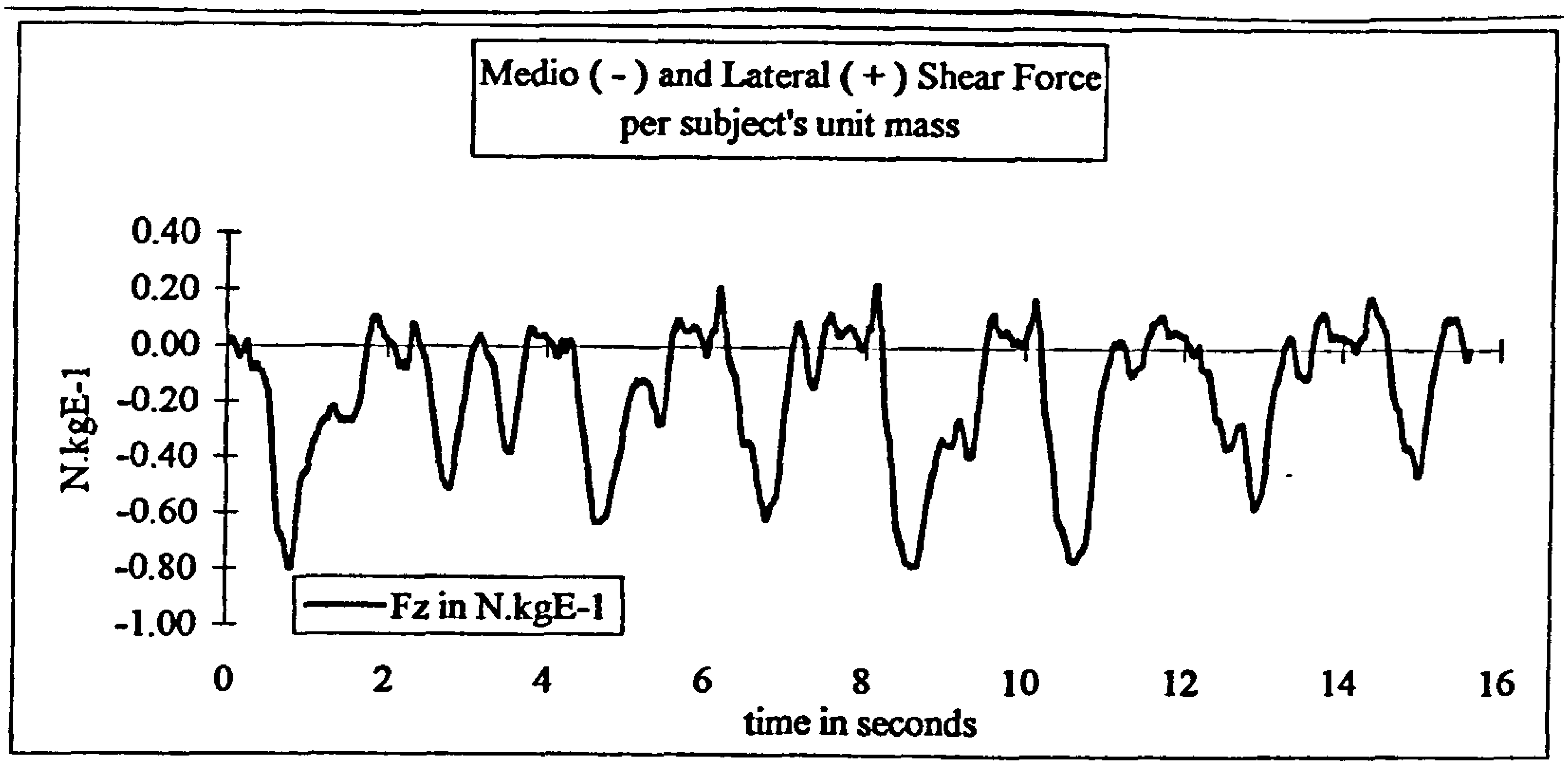
	M/L Shear Force (N)	M/L Bending Moment (N.m)	Transverse Torque (N.m)
Maximum +	67	6	0.7
Maximum -	-12	-3	-4

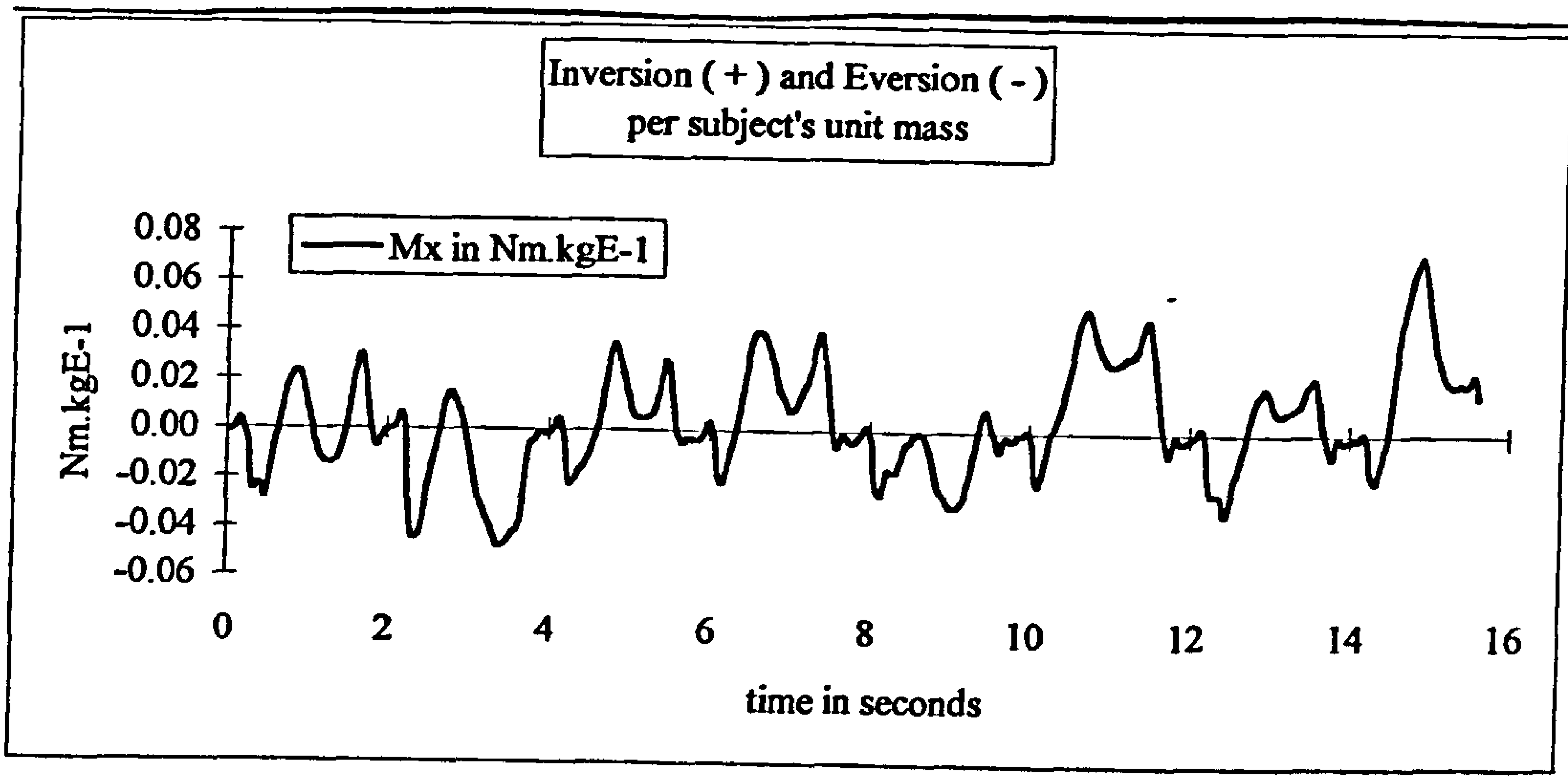
It seems that the two patients had an opposite gait pattern in M/L shear force with similar values in M/L bending moment and transverse torque despite the fact there were right and left transtibial amputees.

Figure VIII.11 shows the same traces recorded from the subject TTR18 using two sticks. The maximum were as follows (body mass 73 kg):

	M/L Shear Force (N)	M/L Bending Moment (N.m)	Transverse Torque (N.m)
Maximum +	9	6	7
Maximum -	-65	-4	-1

The maximum M/L shear force is equivalent for the two right amputees. The maximum M/L bending moment and torque were similar in the three tests.





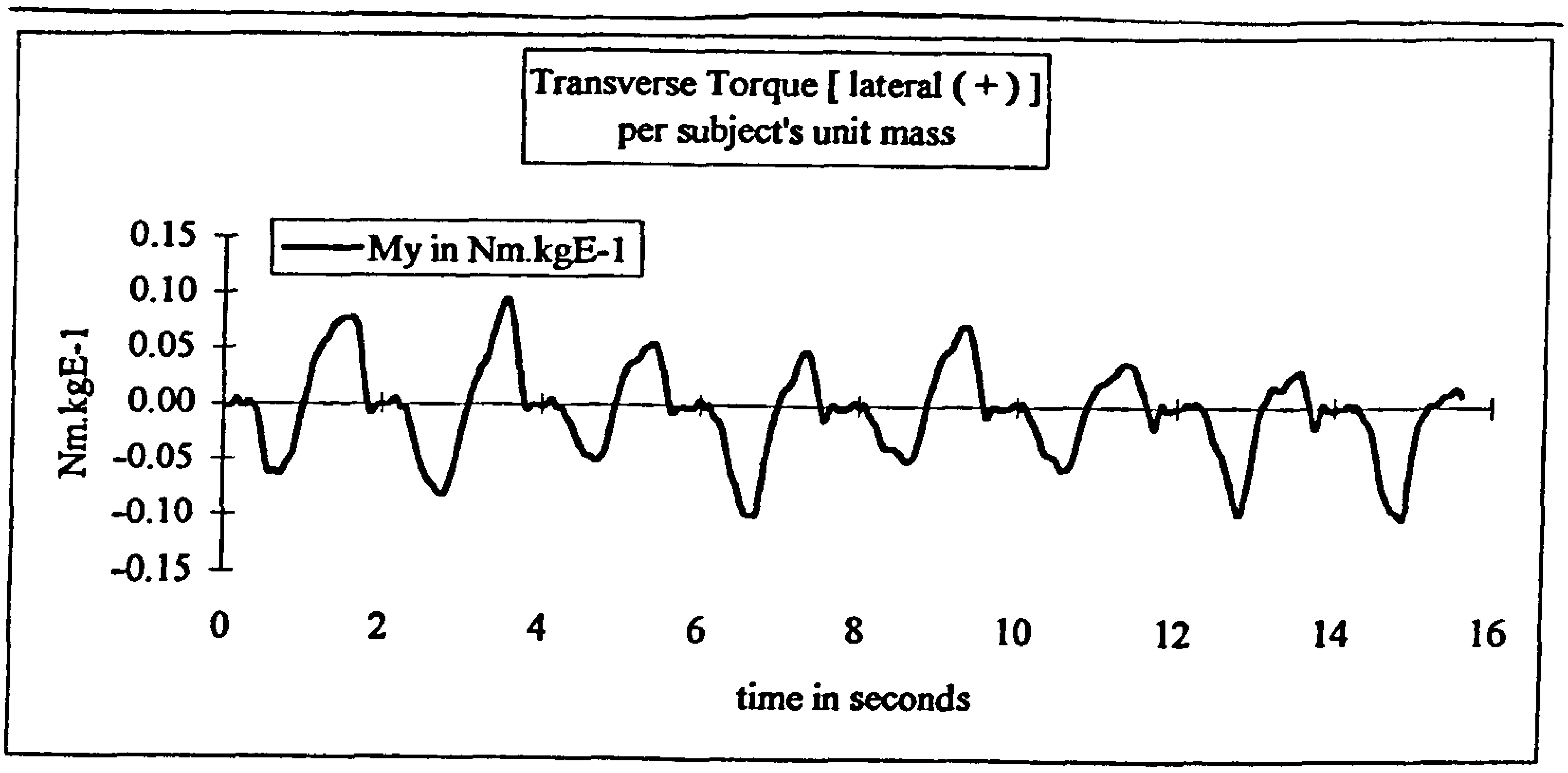


Figure VIII.9: M/L shear force (top), M/L bending moment (middle) and transverse torque (bottom) recorded from the subject TTR17 having a body mass of 81 kg. The patient walked with two sticks. The units are N/kg or N.m/kg per unit mass of the subject.

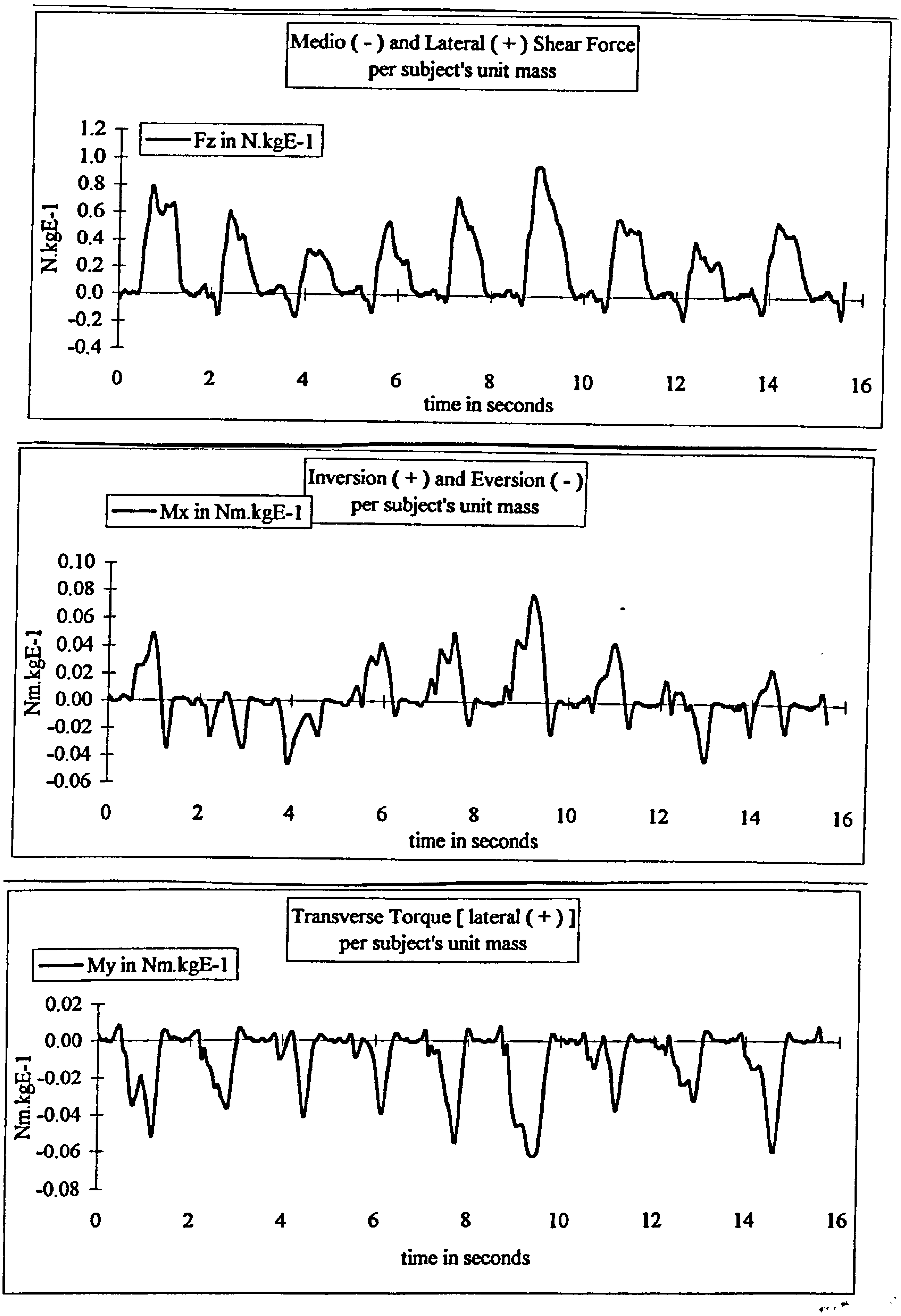


Figure VIII.10: M/L shear force (top), M/L bending moment (middle) and transverse torque (bottom) recorded from the subject TTL8 having a body mass of 70 kg. The patient walked with two sticks. The units are N/kg or N.m/kg per unit mass of the subject.

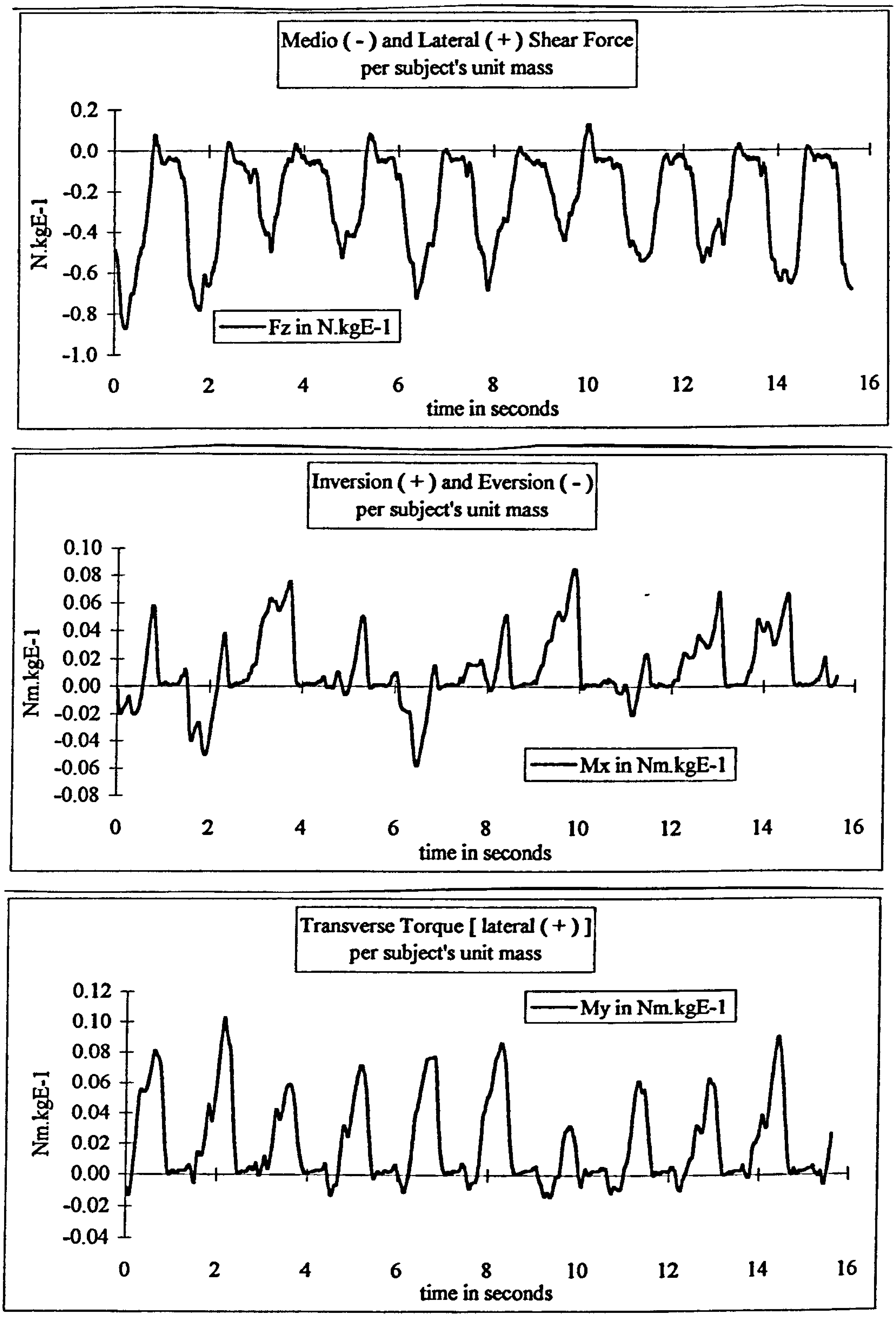


Figure VIII.11: M/L shear force (top), M/L bending moment (middle) and transverse torque (bottom) recorded from the subject TTR8 having a body mass of 73 kg. The patient walked with two sticks. The units are N/kg or N.m/kg per unit mass of the subject.

11.VIII.8 Results concerning transfemoral amputees

Table VIII.9a to table VIII.9d show the results of the four transfemoral patients of the series 6: TFL3, TFL5, TFR5 and TFL4 (see section 8.3.6). The patients were used successively two sticks then two canes during the same test (see section 8.8).

Table VIII.9 has the same arrangement as tables VIII.5 and VIII.7. The notation is also identical as the one shown in table VIII.6.

The standard deviations are provided, they are used for the common statistical analysis of the results (see section 8.4.3).

2 STICKS VS. 2 CANES	Patient TFL4 ARS - Q - LEFT AK **2 sticks**				Patient TFL4 ARS - Q - LEFT AK **2 canes**			
	mean	SD	% of B.W.	N or $Nm.kg^{-1}$	mean	SD	% of B.W.	N or $Nm.kg^{-1}$
Maximum Gait Rate in $s.stride^{-1}$	3.34	0.13			3.31	0.25		
Maximum Axial Load (Fy) N	697	17.03		7.52	705	31.15		7.61
% of Axial Load vs. Body Mass	77 %				77 %			
Maximum Fx Shear negative N	-67.6	10.32	7.43	0.73	-56.9	1.85	6.26	0.61
Maximum Fx Shear positive N	119	6.08	13.09	1.28	135	7.76	14.9	1.46
Maximum Mz plantarflexion negative N.m	-16.8	1.47	1.85	0.18	-14.9	0.82	1.63	0.16
Maximum Mz dorsiflexion positive N.m	19.1	2.27	2.11	0.21	12.3	1.85	1.34	0.13
Maximum Load on both sticks or canes N	392	22.36		4.22	314	25.22		3.38
% of Sticks Load vs. Body Mass	43 %				34 %			
Maximum Load on Right Stick or Cane N	212	11.36	23.37	2.29	197	17.36	21.7	2.12
Maximum Load on Left Stick or Cane N	179	21.79	19.71	1.93	116	12.31	12.8	1.25
time from HS to the following TO = prosthetic stance phase (PSP)	2.69		0.09		2.65		0.25	
time from SS (CS) to the following SO (CO) = sticks or canes stance phase (SSP or CSP)	3.08		0.21		3.12		0.08	
time from SO (CO) to the following SS (CS) = sticks or canes swing phase (SSwP or CSwP)	0.26		0.03		0.19		0.02	
time from SS (CS) to the following TO	0.38		0.08		0.22		0.06	
time from TO the following SO (CO)	2.70		0.11		2.90		0.02	
time- interval between SS (CS) and HS	2.30		0.09		2.35		0.05	
time between Max Fy and Max Sticks or Canes = time - interval between axial load & sticks or canes push-up	0.12		0.14		0.19		0.12	
time between Max Mz +, Fx – and Max Sticks or Canes = time - interval between dorsiflexion + posterior shear & sticks or canes push-up	0.8		0.25		0.62		0.2	

Table VIII.9a: The results concerning the transfemoral patient TFL4 using two sticks then two canes.

2 STICKS VS. 2 CANES	Patient TFR7 ARS - Q - RIGHT AK **2 sticks**				Patient TFR7 ARS - Q - RIGHT AK **2 canes**			
	mean	SD	% of B.W.	N or $Nm.kg^{-1}$	mean	SD	% of B.W.	N or $Nm.kg^{-1}$
Maximum Gait Rate in $s.stride^{-1}$	3.17	0.13			3.83	0.29		
Maximum Axial Load (Fy) N	246	9.76		4.34	388	21.93		6.84
% of Axial Load vs. Body Mass	44 %				70 %			
Maximum Fx Shear negative N	-74.1	6.34	13.31	1.31	-105	16.12	18.96	1.86
Maximum Fx Shear positive N	2.55	0.73	0.46	0.04	6.17	2.98	1.11	0.11
Maximum Mz plantarflexion negative N.m	-2.24	0.24	0.41	0.04	-4.32	2.93	0.77	0.07
Maximum Mz dorsiflexion positive N.m	19.08	1.22	3.43	0.34	21.7	3.35	0.61	0.38
Maximum Load on both sticks or canes N	361	10.16		6.36	219	14.25		3.87
% of Sticks Load vs. Body Mass	65 %				39 %			
Maximum Load on Right Stick or Cane N	114	6.06	20.61	2.02	74.2	8.28	13.33	1.31
Maximum Load on Left Stick or Cane N	246	6.66	44.24	4.34	145	6.60	26.07	2.55
time from HS to the following TO = prosthetic stance phase (PSP)	2.3		0.19		3.12		0.23	
time from SS (CS) to the following SO (CO) = sticks or canes stance phase (SSP or CSP)	2.73		0.11		3.49		0.23	
time from SO (CO) to the following SS (CS) = sticks or canes swing phase (SSwP or CSwP)	0.44		0.06		0.34		0.09	
time from SS (CS) to the following TO	0.11		0.12		0.18		0.03	
time from TO the following SO (CO)	2.62		0.12		3.31		0.21	
time-interval between HS and SS (CS)	2.39		0.20		2.83		0.29	
time between Max Fy and Max Sticks = time - interval between axial load & sticks or canes push-up	0.21		0.09		0.24		0.09	
time between Max Mz +, Fx – and Max Sticks = time - interval between dorsiflexion + posterior shear and sticks & canes push-up	0.36		0.13		0.27		0.09	

Table VIII.9b: The results concerning the transfemoral patient TFR7 using two sticks then two canes.

2 STICKS VS. 2 CANES	Patient TFL5 ARS - Q - LEFT AK **2 sticks**				Patient TFL5 ARS - Q - LEFT AK **2 canes**			
	mean	SD	% of B.W.	N or $Nm.kg^{-1}$	mean	SD	% of B.W.	N or $Nm.kg^{-1}$
Maximum Gait Rate in $s.stride^{-1}$	2.22	0.05			2.16	0.06		
Maximum Axial Load (Fy) N	455	22.39		7.38	499	32.25		8.11
% of Axial Load vs. Body Mass	75 %				83 %			
Maximum Fx Shear negative N	-34.7	9.35	5.74	0.56	-21.7	8.74	3.59	0.35
Maximum Fx Shear positive N	99.1	2.53	16.41	1.61	110	4.69	18.24	1.79
Maximum Mz plantarflexion negative N.m	-15.8	0.53	2.61	0.26	-17.3	0.96	2.87	0.28
Maximum Mz dorsiflexion positive N.m	10.6	4.54	1.81	0.17	5.15	2.07	0.85	0.08
Maximum Load on both sticks or canes N	147	12.8		2.38	109	9.63		1.77
% of Sticks Load vs. Body Mass	24 %				18 %			
Maximum Load on Right Stick or Cane N	68.4	10.34	11.31	1.11	64.2	8.28	10.62	1.04
Maximum Load on Left Stick or Cane N	78.7	11.13	13.01	1.27	45.3	8.74	7.51	0.73
time from HS to the following TO = prosthetic stance phase (PSP)	1.51		0.04		1.43		0.06	
time from SS (CS) to the following SO (CO) = sticks or canes stance phase (SSP or CSP)	1.64		0.07		1.65		0.11	
time from SO (CO) to the following SS (CS) = sticks or canes swing phase (SSwP or CSwP)	0.58		0.03		0.51		0.08	
time from SS (CS) to the following TO	1.16		0.08		1.17		0.07	
time from TO the following SO (CO)	0.48		0.07		0.47		0.07	
time-interval between HS and SS (CS)	0.34		0.06		0.25		0.05	
time between Max Fy and Max Sticks = time - interval between axial load & sticks or canes push-up	0.52		0.08		0.21		0.21	
time between Max Mz +, Fx - and Max Sticks = time - interval between dorsiflexion + posterior shear and sticks & canes push-up	0.09		0.04		0.24		0.18	

Table VIII.9c: The results concerning the transfemoral patient TFL5 using two sticks then two canes.

2 STICKS VS. 2 CANES	Patient TFL3 ARS - Q - LEFT AK **2 sticks**				Patient TFL3 ARS - Q - LEFT AK **2 canes**			
	mean	SD	% of B.W.	N or $Nm.kg^{-1}$	mean	SD	% of B.W.	N or $Nm.kg^{-1}$
Maximum Gait Rate in $s.stride^{-1}$	2.61	0.15			2.55	0.24		
Maximum Axial Load (Fy) N	182	21.11		2.91	272	29.25		4.36
% of Axial Load vs. Body Mass	30 %				45 %			
Maximum Fx Shear negative N	-40.6	4.55	6.63	0.65	-57.2	10.26	9.34	0.91
Maximum Fx Shear positive N	17.6	1.05	2.88	0.28	16.96	1.45	2.77	0.27
Maximum Mz plantarflexion negative N.m	-3.69	0.31	0.61	0.06	-4.29	0.57	0.71	0.07
Maximum Mz dorsiflexion positive N.m	10.5	0.96	1.71	0.17	17.63	1.98	2.88	0.28
Maximum Load on both sticks or canes N	511	25.19		8.18	361	13.67		5.79
% of Sticks Load vs. Body Mass	83 %				59 %			
Maximum Load on Right Stick or Cane N	209	6.23	34.21	3.34	183	8.18	29.87	2.93
Maximum Load on Left Stick or Cane N	301	22.28	49.21	4.82	178	12.99	29.08	2.85
time from HS to the following TO = prosthetic stance phase (PSP)	1.65		0.11		1.81		0.11	
time from SS (CS) to the following SO (CO) = sticks or canes stance phase (SSP or CSP)	2.24		0.09		2.25		0.08	
time from SO (CO) to the following SS (CS) = sticks or canes swing phase (SSwP or CSwP)	0.37		0.06		0.30		0.04	
time from SS (CS) to the following TO	1.53		0.11		1.53		0.11	
time from TO the following SO (CO)	0.71		0.04		0.68		0.03	
time-interval between HS and SS (CS)	0.11		0.06		0.27		0.08	
time between Max Fy and Max Sticks = time - interval between axial load & sticks or canes push-up	0.05		0.03		0.03		0.02	
time between Max Mz +, Fx – and Max Sticks = time - interval between dorsiflexion + posterior shear and sticks or canes push-up	0.05		0.01		0.04		0.02	

Table VIII.9d: The results concerning the transfemoral patient TFL3 using two sticks then two canes.

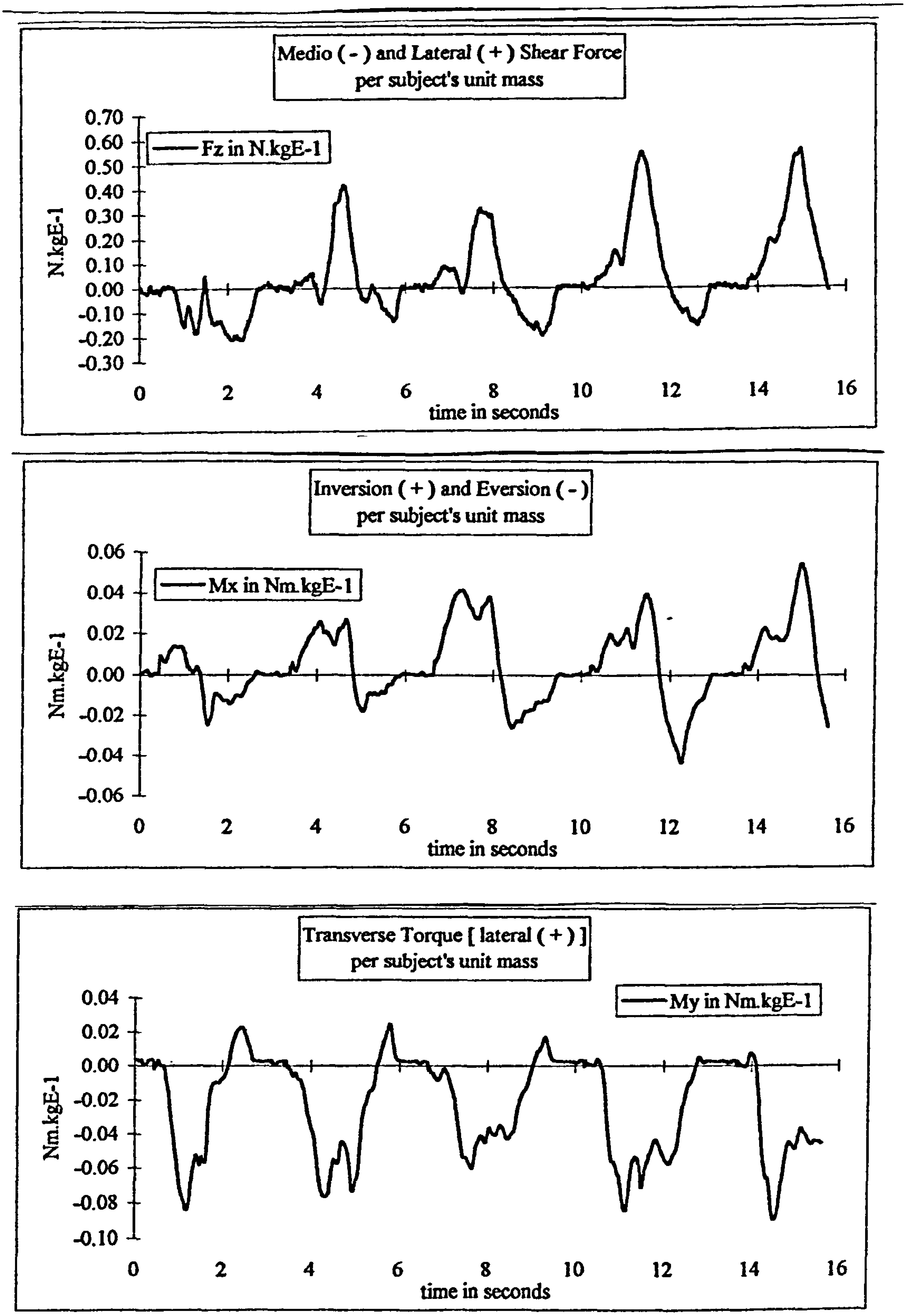


Figure VIII.12: M/L shear force (top), M/L bending moment (middle) and transverse torque (bottom) recorded from the subject TFL4 having a body mass of 90 kg. The patient used two sticks. The units are N/kg or N.m/kg per unit mass of the subject.

11.VIII.9 The traces in medio-lateral shear force Fz, bending moment Mx and transverse torque My for transfemoral amputees.

As example, the four transtibial patients of the series 6 and described in section 8.8 were chosen to show the results in the planes such as medio-lateral (M/L shear force Fz and bending moment Mx) and transverse (torque My). All the traces and maximum values shown are recorded at the transducer level, i.e., at the ankle level. The forces and moments, found in the A/P plane were shown in figure 8.40 (TFL4), 8.41 (TFR7), 8.42 (TFL5), 8.43 (TFL3).

Figure VIII.12 shows the traces recorded from the subject TFL4, using two sticks. His body mass was 90 kg; the maximum values recorded were thus the following:

	M/L Shear Force (N)	M/L Bending Moment (N.m)	Transverse Torque (N.m)
Maximum +	51	5	2
Maximum -	-19	-4	-8

As previously stated for transtibial amputees (see 12.VIII.7), the maximum values of the M/L bending moment and the transverse torque, recorded at the ankle level, are reduced comparatively of those found in literature. I could be the use of the walking sticks but no proof of this can be expressed from the present research: no tests were undertaken with subjects free from any walking assistive devices. A recent dysvascular amputee such as the subject TFL4 can also minimise any M/L shear force or bending moment to decrease stress and pain on the residual limb. These low values concerning the M/L bending moment and the transverse torque can also be related to the low gait rate of such a patient. Moreover, the subject TFL4 had a bad mass/height ratio.

Figure VIII.13 shows the traces recorded from the TFL5, using two sticks. His body mass was 60 kg; the maximum values recorded were the following:

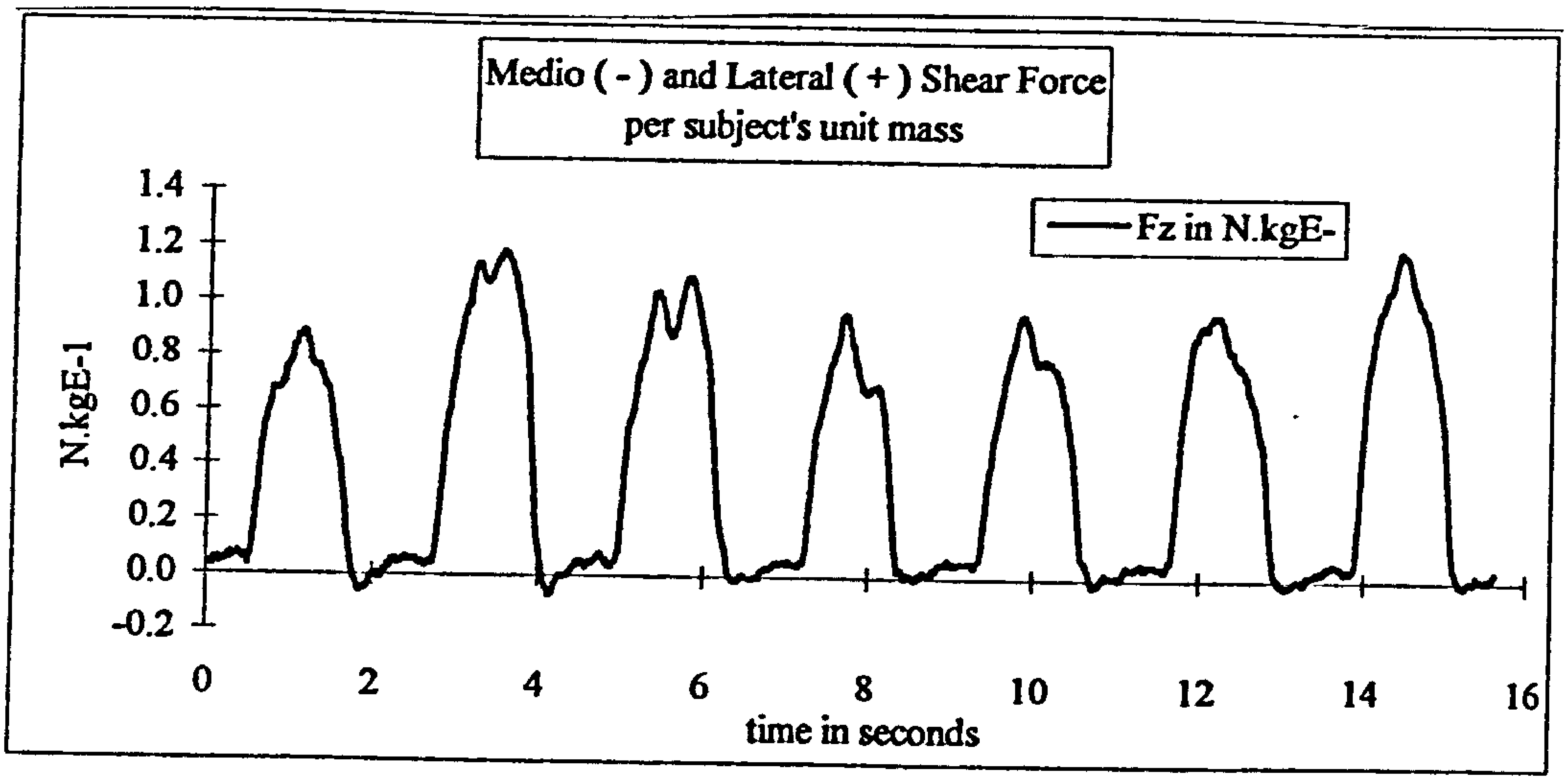
	M/L Shear Force (N)	M/L Bending Moment (N.m)	Transverse Torque (N.m)
Maximum +	73	6	2
Maximum -	-4	-6	-2

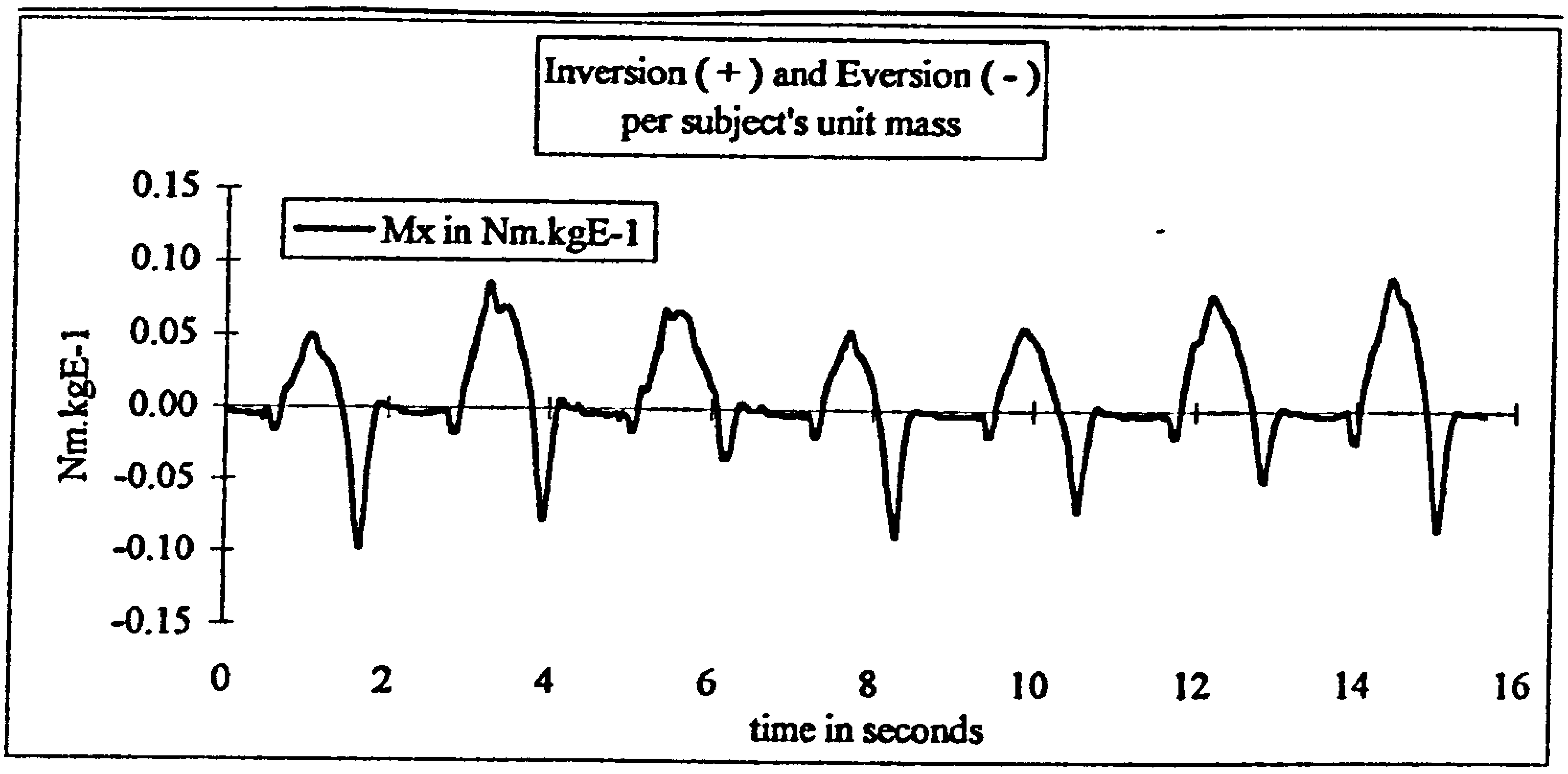
The patient TFL5 had a bad gait pattern: his artificial foot was never behind the axial load line. This is why a so small maximum negative value in M/L shear force was recorded. Here also, the maximum values recorded in M/L bending moment and transverse torque were found small.

Figure VIII.14 shows the traces recorded from the subject TFL3, using two sticks. His body mass was 60 kg; the maximum values recorded were the following:

	M/L Shear Force (N)	M/L Bending Moment (N.m)	Transverse Torque (N.m)
Maximum +	24	5	0
Maximum -	-1	-1	-2

The patient TFL3 had not negative shear force. This patient had a bad range of motion of the hip with a permanent flexion contracture. The M/L bending moment was also permanently positive while transverse torque was negative. This could be related to an alignment problem, however, no proof of this assertion could be provided.





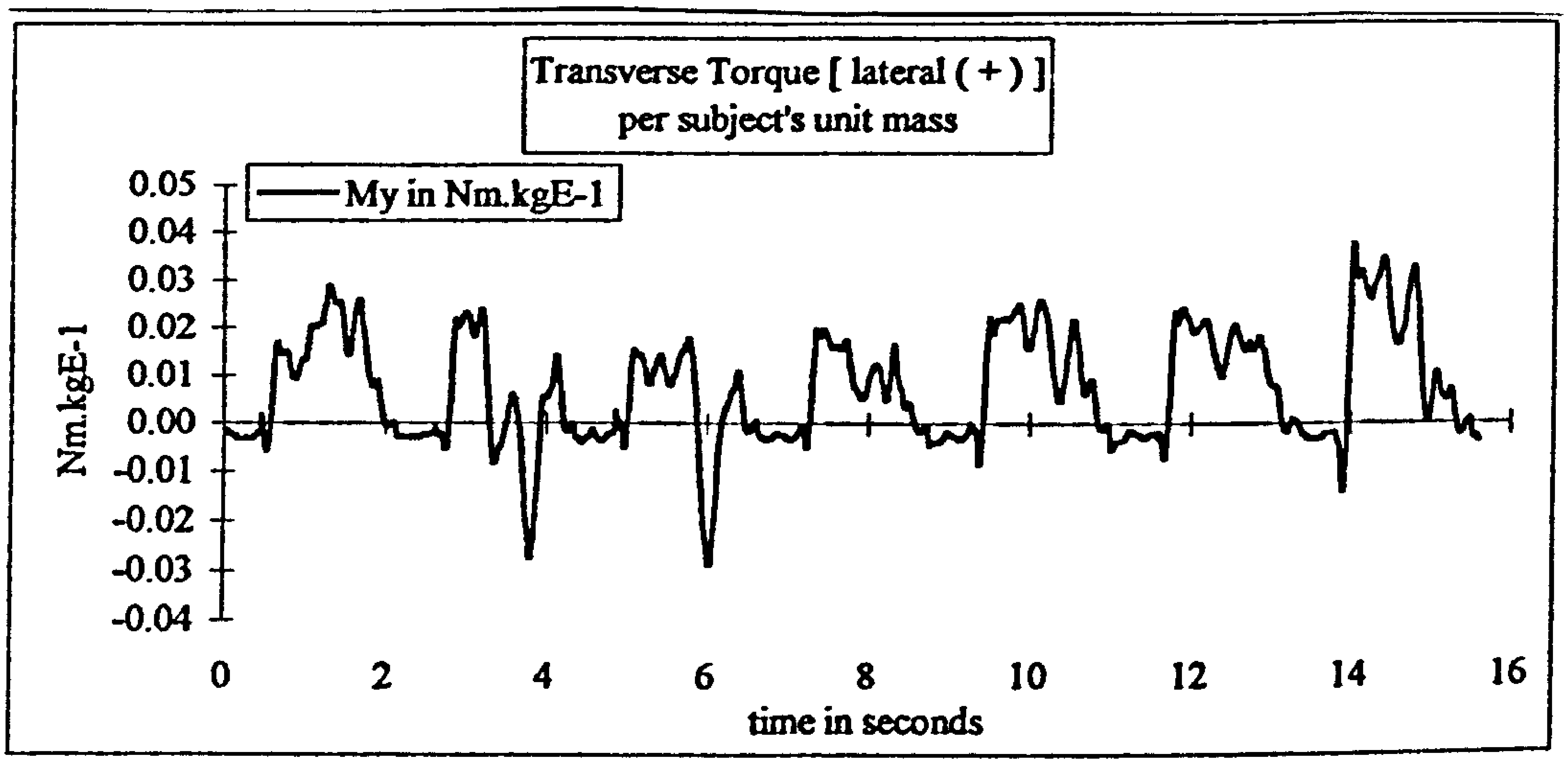


Figure VIII.13: M/L shear force (top), M/L bending moment (middle) and transverse torque (bottom) recorded from the subject TFL5 having a body mass of 60 kg. The patient used two sticks. The units are N/kg or N.m/kg per unit mass of the subject.

Figure VIII.15 shows the traces recorded from the subject TFR7, using two sticks. His body mass was 53 kg; the maximum values recorded were the following:

	M/L Shear Force (N)	M/L Bending Moment (N.m)	Transverse Torque (N.m)
Maximum +	2	0	2
Maximum -	-28	-8	-1

The subject TFR7 was the only right amputee of the series 6. His gait pattern is thus the reverse of the other subjects. The M/L shear force and bending moment were permanently negative. The transverse torque My was very small but it crossed the zero line.

More information concerning the gait pattern of these four subjects tested were shown in section 8.8.

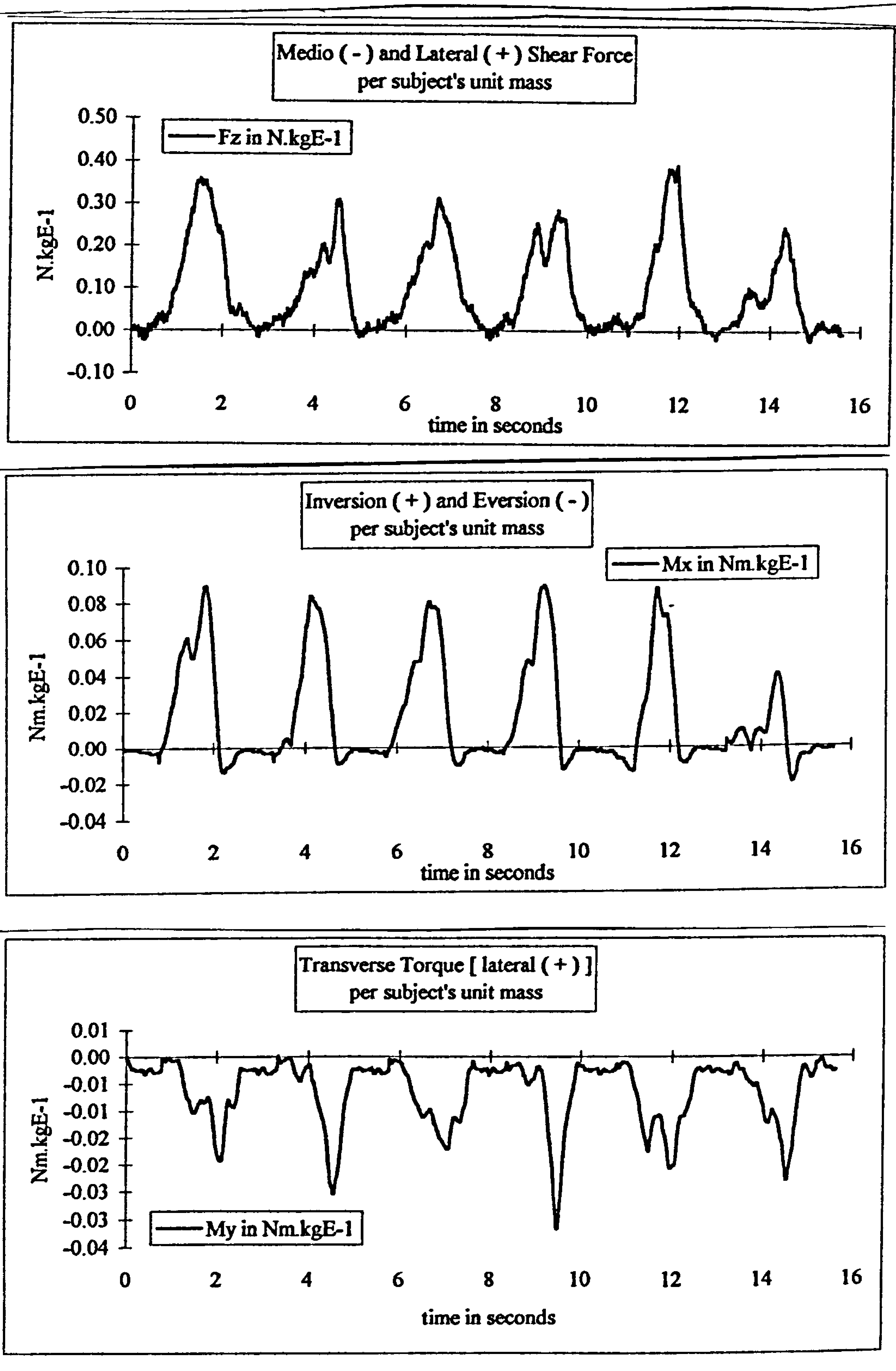
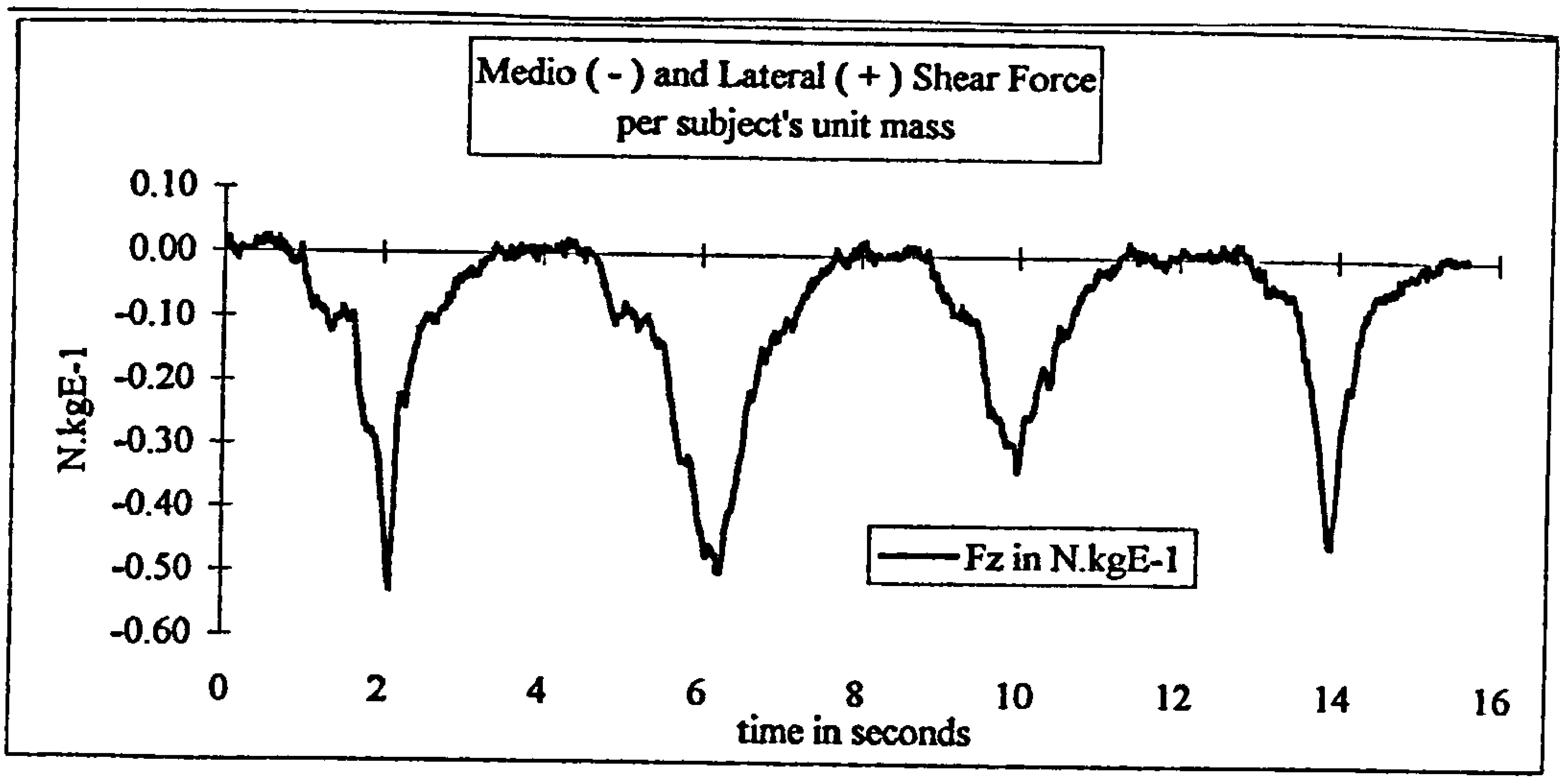
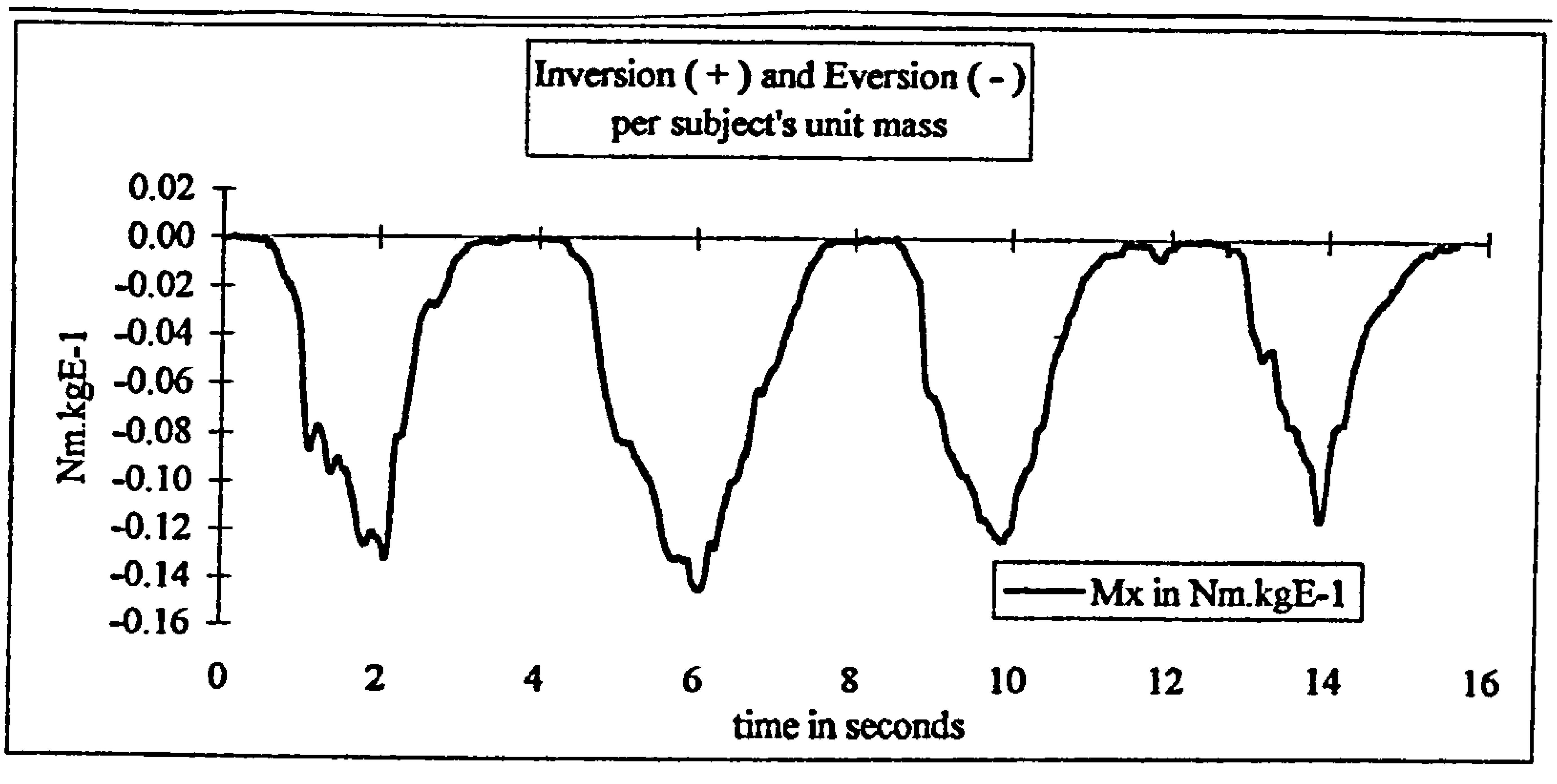


Figure VIII.14: M/L shear force (top), M/L bending moment (middle) and transverse torque (bottom) recorded from the subject TFL3 having a body mass of 60 kg. The patient used two sticks. The units are N/kg or N.m/kg per unit mass of the subject.





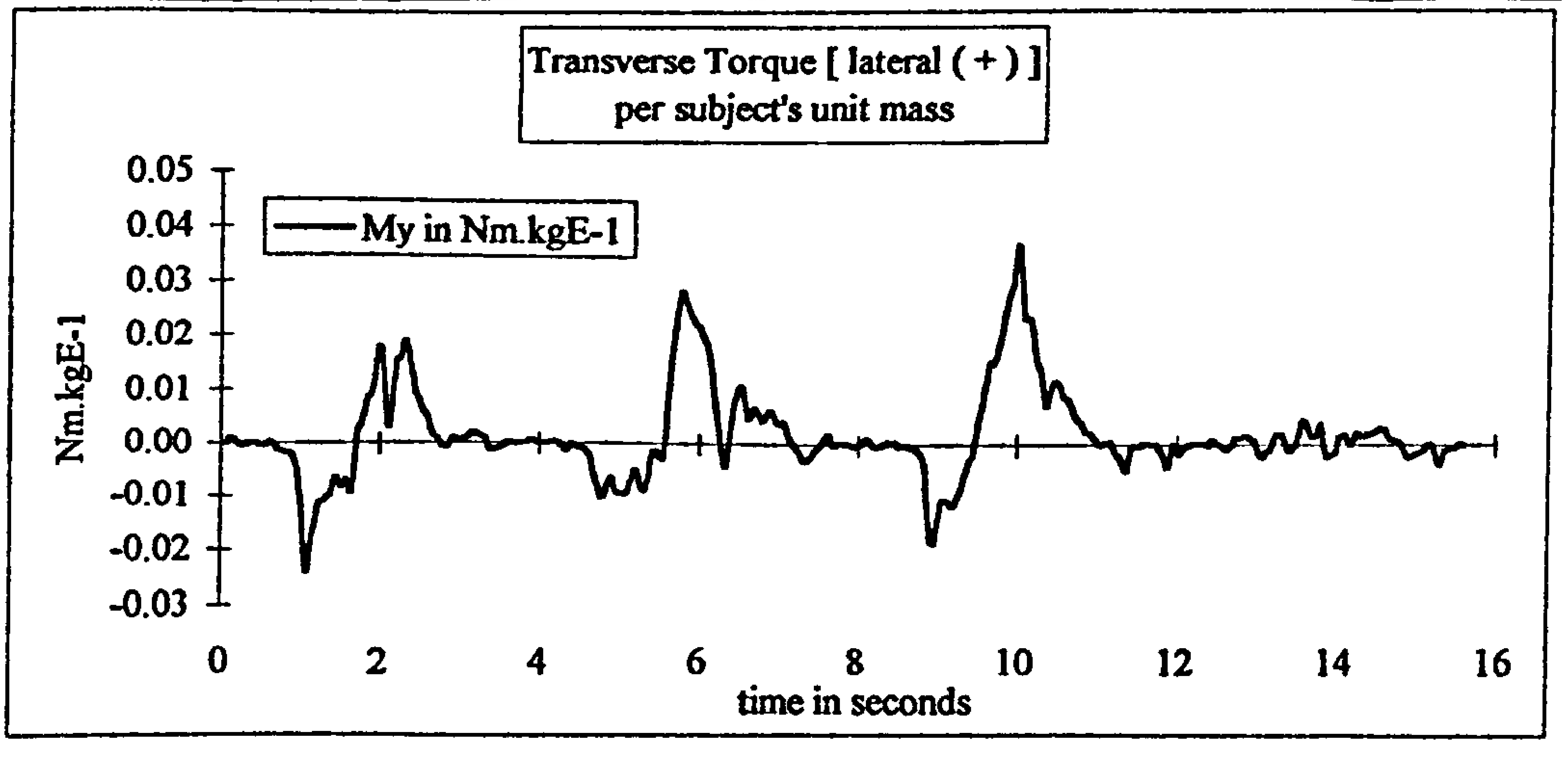


Figure VIII.15: M/L shear force (top), M/L bending moment (middle) and transverse torque (bottom) recorded from the subject TFR7 having a body mass of 53 kg. The patient used two sticks. The units are N/kg or N.m/kg per unit mass of the subject.