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THE INFLUENCE OF THE WALKWAY SURFACE ON THE LOAD DISTRIBUTION IN MODULAR PROSTHESES

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Abstract

In order to reduce the dimensions of weight bearing parts, modular prostheses must be designed using the principles of lightweight construction. This requires that sufficient data concerning the acting forces and moments are available for the design engineer. However the force studies now in existance were carried out primarily under laboratory conditions, i. e. on smooth floors, and this to some extent does not meet the real conditions.

In this investigation, a study was made to determine the variability of prosthesis loading, when an amputee walks on outdoor grounds. For this purpose the shank of an AK-prostheses was instrumented with a strain gauge pylon which allowed for the measurement of the axial forces, the shank axial rotation moments, and the bending moments in the sagittal and frontal plane at two different levels.

The tests were carried out on asphalt flooring, cobble-stone, rubble and fine grain sand. Each run was conducted at velocities of 2 km/h, 3 km/h and 4.5 km/h. For signal transmission a multichannel telemetry system was used. After demodulation in the receiver the results were plotted on a recorder and analysed by means of statistical methods.

The results indicate that the greatest axial forces were obtained on rubble. At a velocity of 4.5 km/h their magnitude was about 150 % of bodyweight, which is an increase of nearly 40 % when compared to the value which occurs on asphalt. The asphalt flooring used here is similar to the laboratory floor of previous investigations. The maximum torque was measured on sand. Its was about 40 % higher than that measured on asphalt. The greatest bending moment appeared in the sagittal plane when

the amputee walked on rubble at a speed of 3 km/h. In comparison to asphalt this load component increased by about 50 %.

Introduction

In 1973, a Conference on Amputee Performance Measurement took place in Dundee, Scotland. This conference was arranged by the ISPO Standing Committee on Research under the Chairmanship of Mr. George Murdoch. One of the recommendations of this meeting was that further research should be done to achieve more reliable load values for modular prostheses [1] . To this end the Technical University of Berlin was charged with the responsibility for conducting rough terrain testing utilising a multi-channel telemetry system. The aim of this project was to determine whether the maximum values of the load components: axial compression, AP and ML knee moments, AP and ML ankle moments, and axial torque would increase during the walking of Ak- and Bk- amputees on rough terrains when compared to the known data from tests on laboratory floors. The results of this research would be helpful in the design of modular prostheses, and for physical testing of prosthetic components.

The purpose of this paper is to present the results which were derived with one above the knee amputee wearing a modular limb on four different walking surfaces at a variety of walking speeds. The worst values thus encountered will be compared with normal walkway tests (i. e. on a plane asphalt surface) of the same subject.

Materials and Methods

In order to measure the loads to which the prosthesis was subjected a shin tube pylon 130 mm long with external and internal diameters of 30 mm and 28 mm respectively was instrumented with strain gauges. The pylon was placed in the prosthesis by means of bolted flanges. The arrangement of the strain gauges was as follows (Fig. 1).

1.	Sagittal bending:	2 independent measuring points with a vertical distance of 86 mm
2.	Frontal bending:	2 independent measuring points at the same vertical positions but turned 90°
3.	Axial load:	1 measuring point
4.	Axial torque:	1 measuring point

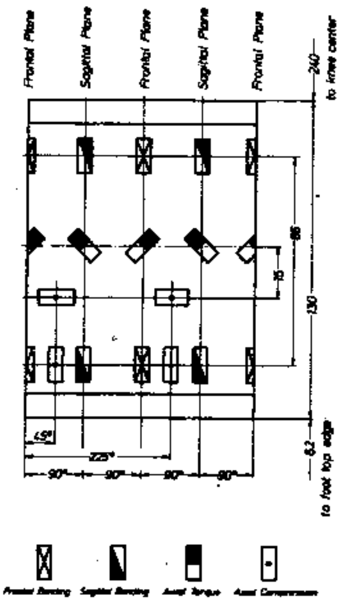

Fig. 1: Arrangement of strain gauge transducers on shin tube pylon (development)

The use of two independent transducers for the bending stresses at different levels was necessary to calculate the moments acting at both the knee and the ankle, which could not be measured directly, due to the limited length of the pylon. A 4-channel telemetry system was used to transmit the six signals indicated above and an additional signal from a heel and a toe switch. Since only four channels were available during testing, it was necessary to repeat each run after having changed the transducer connections. In the first run the axial load and the bending strain of the upper and lower measuring point in the frontal plane were transmitted. During the second run the axial torque and the two sagittal bending signals were recorded. In order to compare and synchronize the two records the heel contact and the toe-off marks were transmitted on the fourth telemetry channel in both instances. A block diagram indicating the operating principle of the telemetry transmitter and receiver is given in Fig. 2. For storage of the demodulated analogue output signals a four channel recorder was used. In addition, the frequency modulated sum signal was picked up at the output of this first demodulator and stored on a tape recorder for further processing. Fig. 3 is a schematic of the measuring arrangement.

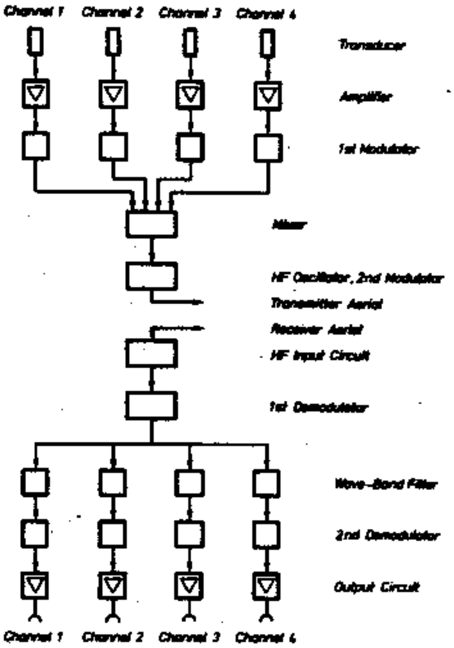

Fig. 2: Bock diagram of the telemetry system

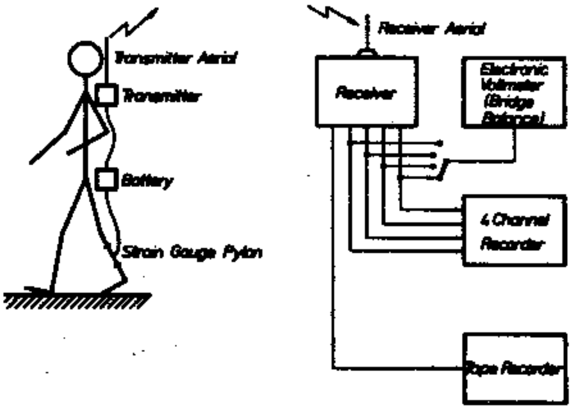

Fig. 3: Schematic of the measuring arrangement

The tests were performed on a 51 year old male amputee who weighes 77 kp, including the prosthesis. The length of his stump is 30 cm. He was fitted with an Otto Bock modular leg and a SACH-foot. Walking surfaces used in this investigation were asphalt, cobble-stone, rubble [+)] and fine grain sand. The structure of the surfaces can be estimated from Fig. 4.

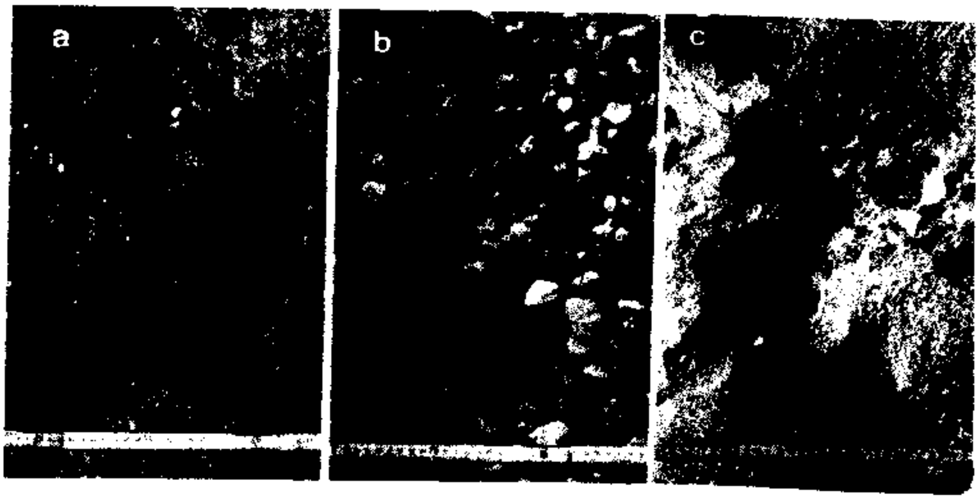

Fig. 4: Rough walking surfaces used in the investigation
(a = cobble-stone, b = rubble, c = sand)

On each terrain runs were carried out at walking speeds of 1.8, 3.0 and 4.5 km/h. From every trial 30 double strides were recorded. The first experiments showed that it was difficult for the patient to walk at a constant velocity. The problem was therefore to find a method which enabled the patient to control his own walking speed. Finally a rather simple but efficient solution was found for this purpose. A red ball was placed on a wire held at a height of about 1.7 m. The subject was told to keep the ball in sight, and walk at the same velocity at which the ball was moving. The velocity of the ball was in turn controlled by a variable speed motor, and could be moved at predetermined speeds. With this equipment the amputee could walk at a constant velocity without difficulty.

[+)] In this paper rubble will be defined to mean a layer of rough natural stone approximately 3 cm in diameter

Before installing the pylon the strain gauge transducers were calibrated on a static universal testing machine. This procedure provided more exact force and moment values than could have been obtained by calculation using the strains and the methods of theoretical mechanics.

Fig. 5 shows the amputee with his test leg and the measuring devices. The patient who carries the transmitter on his back has disloaded his prosthesis for zero balancing. In the van, on the left, the telemetry receiver and an elctronic multimeter is seen. On the right is the four channel recorder.

Fig. 5: **Amputee with test leg and complete**
Measuring device

Results

A typical record which was obtained at 4.5 km/h is shown in Fig. 6. The axial force (upper curve) shows the well known distribution with two maxima, one immediately after heel contact and the second prior to toe-off. The shape of this curve depends on both walking speed and type of surface. The ML bending moment at the upper transducer is to some extent similar to the axial compression curve. The corresponding moment at the lower transducer is smaller than the moment at the upper measuring point. Its peak values can be either negative or positive.

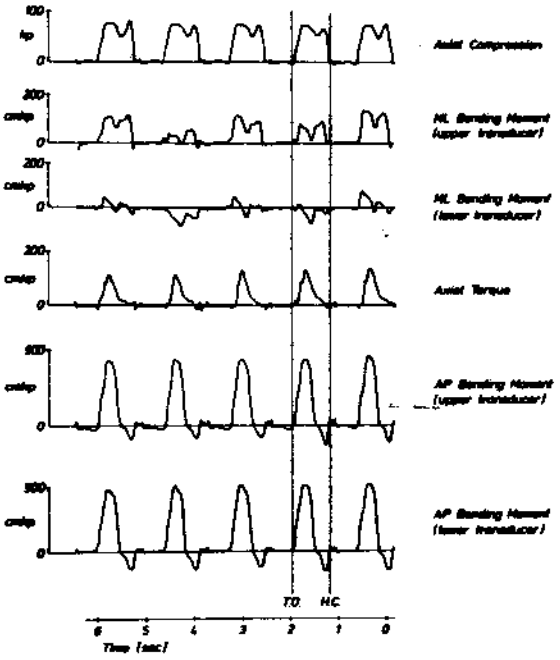

Fig. 6: Typical load/moment record
(v = 4.5 km/h; asphalt)

The axial torque remains positive during the entire stance phase and acts in an everting sense, which is different from the torque patterns of normal subjects. The AP bending moment, after heel contact, is negative at both transducers. At mid-stance it changes into a positive dorsiflection moment.

The analysis of the stored data was conducted by means of statistical methods. In order to evaluate the influence of walking surface on loading the peak values of 30 steps were averaged and their standard deviation calculated. In case of axial compression and torque this could be performed easily by directly reading the absolute maxima from the curves. The determination of the bending moments at the knee and ankle required an intermediate calculation. The first step was to calculate the inclination of the moment line using corresponding moment values of the upper and lower transducer which were located at a vertical distance of 86 mm (see Fig. 1). The required maximum moments were obtained by extrapolating the moment line to the knee and to the ankle.

The results of the analysis are shown in Figures 7, 8 and 9. Each diagram consists of four groups of columns, each representing one surface. The letters a, b and c indicate the different velocities. The axial loads (Fig. 7) on asphalt are of the same magnitude as the load values which have been measured by other investigators on laboratory floors. The forces on sand and rubble are between 20 and 50 % higher, depending on the patient's walking speed. It is surprising that on cobble-stone there is no significant force increase when compared to asphalt. On sand the experiments could not be extended to 4.5 km/h because this was too difficult for the amputee.

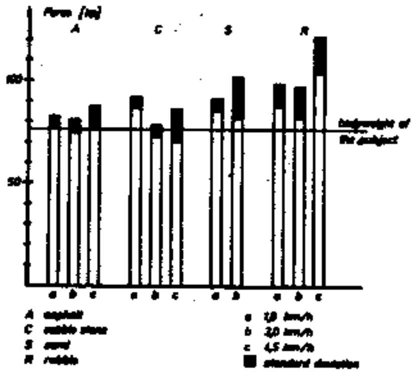

Fig. 7: Axial forces on shank along axis of pylon
(peak values)

Fig. 8 shows the maximum AP and ML ankle moments. From this diagram it becomes obvious that in the sagittal plane there is the greatest increase on the cobble-stone surfaces and on rubble. When compared to the results on asphalt, the AP moments are between 25 and 60 % higher. The ML ankle moments, which depend upon the alignment of the prosthesis, were found to be in the range of 10 to 20 % of the AP values on asphalt, cobble-stone and rubble. However when walking on sand there is an increase up to 50 % of the maximum AP moment.

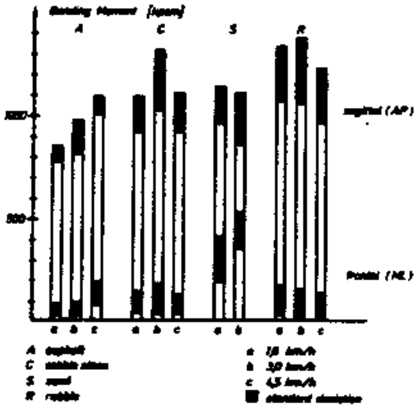

Fig. 8: AP and ML ankle moments (peak values)

The knee moments were not plotted because the resultant of the sagittal and frontal moment at the ankle is greater than the corresponding resultant moment at the knee, and the engineer needs only the maximum loads for designing the prosthesis.

The highest torque occurs when walking on cobble-stone and sand (Fig. 9); the peak values for rubble are in accordance with

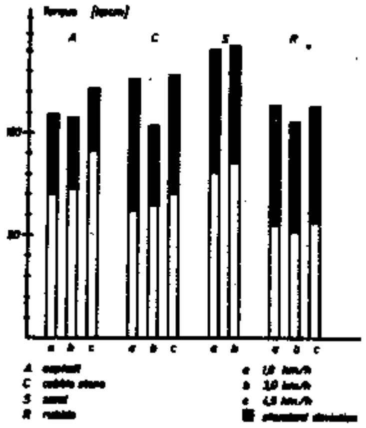

Fig. 9: Axial torque (peak values)

those measured on asphalt. An interesting fact is that the smallest torque occured on each surface at a speed of 3 km/h, which was the preferred velocity of the patient.

Discussion

When evaluating the results it should be noticed that the data were derived from a limited number of experiments and on one subject. The confidence level in the figures therefore needs to be increased. However the results confirm the assumption that there is an influence of the walking surface on some of the loading of skeletal prostheses. This means that some of the load values should be altered when making future design. Similarly new load values should be used in future testing. The following comparison with the load recommendations of the Heathrow-Conference on Physical Testing of Prostheses [2] which were derived from laboratory tests points out this fact in a clear manner. For an active patient with 80 kp body weight a maximum axial load of 106 kp was fixed. According to Fig. 7 this value is on the safe side, with the exception of rubble at 4.5 km/h. In this case a correction of the Heathrow recommendation does not seem necessary. For the AP ankle moment, a value of 1050 kpcm was proposed. As Fig. 8 points out this moment does not meet the real conditions. The ML ankle moment was fixed with 300 kpcm. If the activity of walking in sand is neglected, because this happens so seldom this peak moment seems to be realistic. In comparison to that, the proposed maximum torque of 125 kpcm is too small in relation to the measured moments on rough terrain which are shown in Fig. 9.

References:

[1] Design Criteria in Lower Limb Prosthesis-
Amputee Performance Measurement
ISPO Meeting Report Dundee, June 1973

[2] Bowden, M., H. J. B. Day, D. Murray (Ed.):
Physical Testing of Prostheses
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