CLINICAL TESTING OF AN ABOVE KNEE PROSTHESIS WITH MYOELECTRIC CONTROL

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Summary

At the 5th ETAN Symp. we proposed a new kind above-knee(A/K) prosthesis - "controlled prosthetic leg." This paper is concerned with the clinical testing of this leg.

This prosthesis consists of a damper for the swing phase control and a control unit. We call it an A/K prosthesis with myoelectric(EMG) control. With this prosthesis, damping coefficients of a pneumatic knee damper are automatically changed corresponding to walking speed and walkway by means of EMG control system, in which each EMG potential of hip flexors and M. gluteus medius is used for a signal for distinguishing each of walking speeds and walkways.

As a result of the evaluation testing of the EMG control system and the computer simulation during the swing phase of prosthesis on the basis of normal subjects' data, it was found that this A/K prosthesis with EMG control enabled a patient to walk suitably for walking speed and walkway.

Then, we actually attached this prosthesis to an amputee and had a clinical testing of it. From results of testing, we have a prospect of a feasibility of controlling the swing phase movement of prosthesis adaptable to walking speed and walkway.

Introduction

Since conventional prostheses don't have control systems which can carry out the swing phase control according to changes of walking speed and various circumstances, A/K amputees often experience much difficulty in walking with conventional prostheses. Therefore, we aimed at developing an A/K prosthesis applicable to a more broad range of conditions in order to reduce mental and physical fatigue of an A/K amputee.

In relation to EMG control for an A/K prosthesis, we have already developed two kinds of control systems. One control system which takes the advantage of the relationship between the EMG potential of hip flexors* and walking speed (1) is suitable for it, and the other which makes use of the connection between the EMG potential of M. gluteus medius and walkway (2) is well suited to it.

This study has a series of relation to those studies and have evolved them. On this study, we have really applied the EMG control system to a hardware and investigated its effectiveness.

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* This is the muscules which include M. iliopsoas mainly, and the site of picking up the EMG signal is below the inquinal ligament and activity of muscules is recognized in that site by the voluntary movement of hip joint.

Gait analysis

When normal walking is regarded as ideal of prosthetic walking, it is necessary that the results obtained from gait analysis of normal subjects are reflected in a prosthetic system in order to develop a more excellent prosthesis and make prosthetic gait alike to normal gait.

So, taking into consideration the joint angle from a kinematic point of view and the joint moment from a kinetic standpoint, we have analyzed normal gait as to each parameter of walking speed and walkway.

Despite walking speed changes, the knee joint angle during the swing phase is unchangeable. On the cotrary, the knee joint moment, come under the influence of acceleration, increases as walking speed becomes more rapid. From this result, it is considered that normal subjects walk suitably for each walking speed by means of adjusting their knee joint angles.

And, with regard to walkways, the knee joint angle and the hip joint moment change greatly in case of walking up a ramp compared with walking on a level or up a ramp. But,the knee joint moment varies a little. Consequently, it is assumed that normal subjects obtain an ability of controlling their knee joint angles fitted to every walkway by means of adjusting their hip joint moments without varying their knee joint moments very much.

Results of above gait analysis provide the following functions for the swing phase control desiered to an A/K prosthesis:

(1) When walking speed changes, a damping force around the knee joint during the swing phase is changeable.
(2) As someone heels on in flexion of knee in case of walking up a ramp, a damping force acts on so as to restrain the extension of knee the end of the swing phase.

A/K prosthesis with EMG control

With this A/K prosthesis, the swing phase control is carried out by alerting a damping force exerted on the knee joint by means of the automatic selection of damping coefficients. So, we have constructed the control system which consists of a damper for the swing phase control and a control unit.

The damper is composed of speed-controllers and a sylinder. A speed-controller consists of a combination of an orifice and a check valve as shown in Fig.1. And, a pneumatic system is adopted as the damper. The use of the speed-controllers have made it possible to set up damping coefficients in the direction of flexion and extension, and so an amputee wering this prosthesis can perform the favorable swing phase movement.

The control unit is composed of solenoid valves and a circuit for processing control signals. A pneumatic circuit connected in parallel with them is shown in Fig.2. Our control system is EMG one. It can discriminate changes of walking speed and walkway with the help of the imformation included in EMG potential, and after that it can put out control signals for driving solenoid valves so as to select damping coefficients suitable for walking speed and walkway. Therefore, we have constructed the circuit for processing control signals as illustrated in Fig.3. By way of this, the integrated EMG value of hip flexor is sampled at the time of toe-off, devided into two levels according to one threshold and used for the signal for distinguishing each walking speed. And the maximum value of the integrated EMG of M. gluteus medius is sampled between heel-off and toe-off, devided into three levels according to two thresholds and employed for the signal for recognizing each walkway. Each level of these signals corresponds to walking speed and walkway as listed in Table 1. The combination of signals is found out by the logic circuit. By way of the driver, outputs of the logic circuit can drive solenoid valves.

On the other hand, the hardware of this prosthesis is equipped with a ratchet and an elastic material on the prosthetic knee for the stability and pliability. The shank is made up of two plates shaped] which face to each other. The damper for the swing phase control and solenoid valves are built into the shank. An elastic material is put into the hind part of ankle axis so that the ankle can rotate slightly by a external force. And, the foot with elastic toe is made of wood.

The whole system of this A/K prosthesis with EMG control can be seen in Fig.4.

Effectiveness of system

Before the clinical testing, we investigated the effectiveness of the damper by the method of computer of simulation on the during the swing phase by a link of two components as shown in Fig.5, and simulated the swing phase movement in walking with a prosthesis. Two samples of this result are shown in Fig.6. They indicate that the choice of adamping coefficient corresponding to each walking speed and walkway can provide the favorable swing phase control.

Besides, as a result of the investigation of the effectiveness of EMG control system on the basis of EMG potential of a normal subject, it was made sure that each of walking speed and walkway was able to be discriminated in use of EMG potential of hip flexor and M. gluteus medius (Fig.7). For this reason, it is characteristics control of prosthesis in response to walking speed and walkway.

Clinical testing

We had a clinical testing under the following conditions (Fig.8):

(1) The subject has a left leg amputated above knee and a right leg amputated below knee (Fig.9).
(2) Two kinds of walking speeds, slow and fast, were determined.
(3) Walkways were a level and a ramp of 3.5[degrees] inclination.

Results of testing were as follows:

(a) Overall characteristics

The amputee wearing this prosthesis walked stably and smoothly. This comfirmed that it should be possible to make the prosthetic walking similar to the normal walking.

With respect to each sub-system:

(b) Characteristics of pneumatic damper

It was confirmed that the selection of a damping coefficient corresponding to walking speed enabled an amputee to control the swing phase prosthetic movement similar to the normal movement in case of walking on a level. Furthermore, the advantage to restrain the impact on his stump and head was recognized at the same time. And, it is desirable that an A/K amputee wearing a prosthesis can heel on in flexion of his knee in order to walk as same as a normal subject in case of walking up a ramp. So, it might be effectual to control the swing phase movement by means of increasing damping coefficients in extension of knee. On the other hand, the result that the amputee wearing this prosthesis controlled the swing phase movement smoothly in case of walking down a ramp indicates that it was effectual to change damping coefficients of the pneumatic knee damper.

From these data, it was resulted that this damper was effective for changes of walking speed and walkway.

(c) Discrimination of EMG information

When solenoid valves were driven soon after discriminatig each walking speed by means of the EMG potential of hip flexor, they hardly worked wrong in steady walking. The EMG potential of hip flexor of an amputee was recognized effective as a signal for the discrimination of each walking speed.

On the other hand, the EMG potential of M. gluteus medius of normal subjects has no relation to walking speed, but changes in response to every walkway. On this clinical testing, the EMG potential of M. gluteus medius of the amputee increased as greatly as that of a normal subject in case of walking up a ramp, and was little generated in case of walking down a ramp. However, it increased as walking speed become higher. Accordingly, it is necessary to reexamine to employ the EMG potential of M. gluteus medius for a signal for the discrimination of each walkway (Fig.10).

Conclusions

We have developed an A/K prosthesis with EMG control which make it possible to control the swing phase movement by means of EMG signals. This prosthesis was equipped with a knee lock mechanism, an elastic ankle, a pneumatic damper for the swing phase control and a control unit.

We practically attached this to an amputee and performed a clinical testing of it. From the results of testing, it is regarded that the swing phase movement of prosthesis can be similar to the normal movement with the help of altering damping coefficients of the damper. In addition, it is assumed that the EMG control system which has employed EMG potential of an amputee makes it possible to change damping coefficients automatically. Especially, we have comfirmed the EMG potential of hip flexor used for the signal for the distinction of each walking speed as effectual.

As you can see from these results, we have a prospect that this type of prosthesis provides a good capability of automatic controlling the swing phase movement applicable to changes of walking speed and walkway.

References

(1) Kato,I., Ooya,A. and Morita,H., "An Above-Knee Prosthesis with Myoelectric Control", Advances in External Control of Human Extremities (5th ETAN Symp.), Dubrovnik, Aug., 1975

(2) Kato,I., Morita,H. and Onozuka,T., "Development of Myoelectric Control System for An Above-Knee Prosthesis", On Theory and Practice of Robots and Manipulators (Ro.man.sy-76), Sept., 1976

Table 1 Combination of signal levels and mode of operation of solenoid valve

walkway	walking speed	signal level		solenoid valve
		integrated EMG value		
		hip flexor	M. gluteus medius	
level	fast	1	1	Sv1
	slow	0	1	Sv2
ascent	—	x	2	OFF
descent	—	x	0	Sv3

x : arbitary signal level

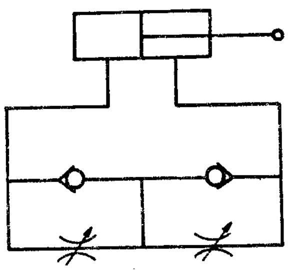


Fig.1 Basic structure of pneumatic knee damper

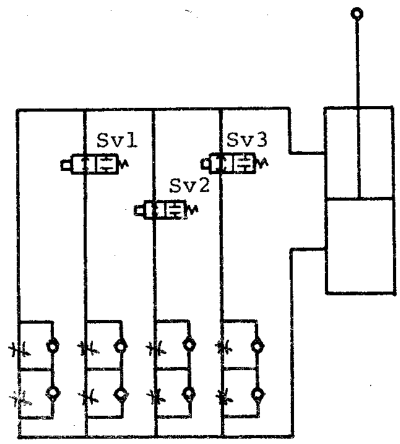
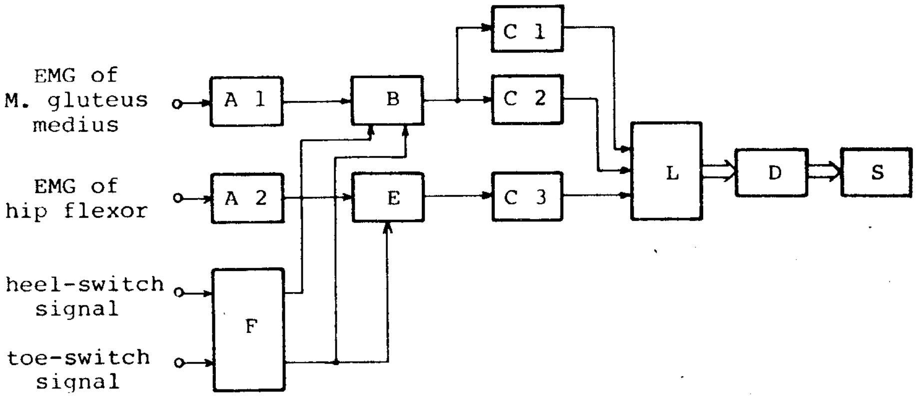


Fig.2 Pneumatic circuit connected in parallel with solenoid valves



A : Amplifier
Rectifier and
Integrator

F : Processing circuit of
foot-switch signal

B : Sample and Hold circuit
of Max. value

E : Sample and Hold circuit

C : Comparator

L : Logic circuit

D : Driver

S : Solenoid valve

Fig.3 Block diagram of control system

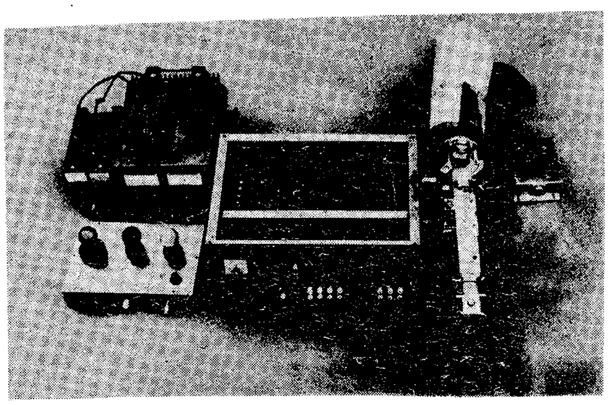


Fig.4 Prototype model of A/K prosthesis
with EMG control

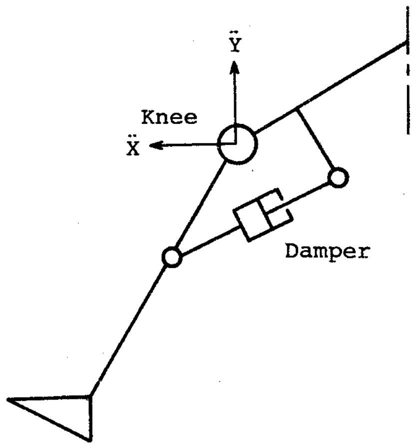
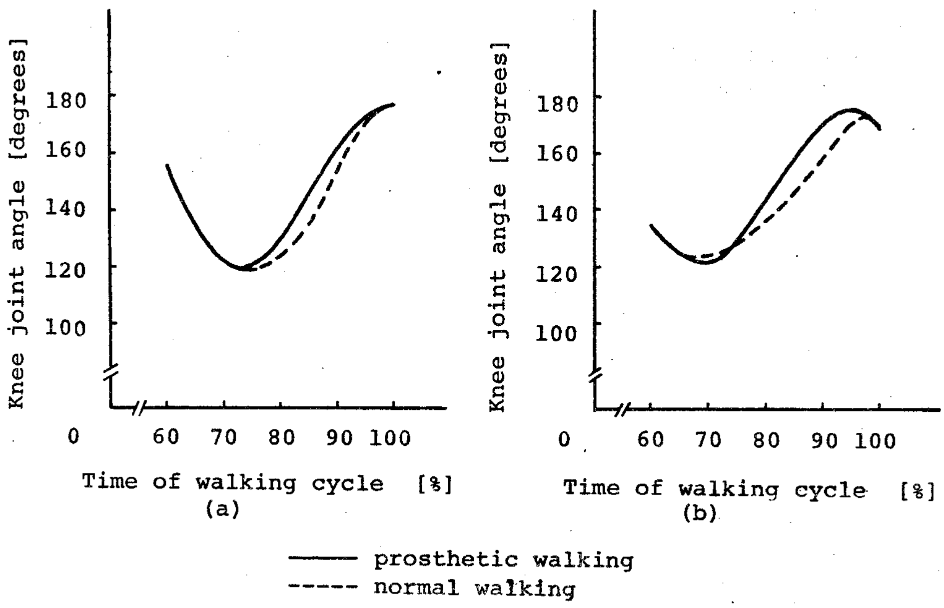


Fig.5 Model of A/K prosthesis during swing phase



(a) level walking (T=1.4[sec])
(b) descent(10[degrees]) walking (T=1.4[sec])

Fig.6 Swing phase control by means of pneumatic knee damper

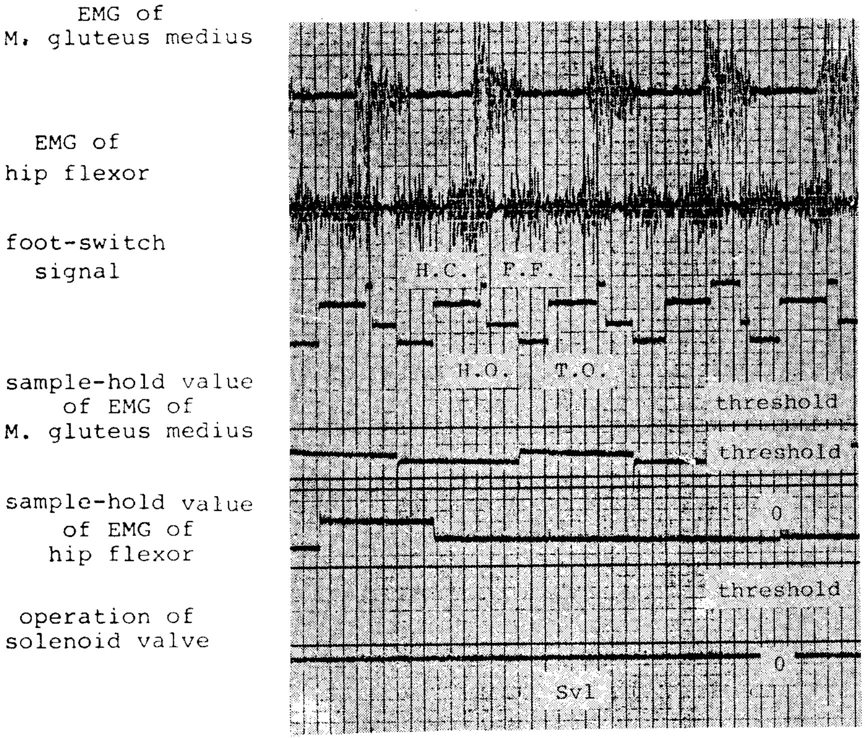


Fig.7 Cotrol signals
in normal level walking (T=1.[illegible][sec])

Fig.8 Clinical testing

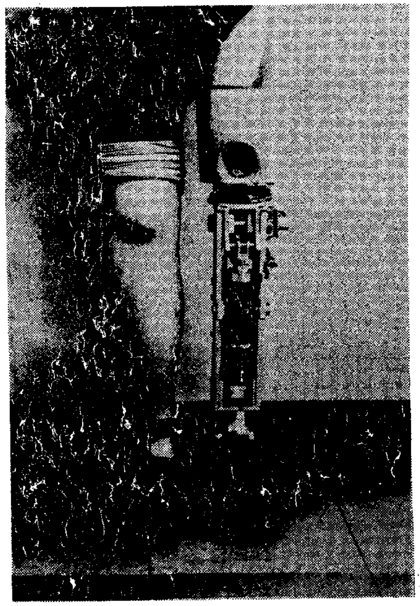


Fig.9 Amputee wearing the prostheses

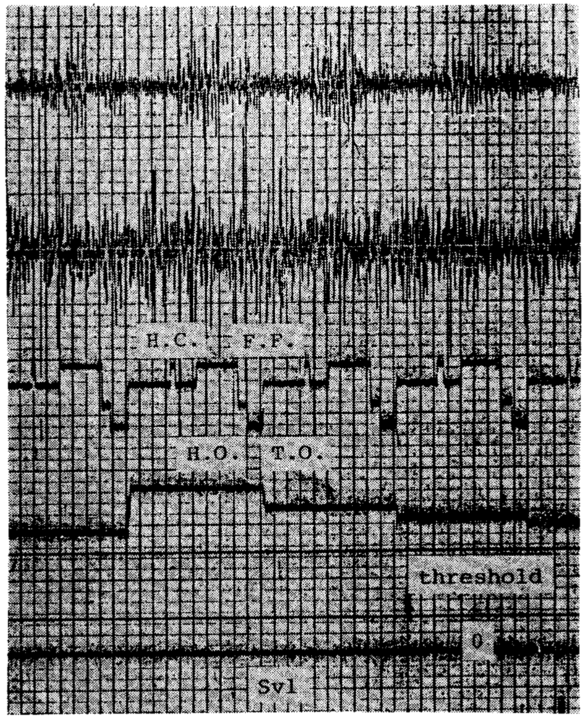


Fig.10 Control signals in prosthetic level walking (T=1.0[sec])