Proceedigns of the Eighth International Symposium on ECHE, 1984, Dubrovnik

AN ABOVE KNEE PROSTHESIS WITH A HYDRAULIC ACTUATOR AND ITS AMPUTEE TESTING

S.Tsutani, S.Hagihara, S.Akishita, H.Maeda, Y.Saida, Y.Saeki

SUMMARY

This paper deals with a prototype model of an active A/K prosthesis and evaluation of its performance. The model is equipped with a hydraulic actuator (RSA) in the knee and foot sensors made of conductive rubber in the sole. The nominal output torque of RSA is 118 Nm, and the oil pressure is 9.8 MPa. RSA is controlled by a microcomputer which determines the stance/swing state according to the signal of foot sensors and generates position patterns of the knee matching with the gait motion. The microcomputer consists of a 8-bit CPU, AD converters and DA converters.

In testing for evaluation, an amputee subject have no significant difficulty in going up and down stairs regardless of various step height. This result shows the control scheme applied to the model is effective for the active A/K prosthesis.

1. INTRODUCTION

It is estimated that in Japan there live about 50,000 people who have lost their legs in an on-the-job accident, a traffic accident, of a disease, etc. Since our legs have an important function of supporting the body weight and moving from place to place, above-knee amputees cannot lead their social life normally without the aid of prosthesis.

However, the conventional prostheses are not satisfactory because amputees can not change their walking speed intentionally or go up and down the stairs smoothly.

Accordingly, many attempts have been made so far to control the prostheses by adapting to the human motions. They are roughly classified into two types. One is the prosthesis intended to control its motion in the swing phase by a damper (1) ∿ (3). A pneumatic or hydraulic cylinder is used as the damper, and the sole load state detected by sensors, knee joint angle and myoelectric potential are used as the control signals. The other is the active prosthesis intended to control its motion in the stance phase. In this category, the investigations by Bertuzzi(4), Flowers(5) and Grimes (6) are known. In particular, the equipment by Flowers (5) (6) is intended to control the hydraulic cylinder, which has two functions as the actuator and the damper, by means of control signals such as the sole load, the knee angle, and the myoelectric potential. However, since the equipment was huge, it was impossible to go out of the laboratory.

The authors have been developing portable active A/K prostheses. They are controlled by a microcomputer, and are driven by a hydraulic rotary servo actuator (RSA) (7).

This paper reports the prototype model of the active prosthesis and the experiment of ascending and descending of stairs by an A/K amputee using it.

2. PROTOTYPE ACTIVE A/K PROSTHESIS

The prototype active A/K prosthesis being developed is intended to allow the amputee to walk on the flat road, go up and down the stairs and ascend and descend a slope smoothly.

2.1 CONSTRUCTION OF THE PROSTHESIS SYSTEM

The scheme of the developed prosthesis system is shown in Figure 1. This system is composed of a prosthesis body, a control circuit, the servoamplifier of RSA, a battery and a hydraulic pump. The prosthesis is attached to the stump of a amputee by means of a suction-fit socket. The knee is driven by RSA, and the ankle has a multiaxial joint. In the sole, pressure sensitive sensors called foot sensor is buried for detecting the contact of the prosthesis. Besides, same as in ordinary endoskeltal prosthesis, an alignment adjusting mechanism is provided. The portable rechargeable Ni-Cd battery is used for the power source of the control circuit, the servoamplifier and the hydraulic pump. The battery supplies +5 volts to the control circuit, and ±12 volts to the servoamplifier and the hydraulic pump. The hydraulic pump supplies a pressure oil of 9.8 MPa to the RSA.

2.2 ROTARY SERVO ACTUATOR

One of the main subject of the study is to miniturize RSA enough to be assembled into the prosthesis. RSA also must be powerful for simulating the human motion.

RSA is a hydraulic servo actuator, and consists of RSA unit, SM cassette and SM drive unit. RSA unit is a hydraulic servo motor with built-in rotary control valve. SM cassette is the servo mechanism to drive the rotary valve, and its servo amplifier is called SM drive unit. In SM cassette, potentiometers are equipped in order to monitor the angular position of the input and the output shafts. For driving this input shaft, a DC motor with a tachogenerator is used. The rotation of the DC motor is transmitted to the input shaft of RSA through reduction gears of reduction ratio 49.2.

In the rotary valve of the actuator, bearing steel is used in consideration of resistance to wear. Other principal parts are made of duralumin. Besides, plastics are used in part of the SM cassette to reduce the weight.

The specifications of RSA system for the prosthesis is shown in Table 1. The performance of this RSA is evaluated by testing. The results are shown in Figure 2 and 3 which illustrate the characteristics of the frequency response and the step response respectively. As shown in Figure 3, the response time to the step inputs of 45 degrees and 90 degrees are 0.2 and 0.4 seconds, respectively. The hysteresis in the static relation between the input and the output angles is ±0.1%. These results show that this RSA has satisfactory performance for the active prosthesis.

2.3 CONTROL CIRCUIT

The control circuit consists of a single chip microprocessor 8751

(Intel), AD and DA converters. The block diagram of the circuit is shown in Figure 4. As shown in the Figure, the major features of the 8751 are 8-bit CPU, 4 K bytes of EPROM, 128 bytes of RAM, I/O ports, timer and interrupt controller. In this circuit, 2 I/O ports are used. One is for the input and output of anlog signals (Foot sensor, Knee angle, RSA command). The other is for the input of digital signals (Mode, Speed). The interrupt controller is controlled by interrupt signals (Start, Stop, Timer). The inputs, outputs and interrupts are summarized as follows:

- Analog inputs: Foot sensor signal, Angular position of RSA output shaft
- Analog outputs: Command signal to RSA servo amplifier
- Digital inputs: Walking speed setting (high, midium, low) Walking mode setting (level walking, ascent and descent of stairs, ascent and descent of slope)
- Interrupts: Start, Stop, Timer

2.4 ACTIVE CONTROL SCHEME

This prosthesis is controlled by the following active control scheme. That is, the basic two gait patterns of the knee motion corresponding to the swing and the stance phase are stored in the PROM. One of the two patterns is selected on the basis of the signal from the foot sensor which detects whether the prosthesis is in the swing phase or in the stance phase. The digital signal of the selected pattern is converted to the analog signal by the AD converter and fed to RSA as a command signal.

This scheme provides the following advantages.

- A microprosessor is sufficient for the control device since our control scheme is simple.
- Since this control scheme does not need any special sensors like myoelectric sensors or sensors attached to the sound leg, the amputees can easily wear the prosthesis just as conventional one.

Figure 5 shows the flow chart for the control program based on this scheme. By the start switch, a start program runs. In this program, according to the digital input for walking speed setting, the sampling period is determined and set in the timer. The period must be shorter than 40 milliseconds to move the prosthesis smoothly. Then according to the walking mode setting, level walking, ascent and descent of stairs or slope is selected. Then the initially set timer is started and the CPU waits for next interrupt signals.

By the interrupt signal of the timer, a gait pattern generation program is started. Depending on the foot sensor signal, it is determined whether the phase of the prosthesis is in the stance or the swing. The data of the pattern corresponding to the determined phase is successively read out from the PROM, and converted to the analog signal as a command of RSA. This processing continues until the interrupt signal of stop is received.

3. EXPERIMENT

First, in order to confirm the safety and adaptibility of the prosthesis to the human body, a preliminary testing by a normal person was carried out. In this case, a dummy model of the prosthesis which can be worn by a normal person is used. Figure 6 shows a normal person with the dummy model of the right leg. As a result, though slightly different from the normal walking, possibility of going up and down the stairs and safety were proved.

Next, a clinical testing by an amputee was performed as is mentioned in detail in the following section.

3.1 CLINICAL TESTING

The subject is a 24-year-old healthy male A/K amputee of the right leg, 173 cm in height and 55 kg in weight. He usually wears a conventional type prosthesis (LAPOC) (8).

In the presence of the medical doctor, he walked up and down the standard stairs with height difference of 16 cm. Figure 7 shows the view of the clinical testing. For safety, handrails were attached to the staircase In Figure 7 the amputee wore a small hydraulic pump. However, in the clinical testing a general-purpose large hydraulic pump was sometimes used so as to withstand a long-period and heavy load testing.

To monitor the prosthesis system during the testing, the command signal, the knee angular position of the prosthesis, the foot sensor signal and other data were measured. At the same time, the walking motion was recorded by 16 mm film and VTR.

3.2 RESULTS AND DISCUSSION

In the first testing, the gait patterns of a normal person were used as the command signal as shown in Figure 8. However, the subject could not go up and down the stairs by these patterns. By this trial, it is found that the gait patterns of normal person are not suitable for our prosthesis because the amputee has poor assistance of hip extensors to lift himself and this prosthesis do not have any ankle actuator.

To obtain the suitable patterns for our prosthesis, the following points were considered.

- When going up the stairs, after the foot contact, the knee is extended too early to transfer the body weight onto the prosthesis.
- When going down the stairs, the knee should be flexed preferably largely to over the step-board.
- A proper training period should be necessary, since the subject usually wore the conventional prosthesis and was accustomed to its peculiar motion of walking.

By using the modified patterns, the second testing was carried out. The subject could fairly go up and down the stairs. However, the walking motion was not smooth and further, in the descent, the subject could not control his walking speed because of the unsuitable pattern.

Considering some comments from the subject and others, the gait patterns were further modified and tested. As a result, the above-mentioned problems were solved, and the amputee could go up and down the stairs smoothly and naturally by the active prosthesis. The result is shown in Figure 9. Using the same patterns, the testing for the stairs with height difference of 10 cm was also carried out and a satisfactory result was confirmed.

4. CONCLUSION

It is found that the amputee wearing our active prosthesis can go up and down the stairs smoothly and naturally. And the safety and adaptibility of the prosthesis to the amputee is confirmed.

For the next stage, we are planning to develop a lightweight and compact prosthesis system and a passive control for level walking to save energy.

ACKNOWLEDGEMENTS

This project was started in fiscal 1980 and is to end in fiscal 1985 under the National Research and Development Program for Medical and Welfare Apparatus of Ministry of International Trade and Industry.

The authors wish to express their cordial thanks to Dr. K. Tsuchiya of chairman and other members of the comittee of this project and clinical advisers for their useful advice and suggestion.

REFERENCES

(1) Kautz, T.O. and Seireg, A., "Feasibility Study of a Computer Controlled Hydraulic Above-Knee Prosthetic Limb," Int. Conf. Med. Devices Sports Equip. 1980, 81

(2) Koganezawa, K., Aoki, T. and Kato, I., "The development of A/K Prosthesis Adaptable to Voluntary Walking Period," (Japanese) Biomechanism Symposium 1983, 265

(3) Nakagawa, A., Kitayama, I., Seguchi, Y. and others, "Intelligent Above Knee Prosthesis, Its Development and Evaluation," (Japanese) Biomechanism Symposium 1983, 252

(4) Bertuzzi, A., Leo, T., Monteleone, M. and Vitelli, R., "A Powered Lower Limb Prosthesis with Myoelectric Control," I Convegno Mostra di Bioingegneria, 1972, R2-10

(5) Flowers, W.C. and Mann, R.W., "An Electrohydraulic Knee-Torque Controller for a Prosthesis Simulator," ASME Journal of Biomechanical Engineering, Feb., 1977, 3

(6) Grimes, D.L., Flowers, W.C. and Donath, M., "Feasibility of an Active Control Scheme for A/K Prosthesis," ASME Journal of Biomechanical Engineering, Nov., 1977, 215

(7) Saida, Y, Saeki, Y. and Sato, T., "The Development of Hydraulic Servo Actuator with built-in Rotary Control Valve," Bull. of Japan Soc. of Precision Eng. Sep., 1979, vol. 13, No. 3, 117

(8) Aoyama, T., "LAPOC System Leg," Proc. of Rehabilitation Eng. Int. Seminar 1980, 58

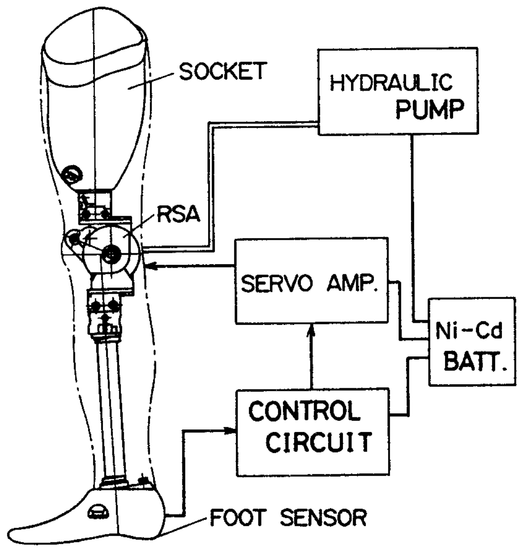

Figure 1. Scheme of the active prosthesis system

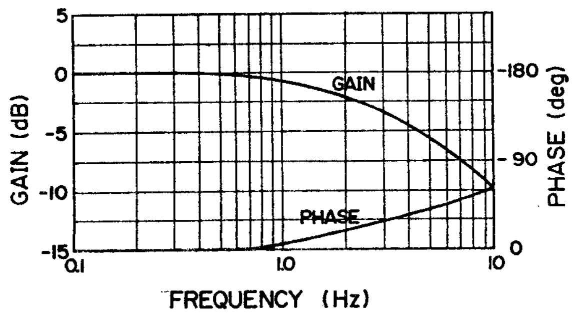

Figure 2. Frequency response of RSA system
(Input: $\pm$ 15 deg., oil pressure: 9.8 MPa)

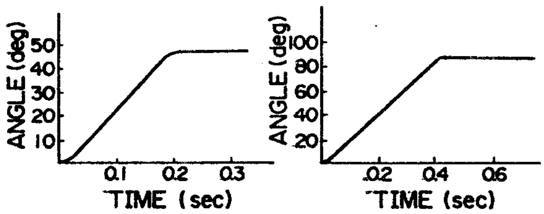

Figure 3. Step response of RSA system

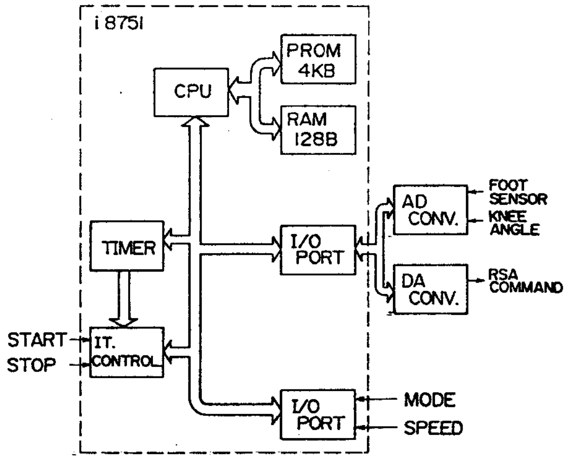

Figure 4. Block diagram of control circuit

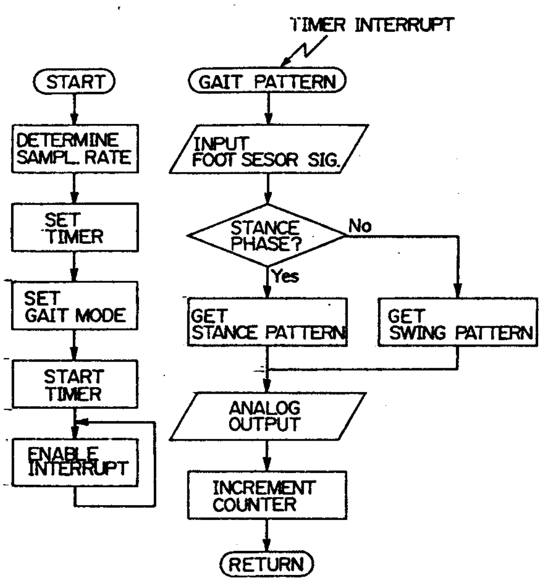

Figure 5. Flow chart for control program

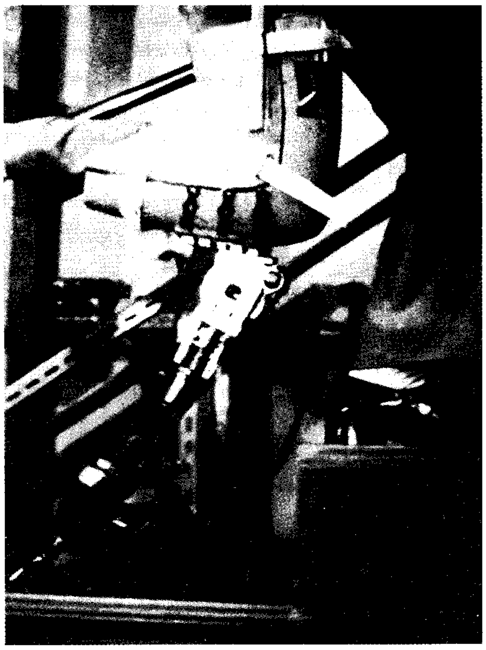

Figure 6. A normal person with the dummy model

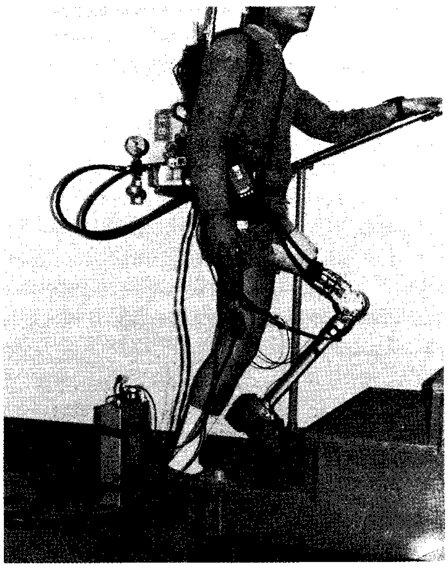

Figure 7. View of clinical testing

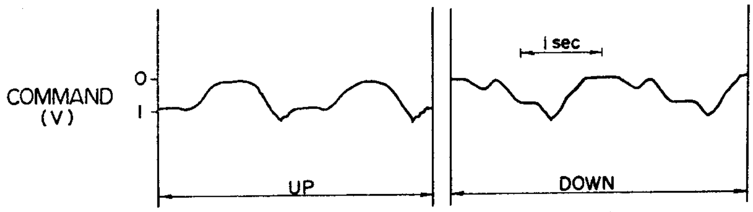

Figure 8. First trial patterns

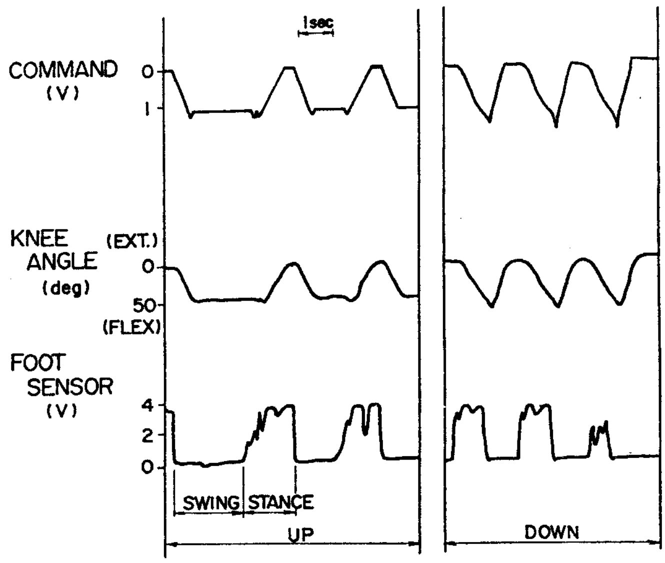

Figure 9. Result of clinical testing

Table 1. Specifications of RSA for the prosthesis

Output torque (Nm)	118
Rated supply pressure (MPa)	9.8
Maximum rotation range (deg.)	110
Maximum angular velocity (deg./sec)	60
Positioning accuracy (deg.)	$\pm$ 1
Time constant (msec)	50