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AN ABOVE-KNEE PROSTHESIS WITH MYOELECTRIC CONTROL

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Summary

The purpose of this study is to apply myoelectric control system to the above-knee prosthesis and to give a feasibility of optimal swing-phase control adapted to the walking rate. This prosthesis is consisted of three parts; pneumatic knee damper, controller and control circuit of EMG signal. From the analysis of EMG signal from leg muscles, the relationship between the walking rate and the amplitude of rectified and smoothed EMG signal of M. ileo-psoas at toe off was recognized. From this result myoelectric control system is constructed which divide the amplitude of signal into four levels,then drive the controller to change the damping factors of knee damper.

Prosthesis system as a man-machine system

A prosthesis is a machine to be connected to the stump of the extremity compensating for the loss of function of the lower extremity. It is inadequate to consider this an independent machine but rather to adopt the concept of man-machine system. On this occasion, in order to increase the adaptability of the prosthesis without giving excessive load physically or mentally to the amputee, it was elected to allow the voluntary decision of the man to change the walking speed to control the physical characteristics of the prosthesis. This would make it possible to produce a man-machine system with one step forward. For this purpose we suggest the following method. As shown in Fig. 1, the myoelectric signal of the amptee is processed and the signal corresponding to walking speed is extracted. With the use of this signal, the controller apparatus is set in motion and the damping coefficient of the damper for the swing phase control is changed. With this, swing phase control for adapt to the walking speed is automatically carried out. It possible to obtain a more natural gait for the amputee.

Myoelectric signal

Myoelectric potential as a control signal of the prosthesis have been used for quite a long time in powered arm prosthesis.The theoretical concept required for the introduction of myoelectric control is based on two well known facts of myoelectric potential.

1. Electrical activity of the muscle may be started, continued and stopped voluntarily.
2. A definite relationship is found between the muscle tonus during isometric contraction and myoelectric potential following rectification and integration.

With this, it became possible to transmit the information from the central nervous system to other functional system via myoelectric signal. When myoelectric control is introduced to the above-knee prostheses, the basic concept is exactly the same. Unlike the arm prosthesis with conscious and delicate motion, however, walking is done partly unconsciously. The muscle from which myoelectric potential is obtained has to be directly connected with walking movement. Otherwise, walking would have to be done consciously. The first item above is therefore to be reconsidered when myoelectric control is introduced to above-knee prosthesis.

1'. Electric activity of the muscle starts, continues and stops with walking movement.

Selection of the site of picking up the myoelectric signal

In order to determine the site of picking up the myoelectric signal, electromyogram was obtained from the muscles of the lower extremity during walking. Walking speed was changed to conduct analysis of myoelectric signal. The site of putting the electrode on was expressed by the name of the muscle. Among the sites of picking up, it is said to be difficult to obtain EMG by surface electrode especially at the iliopsoas portion. Since this portion is related to the flexion of hip joint, this is called hip flexor.

Fig. 2 shows an example of electromyogram obtained from hip flexors, gluteus maximus, semitendinosus, rectus femoris, tibialis anterior and soleus muscles during walking in healthy subjects. The pattern of development is almost constant despite the change of walking speed. Characteristics of each muscle are as follows: Mode of heel contact and toe-off to the floor are also simultaneously recorded, so as to distinguish the moments of heel contact and toe-off to the floor.

1. Hip flexor: Myoelectric potential appears after and before the time of heel contact and toe-off. Amplitude of myoelectric potential suddenly magnified as the walking speed becomes greater than 1.0(sec).
2. M. gluteus maximus: Myoelectric potential appeared around the time of heel contact. Amplitude of myoelectric potential does not change much with the walking speed.
3. M. semitendinosus: Myoelectric potential appears around the time of heel contact. Amplitude of myoelectric potential gradually increases as the walking speed increases.
4. M. rectus femoris: Myoelectric potential continuously appears from before heel contact, through the stance phase and up to immediately after toe-off.
5. M. anterior tibial: Myoelectric potentials appear approximately in agreement with the swing phase. The EMG amplitude gradually increased as the walking speed became more rapid.
6. M. soleus: Myoelectric potential appeared during stance phase. Amplitude increases as the speed of walking increased.

Among these 6 muscles, hip flexor participates in the swinging out of the lower extremity during the swing phase. The EMG amplitude becomes suddenly greater as the walking speed becomes faster. Consequently, hip flexor appears to be most adequate as the site of picking up of myoelectric signal. This site is the nearest to the stump of the amputated thigh and thereby most convenient for practical use.

Relationship between myoelectric signal and walking speed

Myoelectric potentials of hip flexor were measured as the walking speed is changed in healthy subjects walking on level ground. Fig. 3 shows the changes of integrated value curves of EMG obtained from hip flexor at each walking speed. In one walking cycle, integrated EMG value was greatest around toe off and this value increased as the walking speed increases. Especially when it is faster than the walking cycle, 1.0 (sec), the integrated EMG value suddenly becomes greater.

Fig. 4 shows the relationship between the integrated EMG value of hip flexor at the time of toe off and walking speed. Thus a definite relationship was found between integrated EMG value at the time of toe off and speed of walking.

Myoelectric control system

As the relationship between myoelectric signal and walking speed became clear, a control system was designed. This system consists of a damper for the swing phase control, controller, and circuit for the processing of myoelectric signal.

The damper for the swing phase control may utilize either friction system, hydraulic system or pneumatic system. An pneumatic system was adopted here, because of simplicity and the possibility of favorable movement during swing phase. As shown in Fig. 5, with the combination of an orifice and check valve setup independent control in the direction of flexion and extension was made possible. Solenoid valves of 3 ports and 2 position were used for the controller. Through selective operation of the position selector valve damping characteristics corresponding to 4 kinds of walking speed was accomplished.

The system diagram is shown in Fig. 6. The principle of operation consists of sampling of the integrated EMG values from hip flexor at the time of toe-off and transmission of this value to operate the position selector valve according to each level. The recorded myoelectric potential was differentially amplified and passed through a low cut filter to remove drift and noise component. This signal was rectified and integrated. The time constant for the integration was set at 150 (msec). The switch was attached to the tip of the foot (head of the third metatarsal), and the integrated EMG value at the moment of toe-off is sampled and this is maintained through one walking cycle. Threshold values at three levels were set and these sampling values are divided into 4 levels. Each level corresponds to each walking speed. The lowest level corresponds to the slowest speed, while the highest level to the fastest. The position selector valve is moved with this signal. The mode of operation is shown in Table 1.

Setting of damping coefficient

The damping coefficient for the damper for the swing phase control was established for 4 levels of walking speed. The optimal value of damping coefficient is set up as follows:

1. Measurement of damping coefficient of pneumatic knee damper.
2. Measurement of changes of joint angle of lower extremity during normal walking.
3. After simulating the free leg movement in the swing phase during walking on prosthesis, the optimal damping coefficient is determined.

The damping coefficient of pneumatic knee damper changes according to the area of opening of the orifice, so that the damping coefficient for each degree of opening of the valve was determined.

Angle of the hip joint of the lower extremity and change of the angle of knee joint during normal walking are measured, and expanded by Fourier series to calculate Fourier coefficient.

From these result, swing phase movement during walking on above-knee prosthesis was simulated by a model consisting of a link of two components hung from the fixed hip joint as shown in Fig. 7. Simulation of the movement of the below knee portion of the prosthesis could be carried out when the walking period, swing phase period, and hip joint angle were provided.

The following conditions were added on this occasion.

1. The amputee can move the thigh as in normal walking.
2. At the time of beginning of swing phase movement, the angle and angle velocity of the knee joint was similar as in normal walking.

When the damping coefficient is set at an optimal point, the swing phase movement was made to simulate the movement in normal walking as much as possible. For comparison, the square area of the difference between swing phase movements in normal walking and on prosthesis was used. Using this method, values for damping coefficient at each walking speed were provided. (Table 2)

Evaluation of myoelectric control system

The circuit for processing myoelectric signal was attached to normal subjects and the operation of the controller (position selector valve) was measured at each walking speed.

When the test subject walked at a constant speed of 1.8, 1.3, 1.0, and 0.8 (sec), the each position selector valve shows the mode of operation as planned. This corresponds to the stationary characteristics of the myoelectric control system.

The threshold values were set at 10, 29, and 73% of average value of sampling voltage at the walking period of 0.8 (sec).

Conclusion

1. The integrated value of myoelectric signal flat value of the hip flexor at the time of toe-off corresponds to the walking speed.
2. This myoelectric control system shows consistent favorable stationary characteristics upon walking at each walking speed.
3. Introduction of myelectric control system to the above-knee prosthesis is effective.

Table. 1 Mode of operation of position selector valve

Walking period	Position selector valve		
	SV-1	SV-2	SV-3
Late	0	0	0
Normal	1	0	0
Fast	0	1	0
Fastest	0	0	1

Table. 2 Setup of damping coefficient

Walking period (swing phase period)	1.80 (0.72)	1.33 (0.48)	1.00 (0.40)	0.80 (0.36)
Viscous resistance for flexion kgcmsec/nad	10.5	10.5	11.3	11.8
Spring coefficient for flexion kgcm/rad	3.5	3.5	3.8	8.0
Viscous resistance for extension kgcmsec/rad	14.2	14.2	13.4	11.5
Spring coefficient for extension kgcm/rad	15.0	15.0	6.5	2.2

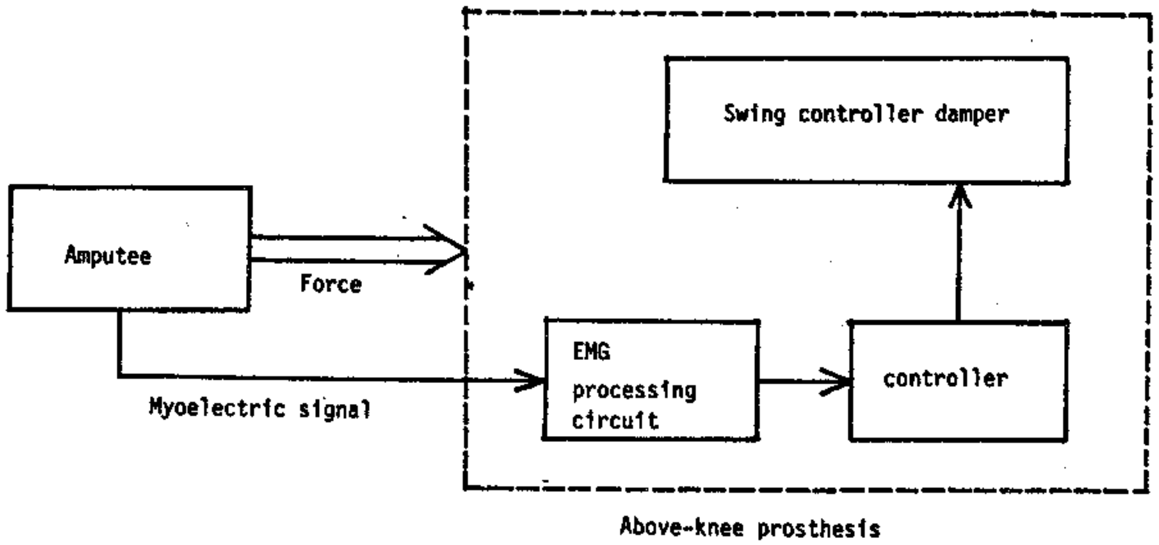


Fig. 1 Myoelectric control system

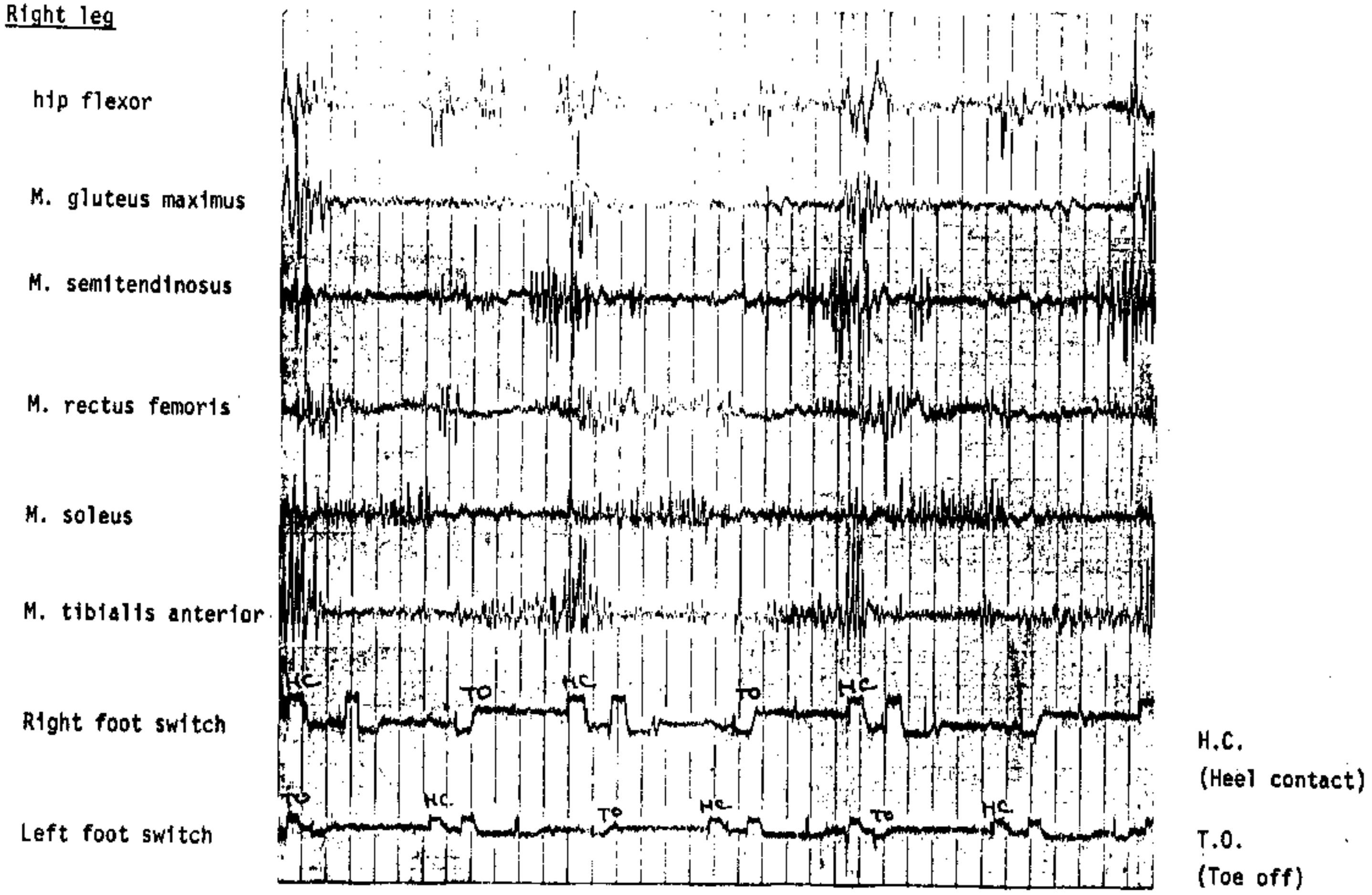
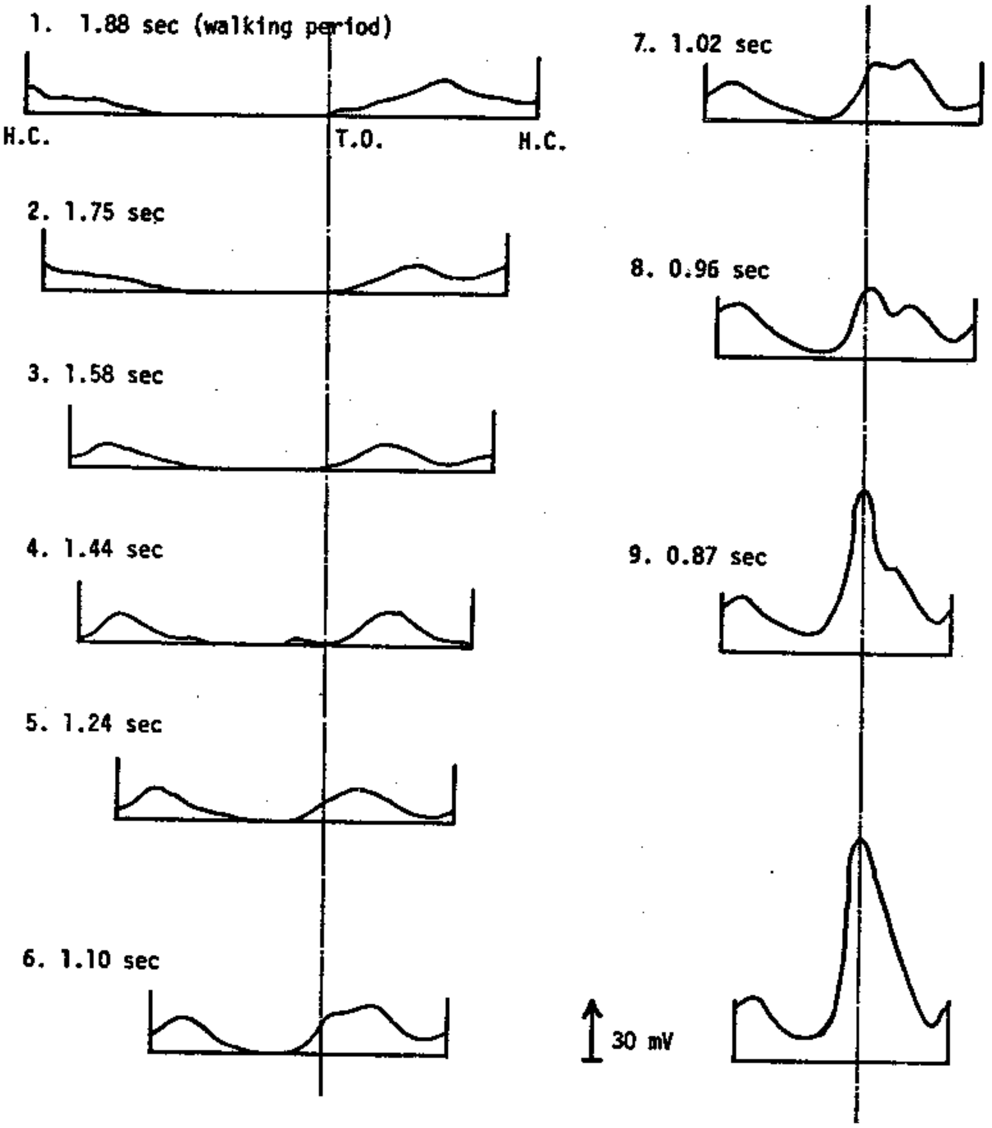


Fig. 2 Electromyogram of lower extremity in walking



H.C.	Heel contact
T.O.	Toe off

Fig. 3 Changes of integrated EMG value curves from hip flexor

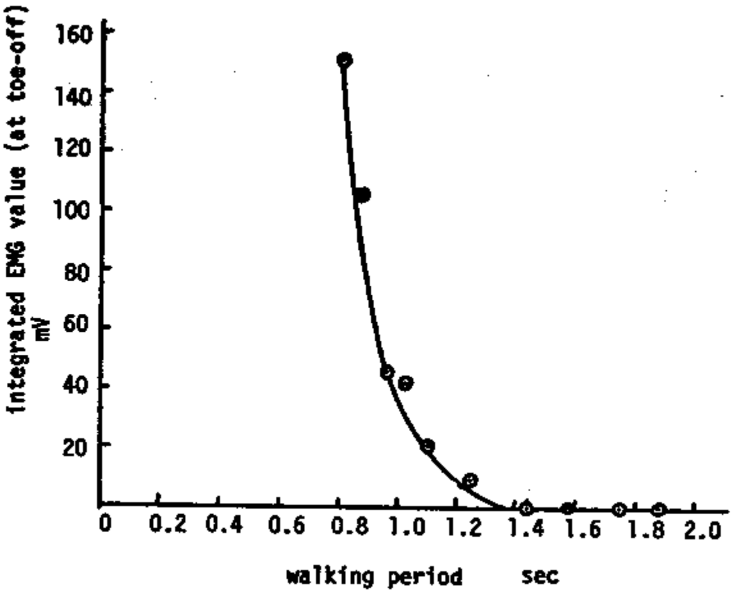


Fig. 4 Relationship between the integrated EMG value of hip flexor at toe-off and walking speed

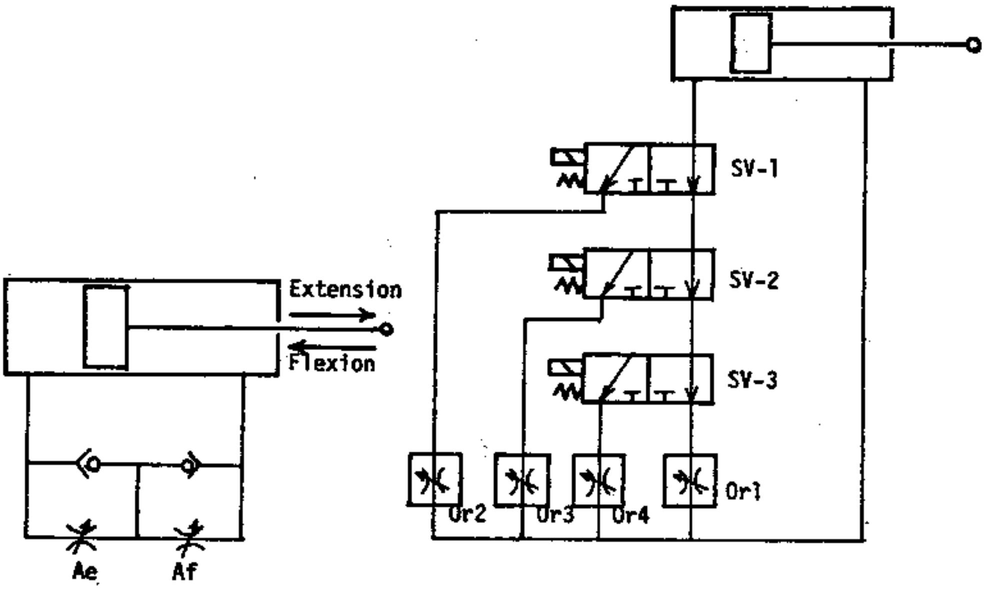


Fig. 5 (a) Pneumatic knee damper

Fig. 5 (b) Pneumatic knee damper and controller

Fig. 5

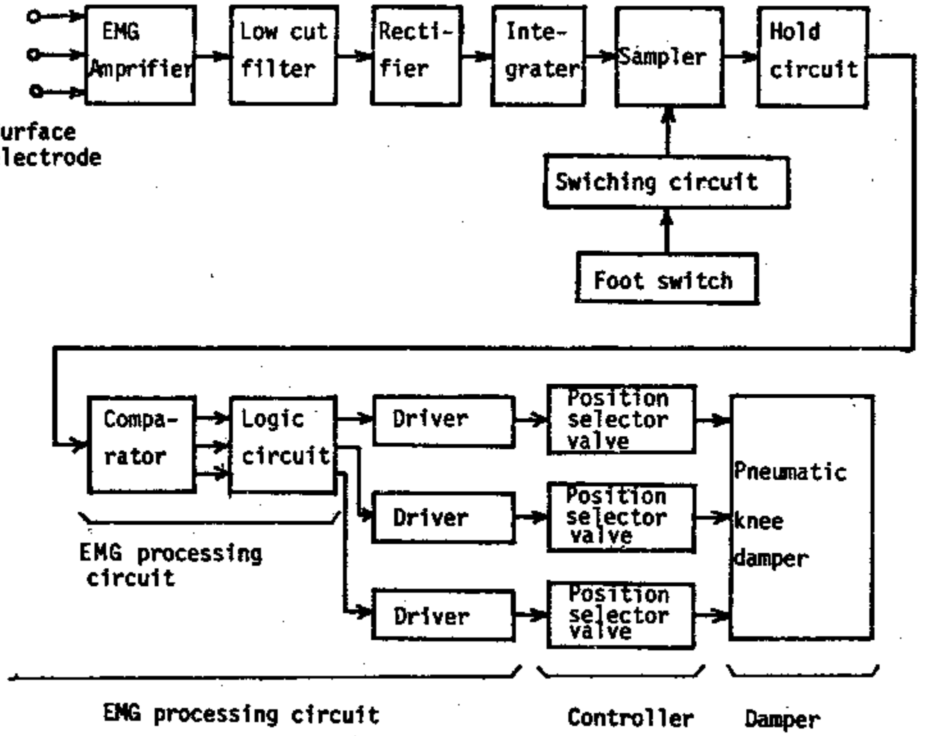


Fig. 6 Block diagram of myoelectric control system

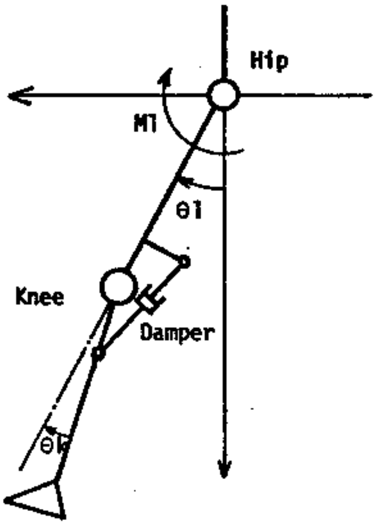
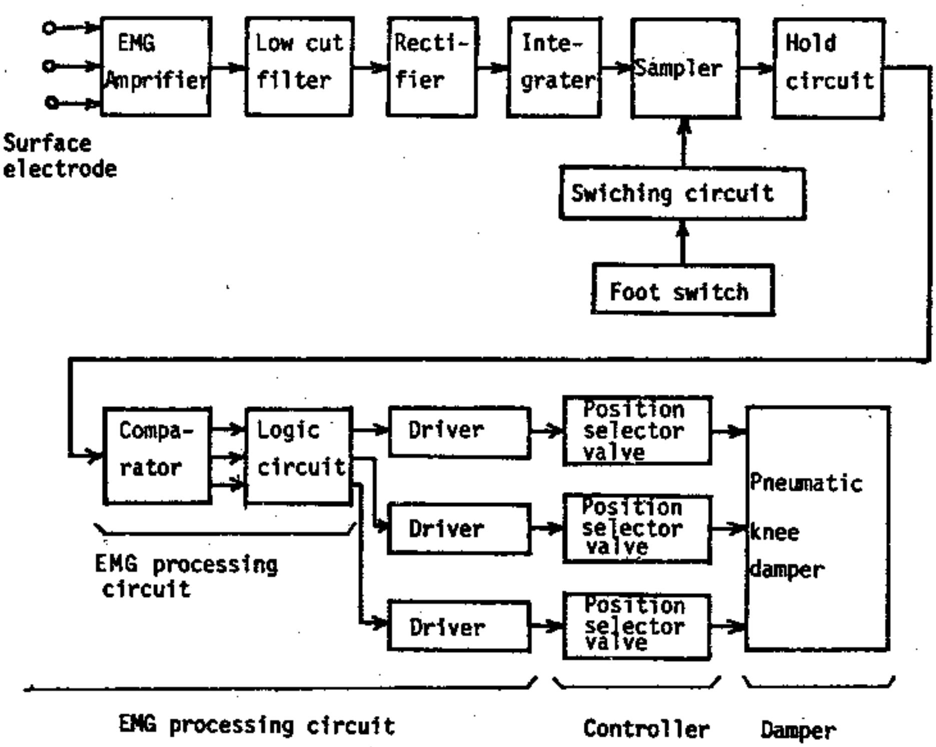


Fig. 7 Model of above-knee prosthesis in swing phase



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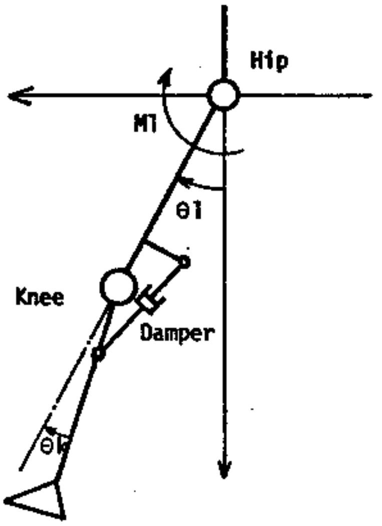

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