DESIGN OF A
MYOELECTRICALLY-CONTROLLED KNEE EXERCISER

by

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ABSTRACT

The objective of this thesis is to investigate improvements upon existing isokinetic knee exercisers. Most available knee exercisers are open loop systems that do not monitor or adjust resistive loads according to muscle effort and user needs. A closed-loop biofeedback-controlled exerciser would provide a more versatile alternative.

The myoelectrically-controlled knee exerciser is designed to provide flexibility and controllability over various parameters of the system. The unique aspects of this device include control of the muscle effort, control of the system time response, and control of the system's torque output. The end result is a highly programmable and hence user adaptive device that can be suited to meet the needs of the user.

Thesis Supervisor: Prof. Woodie Flowers

Title: Associate Professor of Mechanical Engineering

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I express my deep appreciation for the guidance and support from my thesis advisor, Professor Woodie Flowers. His creative ideas and phenomenal insight have constantly renewed my hope whenever I was lost for ideas.

To the students at the Laboratory for Biomechanics and Human Rehabilitation, I extend my many thanks for their time and assistance in the progression of this project.

I am sincerely thankful to all my friends who have supported me in their own special way throughout the rough times of this thesis.

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Words cannot express my warmest appreciation for the infinite support and understanding of my family and Simon. I never would have made it without them!

Jane H. Lee

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1. Introduction

A need exists for a programmable knee exerciser which suits an individual's therapeutic needs. Most of the conventional knee exercisers that exists today are designed primarily for the general population rather than for the individual. For example, weight machines are basically open loop systems. There are no control mechanisms with which the system can be customized to the user.

The scope of this thesis is to design a programmable knee exerciser that provides controllability over the forces applied by the user, the time response of the system, and specific muscle development. Basically, it is a closed loop biofeedback system in which muscle activity controls the resulting activity of the knee exerciser.

2. Experimental Procedure

The experimental work of this project involves three basic areas:

1. Myoelectric Signal Receptions
2. Electrical Interfaces
3. Magnetic Particle Brake

Figure 1 is an illustration of the the experimental setup. The myoelectric signals are detected by electrodes attached to a muscle pair,i.e., a flexor and an extensor. The signal is processed through the electrical interface which will then output a particular current level to the magnetic particle brake to control the movement of the knee. A more detailed description of the exerciser is in the following section.

3. Knee Exerciser

As was mentioned previously, the capacity of the knee exerciser may be divided into the following: the myolelectric signal receiver, the electrical interface, and the magnetic particle brake. Figure 2 is a block diagram of the biofeedback controller. The input myoelectrical signals pass through the Myo/Amp and filter and are added together in the summer. The resulting signal is then compared with certain threshold voltages in the Schmitt Trigger. Selected data points determined by the clock circuit arethen sampled. As a means of system time response control, the propagation of the signal will be delayed five clock cycles of which cycle time is chosen by the user. The output is then relayed

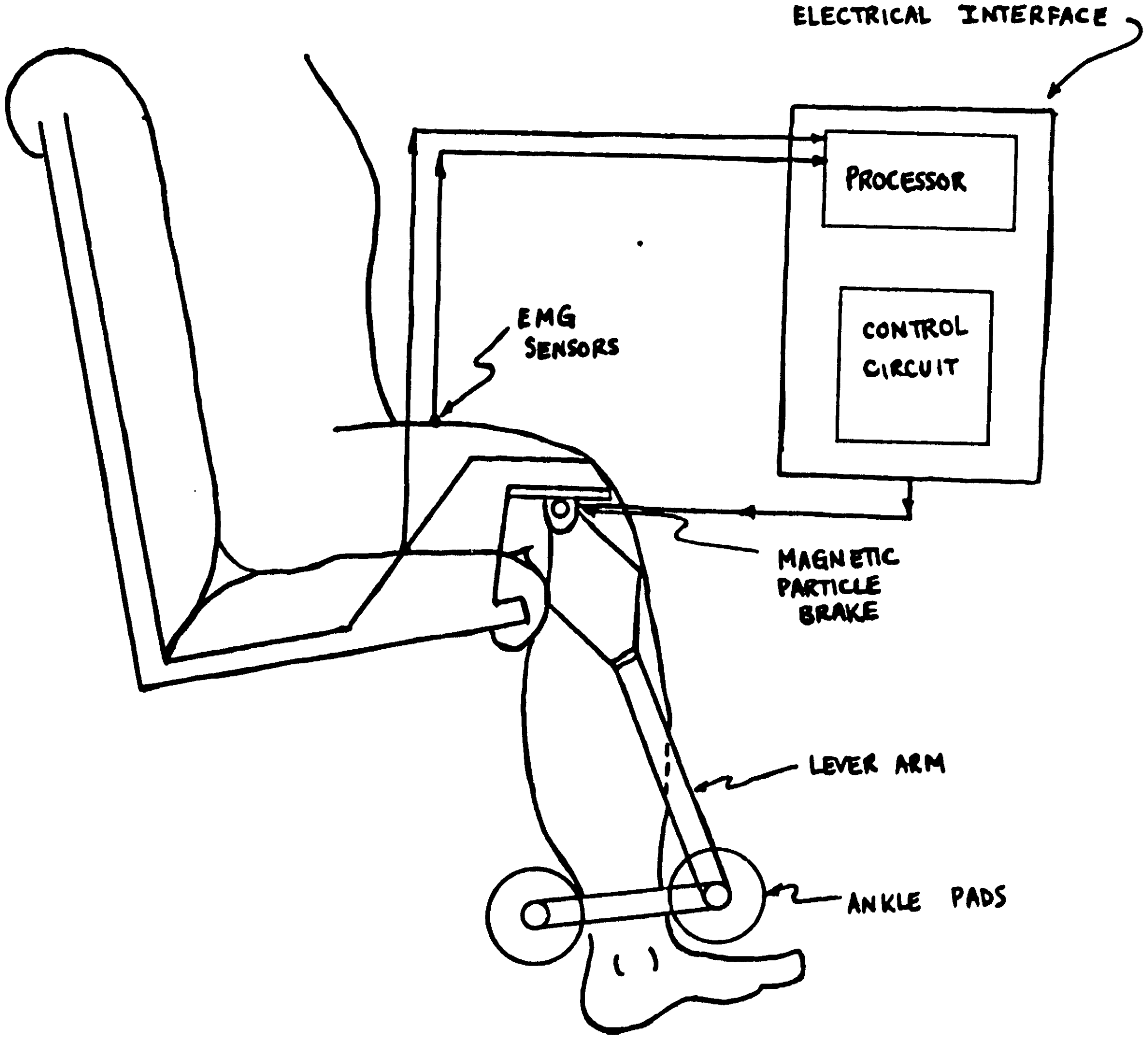

Figure 1.: Illustration of experimental set-up

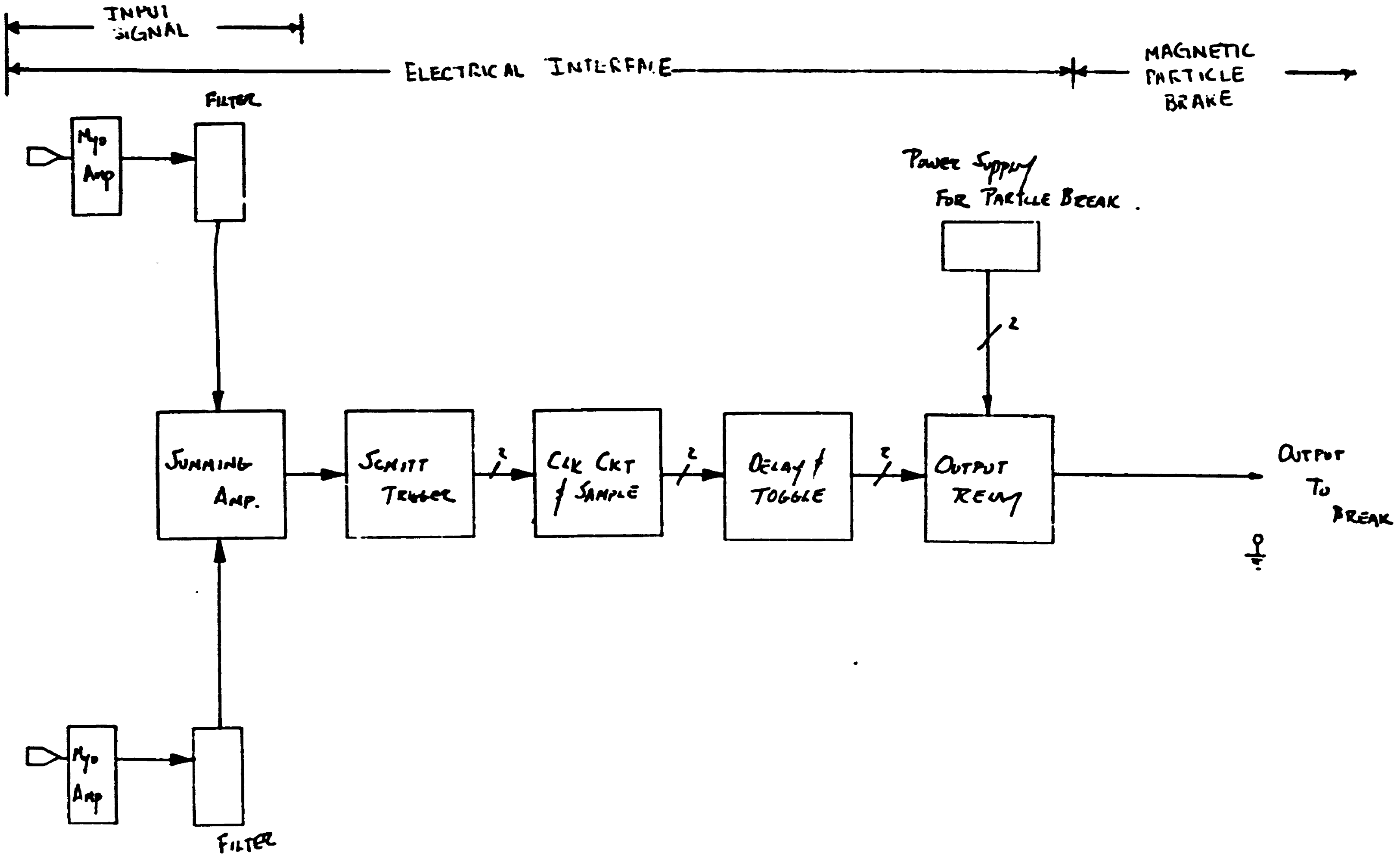

Figure 2.: Block diagram for control

to the magnetic particle brake. The following sections will discuss the various functions of the design of the exerciser.

3.1. EMG

Skeletal muscle contraction is affected by an ionic depolarization wave which is propagated along muscle fibers. The resulting electrical activity is known as myoelectric activity, or more commonly known as E.M.G. (ElectroMyoGram). This action potential of skeletal muscles may be detected by electrodes placed on the surface of the skin or through needle detectors inserted into the muscle.[1] Theoretically, the amplitude of EMG is related to the square root of the force exerted.[3]

For the purpose of this project, the major elements used in receiving the myoelectric signals are the surface electrodes, the myoprocessors, and the summing amplifier. The surface electrodes placed on the skin directly above the muscle provide intimate contact with the potential field of the muscle.[1] The signals are then sent through a myoprocessor and a summing amplifier, which will be discussed later in section 4.3.

3.2 Magnetic Particle Brake

The magnetic particle brake used for this project is actually a component of the "Lampe knee" which was designed by David Lampe (MIT 1976). The Lampe knee is shown in figure 3. The magnetic particle brake itself has the following characteristics:[2]

Size- Right circular cylinder: 2.1 in. dia
x 1.75 in. high.

Weight- 1.3 lbs.

Response Time- 10 ms. to rated
torque (25 in-lbs).

Torque Range- 0 to 40 in-lbs at 5000 rpm.

Power- 0 to 400 ma at 24 v.

Figure 4 shows a characteristic curve of the torque as a function of current. For the purpose of this project, we will assume a linear section of the curve between 0 to 25 in-lbs. So the following assumption will be made: The output of the magnetic particle brake has been amplified through a particular gearing arrangement. Thus, the resulting torque range of the Lampe knee with a gain of 7.5 is now 0 to 300 in-lbs.

3.3 Electrical Interface

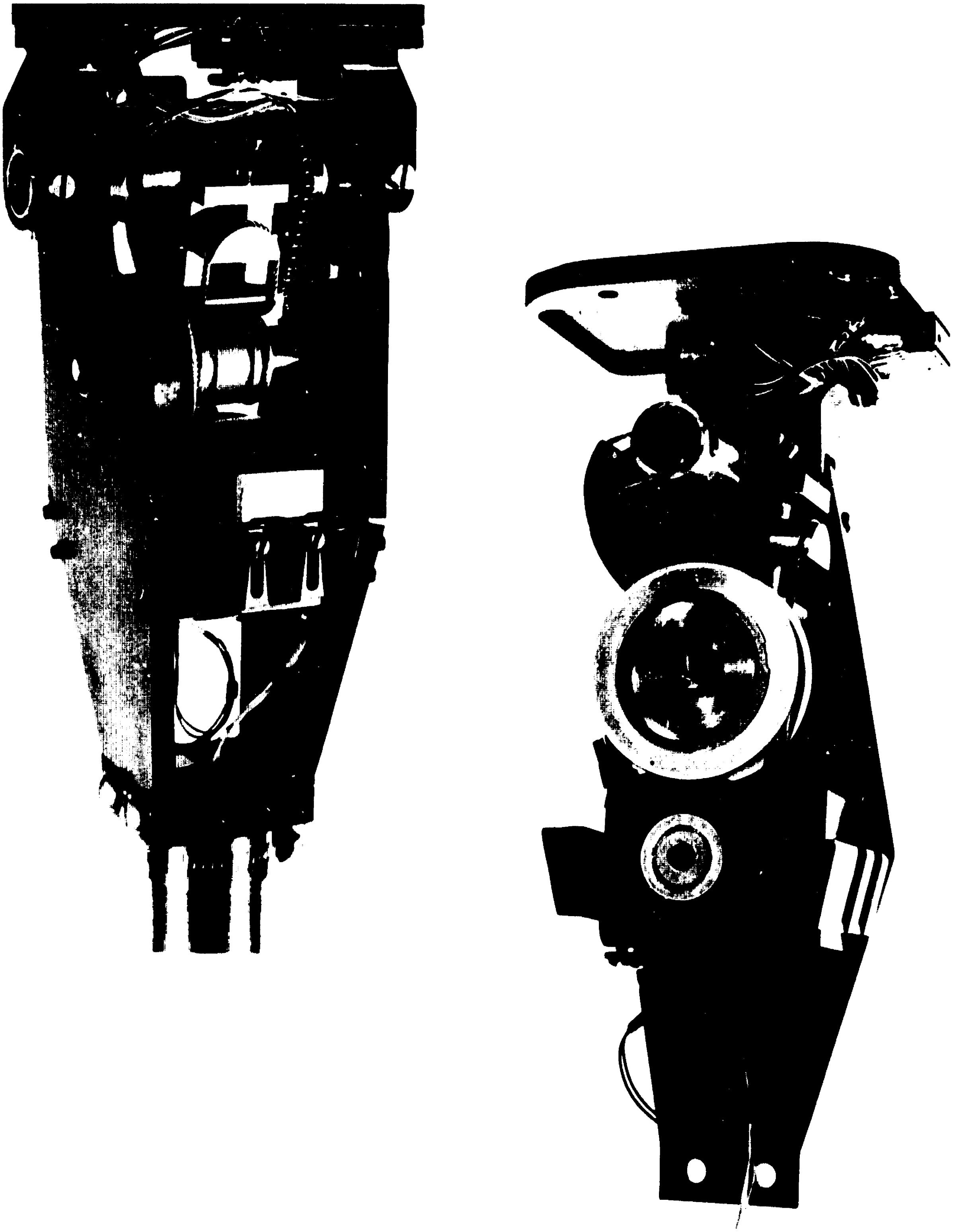

Figure 3. Magnetic Particle Brake - a component of the Lampe knee.

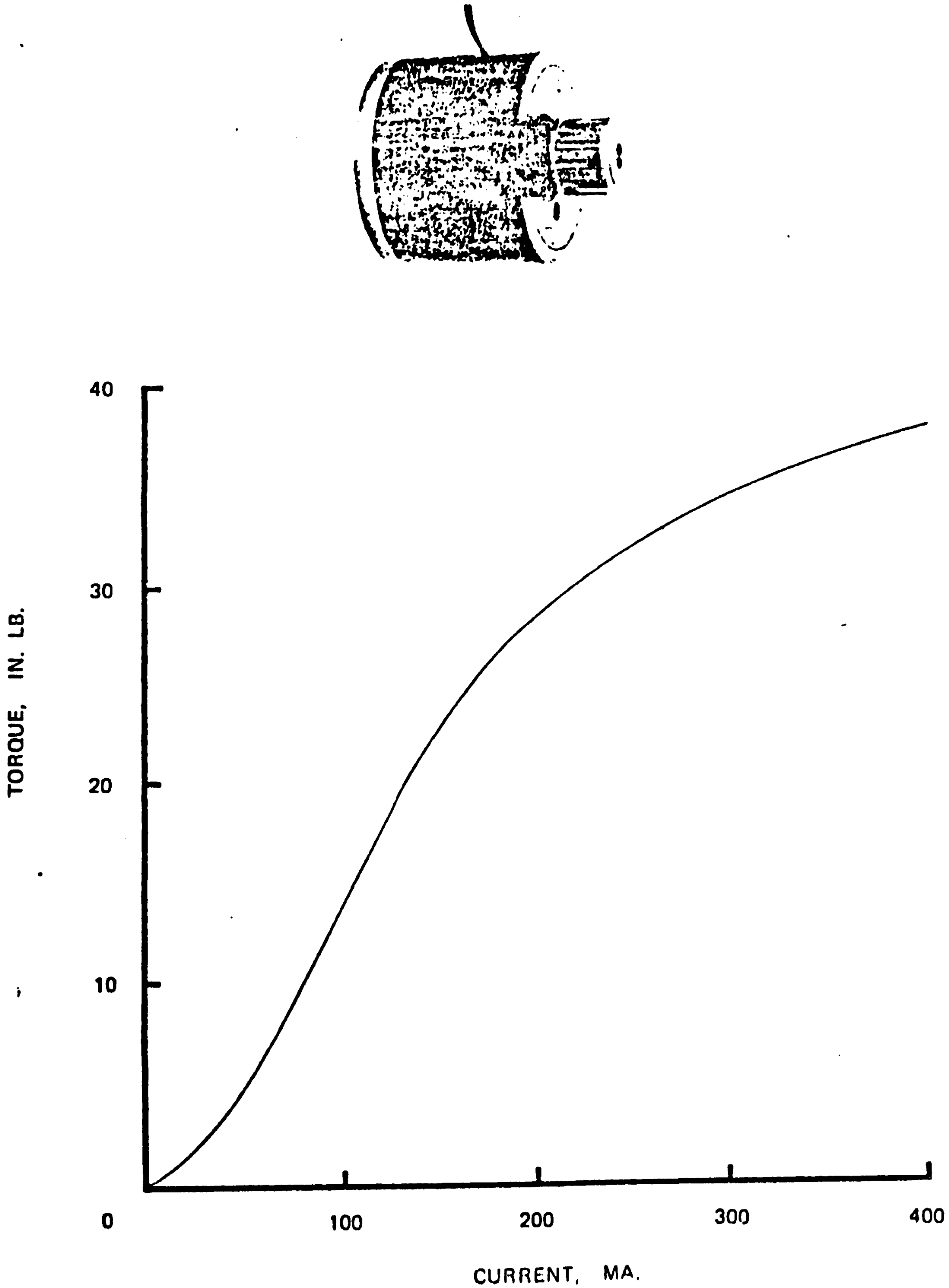

Figure 4.: Characteristic curve of the MPB- Torque vs. Current.

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3.3 Electrical Interface

The hardware necessary to implement the biofeedback controller is discussed in this section. A flow chart for the controller is shown in figure 5. Recall from figure 2 that the biofeedback controller receives as input the signals from the two EMG sensors, and outputs the control current for the magnetic particle brake. In order to design the biofeedback controller, several assumptions must be made as to the operation of the circuit.

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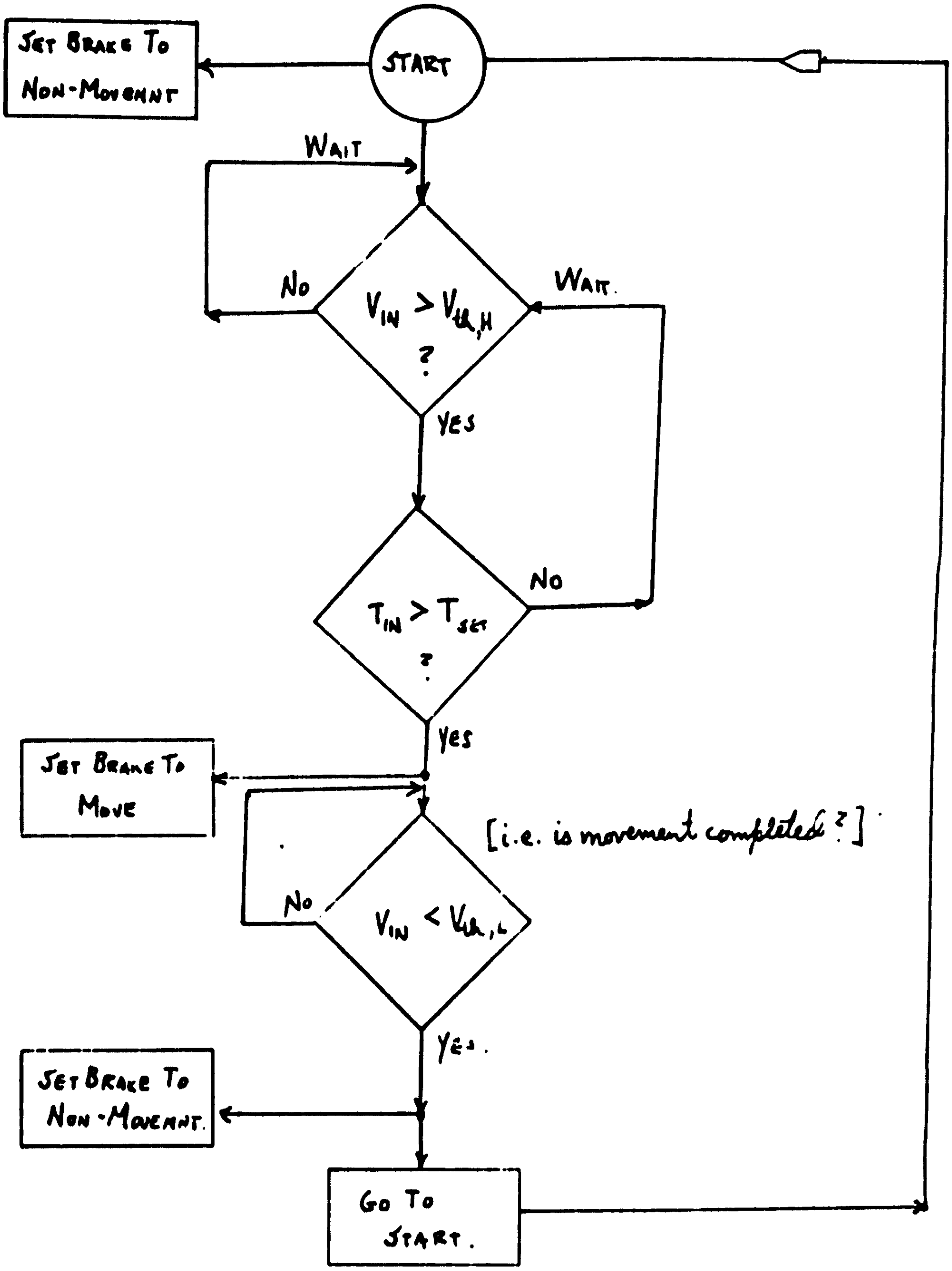


Figure 5.: The control mechanism of the knee exerciser.

i) Due to the nature of muscle-pairs (i.e., flexor and extensor pairs), it is assumed that the flexor and extensor will never be used at full capacity at the same instant. This implies that the total output voltages from the EMG sensors will primarily come from one muscle, either the flexor or the extensor.

ii) The particle brake will be operated in a binary fashion, using only two modes:

Mode 1: The particle brake is given a high current, such that the user is not allowed to move the restraining lever-arm at all.

Mode 2: The particle brake is allowed to move at a force level determined by the user and/or the user's trainer.

Using these assumptions, let us begin the design of the biofeedback controller.

3.3.1. Myoprocessor Amplifier/Filters

Looking again at the block diagrams, note the the EMG sensors are fed into the

Myofeedback Amplifiers. The Myo/Amp is used to do initial filtering, amplification, and rectification of the signal that comes from the EMG sensors.

Figure 6 illustrates the function of the Myo/Amp. The resulting smoothed and rectified signal is passed to the next part of the circuit, the Summing Amplifier.

3.3.2. The Summing Amplifier

The Summing Amplifier is used to add together the outputs from the Myo/Amp, in order to consolidate the signals that come in from the EMG sensors. This allows the flexor and extensor pair to use the same control circuitry.

3.3.3. The Schmitt Trigger

The Schmitt Trigger is used to differentiate between the voltage that is used to allow movement of the magnetic brake, and the voltage used to reset the magnetic brake after the user has completed either a full extension or flex. In addition, the output from the EMG sensors reflect the signals that are being used to control the user's leg movement, and as such, are noisy and erratic. In addition, the hysteresis band, (High-threshold-voltage - Low-threshold-voltage), provided by the Schmitt Trigger gives good noise

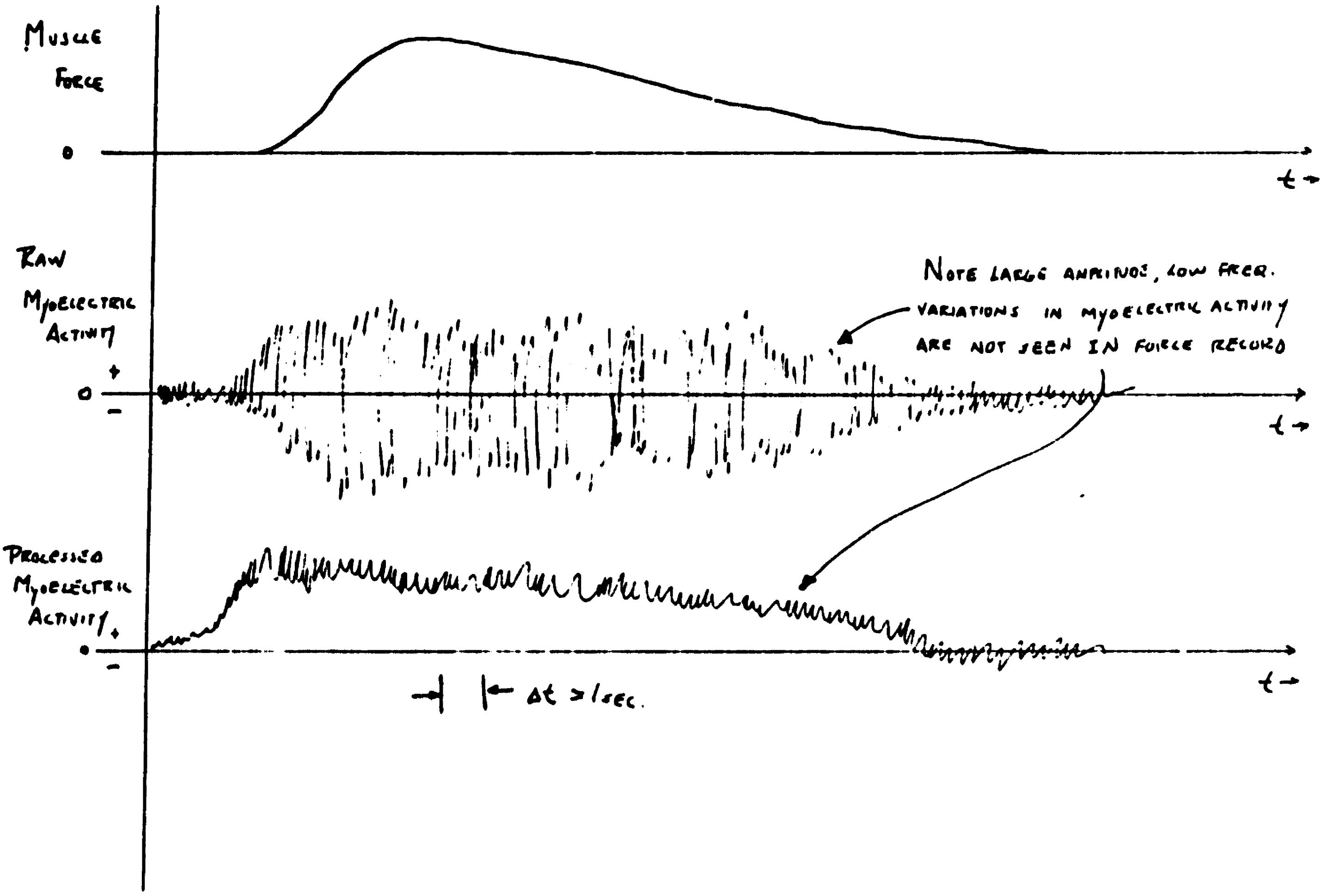


Figure 6.: The action of the Myo/Amp

immunity to the erratic signals that are received from the user's EMG sensors. An example of the hysteresis band in shown in figure 7.

3.3.4. The Clock and Sample Circuit

This portion of the circuit is used to sample the output of the Schmitt Trigger and determine whether or not the user has exceeded the specified high pressure threshold for the required amount of time. If the Schmitt Trigger shows that the high threshold has been exceeded, then the clock circuit tests to see if the input force is held above the threshold for the specified amount of time. If these conditions are both true, then control is passed to the Delay and Toggle circuit. In addition, this portion of the circuit also checks to see if there is a need to reset the particle brake to a no-movement condition, asuming the user has completed a complete extension or a complete flex.

3.3.5. Delay and Toggle Circuit

The Toggle Circuit in effect changes the state of the magnetic particle brake to Mode 2, allowing the user to move the lever arm until the lever arm reaches the limit of its travel.

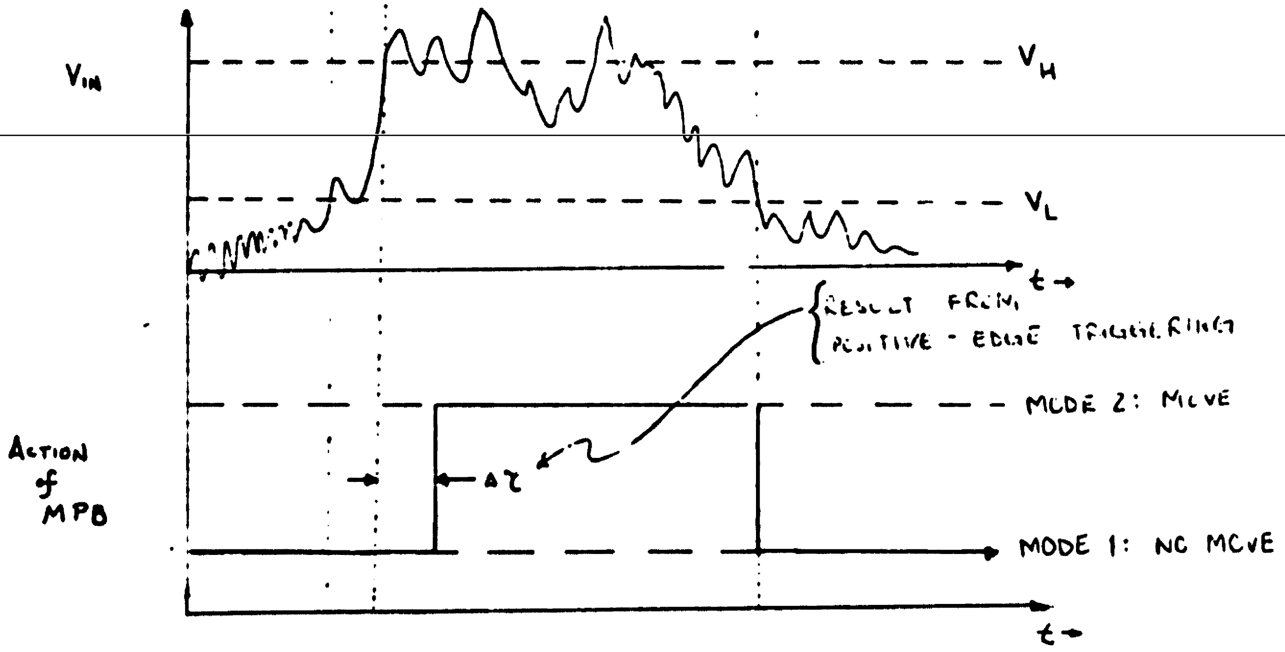


Figure 7.: Example of hysteresis band

3.3.6. Output Relay

The Toggle Circuit feeds directly into a magnetic relay that is used to control the amount of current that is sent to the particle brake to allow movement or no-movement.

3.3.7. Realization of the Circuit

Figure 8 shows the circuit realization of the circuit described in the preceeding section. All of the components and design techniques are in standard use, so I will concentrate on pointing out the unique aspects of the system.

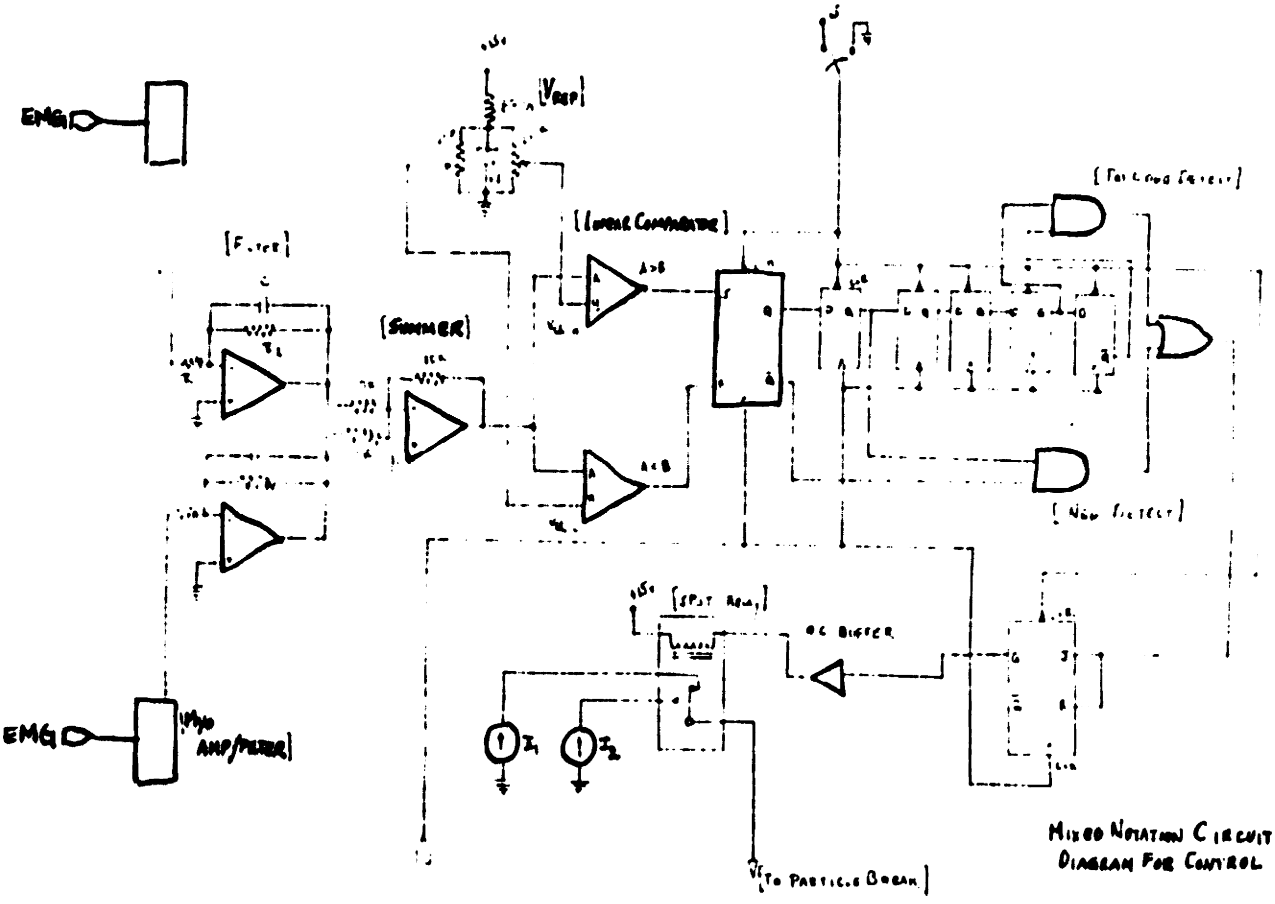


Figure 8.: Circuit diagram for control

1) Control of High and Low Muscle Effort Thresholds: Because two independent linear comparators have been used, the reference voltages for the two threshold levels can be changed independently. This allows adjustment band width and the effort needed to set off the timing mechanism.

2) Control of the time needed before movement of the particle brake is allowed: Because the control circuit is synchronously clocked, the clock cycle can be changed from a few fractions of a Hertz to several Hertz, to alter the response time of the circuit and to alter the time/effort product for each person.

3) Control of the Resistive Torque of the Particle Brake: Because the settings of I1 and I2 can be altered, the amount of resistive torque that is generated in Mode 1 and Mode 2 can be directly controlled.

4. Experimental Results

The parameters chosen for this experiment are as follows:

$V_L = 1V$

$V_H = 4V$

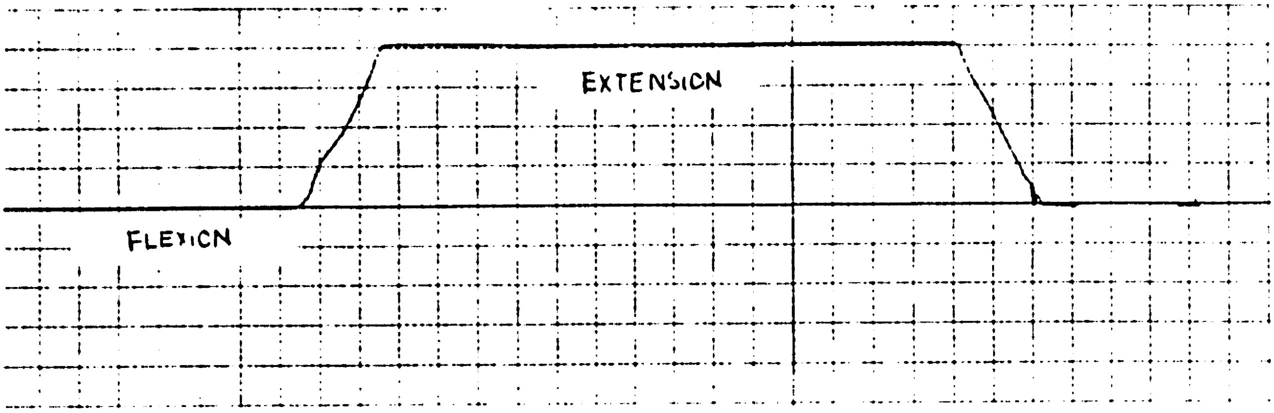
$i_L = 20$ ma

$i_H = 40$ ma

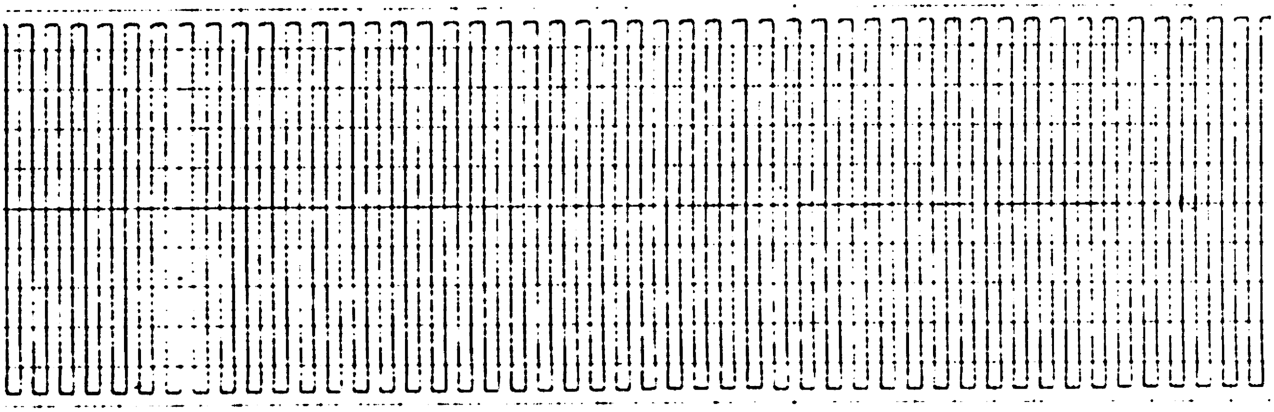
$C_c = 2$ Hz

where V_L and V_H are the low and high thresholds for the myoelectric operating range, i_L and i_H are the low and high current levels which determine the low and high resistive torque output of the system, and C_c is the clock cycle setting. The i_L and i_H correspond to torque levels of 15 in-lbs. and 30 in-lbs.

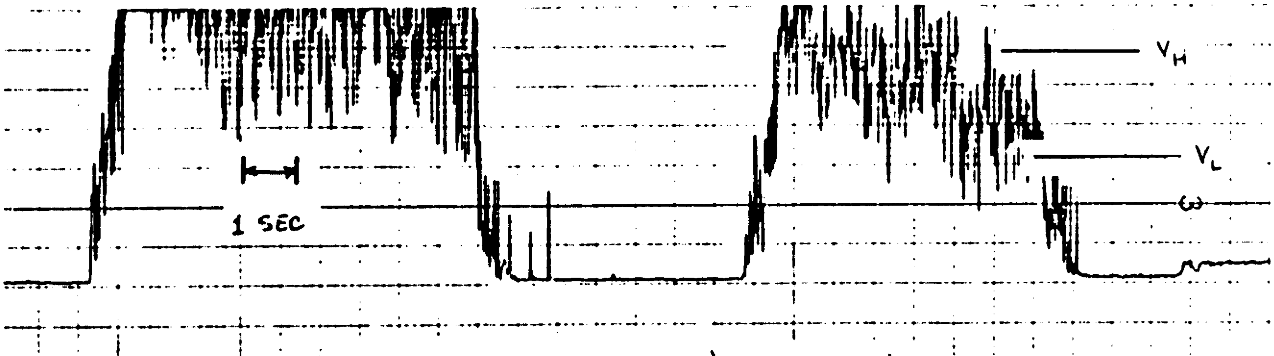
A Gould Recorder 2400 4-channel strip chart recorder was used to provide a visual record of the output of the knee exerciser. Figure 9 is a synchronous mapping of the knee exerciser (flexed or extended), the clock cycle, and the output of the summing amplifier. A position slope in the exerciser output maps the full extension of the knee. Likewise, the negative slope reflects the activity of the extensor.



(a) MPB POSITION



(b) CLOCK CYCLE (2Hz)



(c) EMG (SUMMED & AMPLIFIED)

Figure 9.: Experimental results- a map of MPB position, clock cycle,and EMG activity.

The output of the knee exerciser is a distinct correspondence to muscle activity. The transitions between the fully-extended and fully-flexed states of the biofeedback controller are triggered only by high muscle activity maintained for 2.5 seconds (5 clock cycles at 2 Hz) above V_H. The mode of the particle brake remains constant when muscle activity is low.

5. Conclusions and Recomendations

The myoelectrically-controlled knee exerciser is highly flexible and controllable to suit the needs of its user. The unique aspects of the system include:

1) control of high and low muscle effort thresholds
2) control of the time needed before movement of the particle brake is allowed
3) control of the resistive torques of the particle brake.

The major problems encountered in the project included:

1) significant disturbances to the system resulting from cross-wiring of the circuit
2) insensitivity of the surface electrodes due to impedance of the skin and possibly quality control of the device
3) the desired torque output exceeding the capacity of the system components.

6. References

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