DEVELOPMENT AND EVALUATION OF EXTERNALLY POWERED UPPER-LIMB PROSTHESIS [a]
SUMMARY OF RESEARCH PROJECT ACTIVITIES
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This progress report covers the engineering design and development of basic components for the servo-controlled external power unit for upper-limb prostheses. The overall objective of this Veterans Administration-sponsored research is to develop and evaluate a servo-controlled external power unit which could be used to move any single articulation or any two articulations of a conventional upper-limb prosthesis without limiting the number of styles or sizes of terminal devices or other components which might be used as part of the total prosthesis. In addition, applicability of this concept to orthotic braces and other special purpose terminal devices would be investigated.

Overall progress on this Veterans Administration work statement is proceeding on schedule. Design, fabrication, and engineering evaluation of the basic power pack system are approximately 80 percent complete. Amputee evaluation is expected to be conducted during the February-June 1970 period.

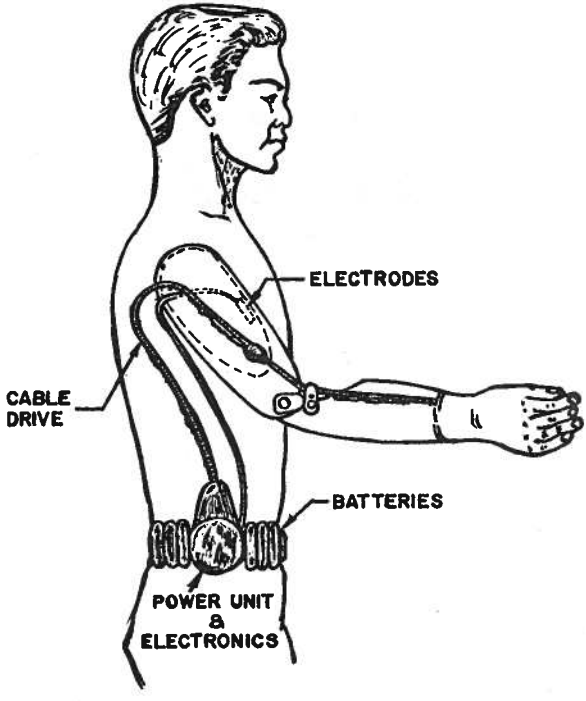
PROSTHETIC CONTROL SYSTEM

The basic system under development is the single control site/proportional control "power pack" system described in Reference [1]. It is believed that one servo-controlled external power unit such as shown in the illustration in Figure 1 will be capable of operating conventional terminal devices in addition to providing wrist rotation and elbow flexion capabilities for above-elbow amputees.

The major components of the system are:

1. the electrode (sensor) assembly,
2. power unit/cable drive system,
3. electronic control circuits, and
4. battery pack.

[a] Based on work performed under VA contract.



TYPICAL "POWER PACK" SYSTEM UTILIZATION

FIGURE 1

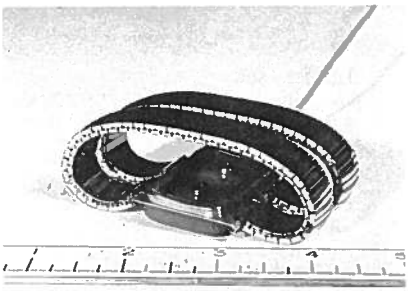
The status of development of each of the above components is as follows:

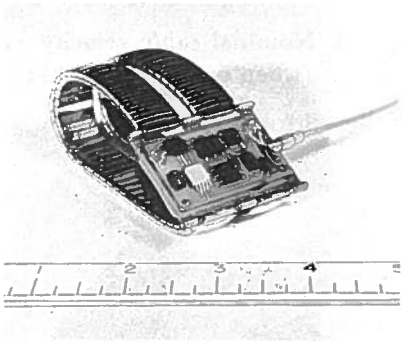
1. The Sensor Assembly

The sensor consists of two stainless steel surface electrodes which make contact with the skin over the muscle at a single control site. The preamplifier was designed as an integral package with the sensor in order to minimize 60 cycle pickup and provide a proportional signal for control of the servo power unit. A dynamic range of over 20 to 1 has been achieved on the experimental models under rather severe 60 cycle environment in the electronics laboratory.

Two EMG sensor units of the configuration shown in Figures 2 and 3 were fabricated and tested. One of these units was delivered to JHMI for mounting in the stump socket of the first amputee who is to evaluate the JHU system. An experimental version of the sensor and a battery/detector/meter test unit which were supplied to JHMI were

used to determine if signals from amputees were satisfactory for use in control of prosthetic systems of this type. The sensor was fitted on the stumps of several amputee subjects. Signals were consistently large enough in amplitude and had suitable signal-to-noise ratios. Complete technical details and performance of the sensor are documented in Reference [2].





2. Motor Package/Cable Drive System

The design concept selected for the remote power pack unit is based on the use of a low speed, high torque d.c. motor to provide a force to pull the Bowden cable. Since the terminal device is spring loaded, the motor is not required to drive in the reverse direction. Some of the important considerations which led to the selection of this motor drive/concept include the following:

a. The required gear train for this type of motor is approximately 15:1. The low gear ratio provides a simple mechanical design which is expected to create less gear noise and have less wear than a high speed gear box.

b. The d.c. torque motor is capable of delivering the required operating torque for long periods without overheating. No clutches or mechanical stops are required in the motor assembly.

c. Operation of the motor such that it provides unidirectional torque results in simplified electronic controls and results in minimum consumption of battery current. One control transistor is required instead of the usual four found in a typical bidirectional motor drive amplifier.

d. The operating life of the unit is expected to be in excess of 5 years at 200 cycles/day. High reliability is a design requirement for this unit.

Some of the more important characteristics of the power pack unit shown with the battery pack and electronics module in Figure 4 include:

a. Weight:	1.3 lb.	power pack only
b. Size:	4 x 2-9/16 x 1-3/4 in.	power pack only
c. Max. operating force to cable:	30 lb.	
d. Nominal cable velocity (when operating hook) :	1.5 in./sec.	
e. Stroke:	4.6 in.	

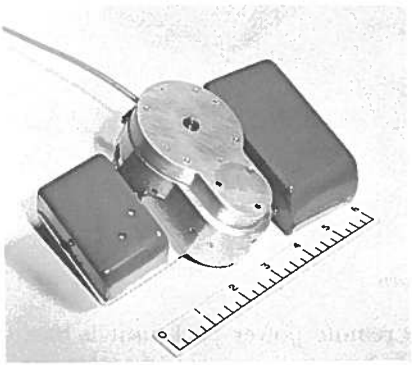


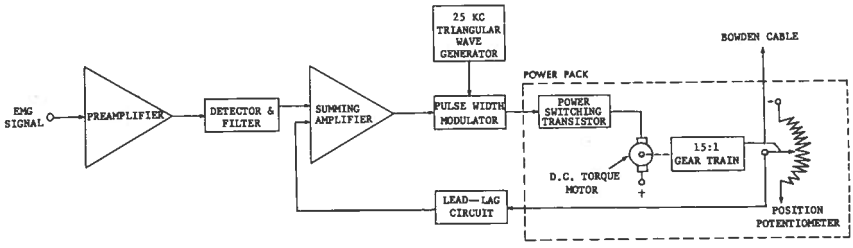
FIGURE 4

The efficiency of the cable drive system is an important factor in minimizing power consumption of the system. Limited life cycle testing has been done on a mechanized tester on three types of cable assemblies under typical load and installation conditions. Results from this testing has led to the tentative selection of a Teflon coated cable in a nylon liner for the initial amputee evaluation testing of the prosthetic control system.

3. Electronic Control Circuit

The prosthesis is to be operated as a proportional system. This provides smooth yet responsive control for the terminal device and/or elbow operation. A block diagram of the control loop is shown in Figure 5. The system is basically a rate servo with position feedback at low frequencies.

In order to minimize electrical power consumption, particularly when the control voltage is not commanding the motor to pull the control cable, a pulse-width modulation system is used to control the motor output torque. The pulse-width converter stage utilizes the 25 kH output of the triangle wave generator and the output of the servo amplifier



SCHEMATIC DIAGRAM-PROPORTIONAL SERVO CONTROLLER FOR UNIDIRECTIONAL TORQUE MOTOR

FIGURE 5

stage to provide a pulse-width modulated signal which regulates the motor current. By operating the output transistor in a switching mode, relatively little power is dissipated in the electronics package. When the electrodes are not sensing an EMG signal, standby current consumption of the servo sensor electronics is less than 20 ma. No mechanical switches or special power cutoff relays or circuits are required to switch from "standby" to "operate" condition.

4. Portable Battery Pack

As of December 1, 1969, development of the engineering model of the prosthetic "power pack" had progressed to the point where meaningful tests could be run to determine how many times the terminal device could be operated before the batteries had to be recharged. It was understood that the Veterans Administration considers 250–300 operations per 10-hour day to be a reasonable goal. It is desirable that the battery pack be capable of storing enough energy to operate the prosthesis for a full day without recharge.

A photograph of the test prosthesis used for battery life cycle testing is shown in Figure 6. For these tests the operator controlled the hook by utilizing electrodes on his forearm. The forearm muscles were contracted to control the opening of the hook. Two rubberbands were used on the voluntary opening Dorrance hook. Pinch forces of 5 and 7 lb. were developed at the tines with openings of 0 and 1 in., respectively. With his other hand, the operator placed objects between the tines of the hook. Five objects (measuring 3, 2, 1-¼, ½, and 3/32 in.) were grasped sequentially. Objects of different sizes were used to simulate everyday activity.

The results from these tests, which were repeated several times, indicated that approximately 600 operations are provided by one charge of 12 penlight cells. This appears to be adequate for one day's usage.

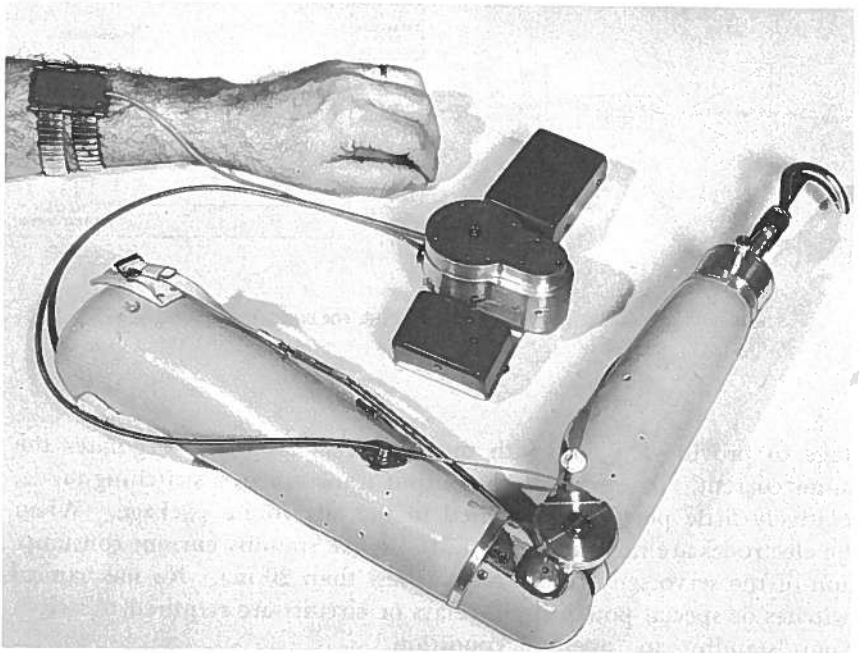


FIGURE 6

FUTURE PLANS

Plans have been formulated to evaluate three power pack systems on amputees during the period February to June 1970. An amputee has been selected for the initial test and has been fitted with a prosthetic socket containing the EMG sensor as shown in Figure 7. Complete fitting of the power system on this amputee will be accomplished early in February.

Concurrent with the development of the basic power pack for the control of terminal device opening and elbow flexion-extension, a limited amount of work has been conducted on control of two functions with a single EMG control signal. Wrist rotation in combination with the grasping function of the hook was the subject of this initial study. Preliminary results from these studies indicate that dual mode control from a single EMG site is possible and should be further exploited.

REFERENCES

1. Seamone, W. and C. H. Hoshall: A Single Site Myoelectric Control System for Prostheses. Paper presented at the Third International Symposium on External Control of Human Extremities, Dubrovnik, Yugoslavia, Aug. 1969.
2. Konigsberg, R. L.: Electromyographic Sensor Design for use with Externally Powered Prosthetic Arm, APL/JHU Report, MS-175, Feb. 1970.

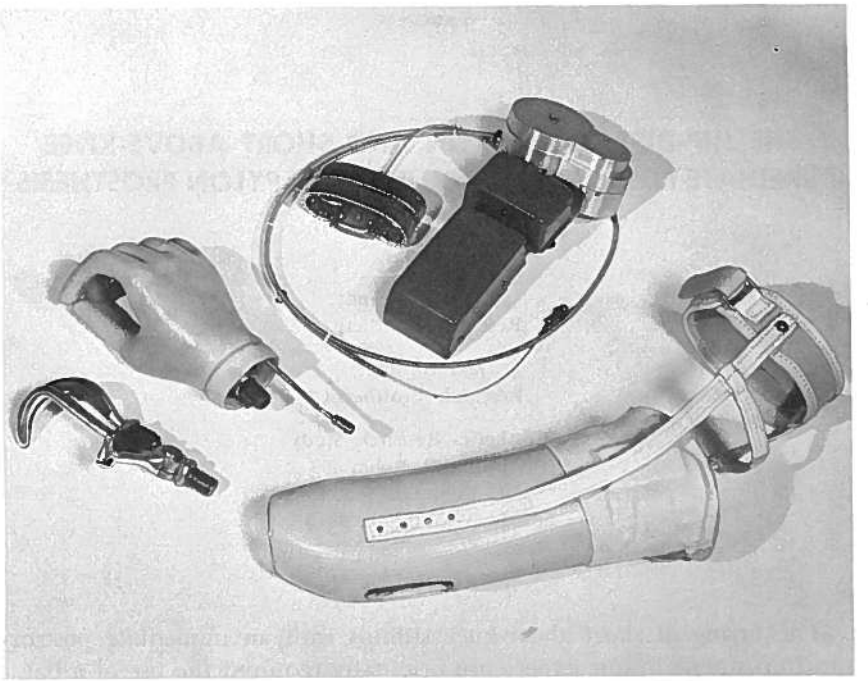


FIGURE 7