DEVELOPMENT of a MYOELECTRICALLY-CONTROLLED PROSTHESIS

When muscles contract they produce minute electrical potentials that usually exist for a few milliseconds. The potentials produced by the voluntarily-controlled muscles of an amputee should, in concept, be ideal control signals for prostheses. A prosthesis that responds to muscle contraction in the same way that the replaced part of the body responded could be used "naturally" with a minimum of retraining.

Muscle EMF's are called *myoelectric* (or "action") potentials (*myo* is derived from the Greek myos for muscle). Electrical volume conduction of these potentials through body tissue and fluids results in potential differences that can be sensed on the skin. Myoelectric potentials measured on the skin are much attenuated relative to the amplitude of the "signals" at their point of origin in the muscle. They are composite signals from many muscle fibers. Surface electrodes in contact with (but not penetrating) the skin are used for prosthesis control despite the smallness of the signal and its composite nature because of the formidable problems encountered in the use of percutaneous electrodes for any length of time.

The myoelectric signals acquired on the skin cannot be precisely described because they are affected by many factors. Among these are: (1) muscle type, function, and condition (including fatigue); (2) characteristics of the tissue, bone, and skin that lie between the muscle and the electrodes; (3) electrode material, surface texture, geometry, and spacing; and (4) the location of the electrode relative to the muscle. However, some characteristics of the myoelectric signal acquired on the skin are typical. These are: (1) the signal is an AC voltage that is roughly proportional (in amplitude) to the force developed by the muscles that generate it; and (2) the power spectrum is such that the major portion of the power lies between 30 and 500 Hz. Signal amplitudes on the order of 100 microvolts RMS are typical for healthy muscles developing modest tension. Paralyzed muscles often produce myoelectric voltages, but their amplitude is much lower than for healthy muscles. Some prostheses that are controlled by myoelectric potentials are unsatisfactory because of difficulties encountered in obtaining signals that are both sufficiently large in amplitude and relatively free of noise and "crosstalk." Crosstalk results when unwanted signals produced by antagonist (and other) muscles are sensed along with the desired signals.

An electrically powered artificial hand and control system has been designed and fabricated at the Applied Physics Laboratory. This closed-loop system (Fig. 1) comprises a servo operated hand, signal acquisition electrodes, signal amplifiers, a servo amplifier, power control circuits, and a battery pack power supply.

The APL system differs from open-loop systems that are presently in use in that electrodes are

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placed at only one site. Problems from signal crosstalk between different electrode sites are thus completely obviated. This system duplicates the operating characteristics of a voluntary opening hook. Cosmetically, the artificial hand is far superior to the hook. Problems attendant to harnessing and control cable routing are minimized. The servo control system is designed so that the hand opens in approximate proportion to the amplitude of the myoelectric control signal. Other single site closed-loop prosthetic systems that are now in use or being developed require that the user deliberately sequence or control the system to control the position of the fingers. Such mode switching is not required with the prosthesis developed at APL, and in this respect it more closely duplicates the action of the natural hand it replaces.

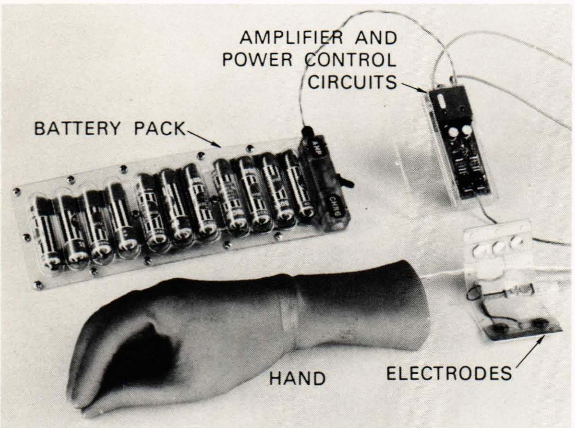

Fig. 1—Myoelectrically controlled artificial hand.

The hand, shown in Fig. 1, is driven by a small motor inside a metal shell. The shell is from an Army Prosthetics Research Laboratory—Sierra mechanical hand from which the internal mechanism and the actuated fingers and thumb have been removed. A gear reduction and lead screw mechanism designed at APL operates the thumb in opposition to the fore and middle fingers. The operating fingers are made of silicone rubber that is cast on "skeletons" made of aluminum. The hand is relatively rugged. Because of the silicone rubber, it is superior to cast plastic hands for picking up objects of small diameter. The resiliency of the silicone rubber also minimizes loss of grip resulting from structural deformation of the fingers. The hand is covered with a realistic looking cosmetic glove.

A block diagram of the system is shown in Fig. 2. The myoelectric signal is acquired by stainless steel button electrodes that are held in contact with the forearm. The electrodes can be placed in close proximity to either the flexor or extensor muscles that control the fingers. One integrated circuit operational amplifier is used in the preamplifier. The circuit has a gain of approximately 2000. The output signal from the preamplifier is amplified by an additional stage before it is detected. Over the operating range of the system, the DC output of the detector is roughly proportional to the amplitude of the input signal.

The output of the detector is applied to a servo amplifier that controls an electric drive motor in the hand. With the muscles relaxed, and minimum control signal, the hand is in its closed position. With the muscles tensed, the electrodes pick up a control signal. As the control signal increases, the servo amplifier drives the motor, opening the hand. The hand continues to open until the voltage on the wiper of a potentiometer driven by the lead screw follower in the hand is equal to the control signal. The hand is servo controlled for all positions between closed and full open.

The power control circuits operate from the error signal in the servo amplifier. If the hand closes fully or is stalled when it grasps an object, power is automatically disconnected from the servo amplifier. It is these power control circuits that enable the hand to operate like the voluntary opening hook. Additionally, power consumption is greatly reduced. This is very important in systems that must operate from portable power sources.

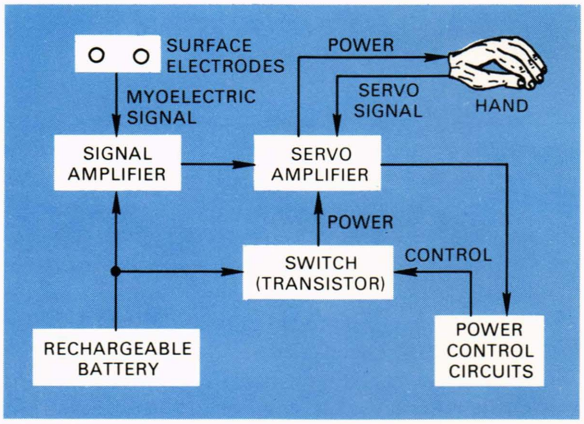

Fig. 2—Block diagram of servo-controlled prosthesis.

The hand weighs approximately 18 ounces. It develops a "grip" of approximately five pounds at the finger tips. This is sufficient for many of the tasks performed in normal everyday activity. The fingers open or close in approximately 0.9 second. Maximum opening between the fore and middle fingers and the thumb is approximately 3 inches.