BIOELECTRICALLY CONTROLLED ARTIFICIAL HANDS

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The development of bioelectrically controlled artificial hands has become a possibility due to the emergence of an entirely new trend in artificial limb making, which relies on advances in electrophysiology, biomechanics, semiconducting electronics and automatic control.

A lot of research and experimental work has been done in the Soviet Union to develop a number of artificial upper limbs equipped with an external source of energy for driving micromotors mechanically geared to the prosthesis mechanisms. The micromotors are controlled at the amputee's will by means of bioelectrical action potentials picked off his skin and amplified.

The development of bioelectrically controlled artificial limbs called for the solution of the following problems:

1. the choice of muscles for bioelectrical control and the development of training procedures;
2. the design of reliable skin electrodes for picking up action potentials;
3. the development of miniaturized units for amplification and conversion of action potentials;
4. the development of small-sized, sufficiently powerful and low-noise drives;
5. the selection or development of small-sized storage batteries of sufficent capacity;
6. the design of highly functional mechanisms of the hand and other parts of the prosthesis in keeping with the possibilities offered by bioelectrical control;
7. the development of rational systems of controlling several actuating mechanisms in highly functional prostheses.

These problems have for a number of years been studied at the Central Research Institute of Artificial Limbs and Limb Making of the Ministry of Social Maintenance, Russian Federation, (director of the Institute B.P. Popov), in the artificial upper limbs laboratory (under the direction of Y.S. Yakobson), in the bioelectrical control systems laboratory (under the direction of D.M. Ioffe), in the physiology laboratory (under the direction of Y.L. Slavutsky), and in the clinic (under the direction of L.M. Voskoboinikova).

The manufacture of bioelectrically controlled forearm prostheses commenced at Soviet artificial limb making enterprises in 1963 and since then the number of such enterprises has been growing with every year. Above-elbow prostheses are being introduced this year. Preparations are under way to start production of bioelectrical artificial limbs of increased functional ability.

The latest model of the bioelectrically controlled forearm prosthesis with one pair of movements, prepared for wide introduction, has a number of improvements.

First, the prosthesis uses a hand with elastic finger coating. This feature improves the clutching function and increases the service life of the cosmetic coating. The central feature of the new model is that the electronic control unit is housed inside the prosthesis, owing to its further miniaturization. Thus, using this prosthesis the amputee is spared any discomfort from wearing the electronic unit in the clothes and from having to pull bulky amplifier wires through the sleeve.

A bioelectrical signal is amplified by three voltage amplifying stages. A ful-wave rectifier serves as a connecting link between voltage amplifiers and current amplifiers. In each of the two channels of the power amplifier an electromagnetic relay is mounted whose winding is connected to the load of the second stage of the amplifier. Relay contacts are commutated in such a way that when there is no signal in both channels at the amplifier input or when there are higher-than-threshold signals simultaneously at the input of both channels the motor is cut off from the power source.

When signals are separately fed to the input of one or the other amplifying channel, the motor rotates in the corresponding direction. The presence of an antagonist signal below the threshold level does not interfere with the operation of the actuating mechanism.

Figure 1 shows a block diagram of the forearm bioelectrical prosthesis.

Figure 2 shows a photograph of the forearm prosthesis with the control unit housed inside and the power pack worn on the shoulder. The power pack shown is one of the alternative designs of placing the storage battery. In this case all the units of the bioelectrical forearm prosthesis do not protrude beyond the exremity fitted with a prosthesis and the amputee is entirely free from the burdensome wires.

The force of finger grip, plus effect of additional clutching, can be brought to four kilogrammes. The hand weighs 350 grammes.

An alternative of the bioelectrical forearm prosthesis, which is also used in practice, is a prosthesis for fitting the long forearm stump, whose residual pronation and supination are employed for active rotation of the hand. Proper training ensures that the movements of fingers controlled by bioelectrical currents of the stump muscles and the hand rotation are independent of each other.

The development of the forearm prosthesis was followed by the more difficult task of developing a bioelectrically controlled upper arm prosthesis. The difficulties are in particular due to the fact that the elbow bending of the prosthesis is accompanied by the raising of the forearm, which requires far greater power than the movement of fingers and the clutching of an object.

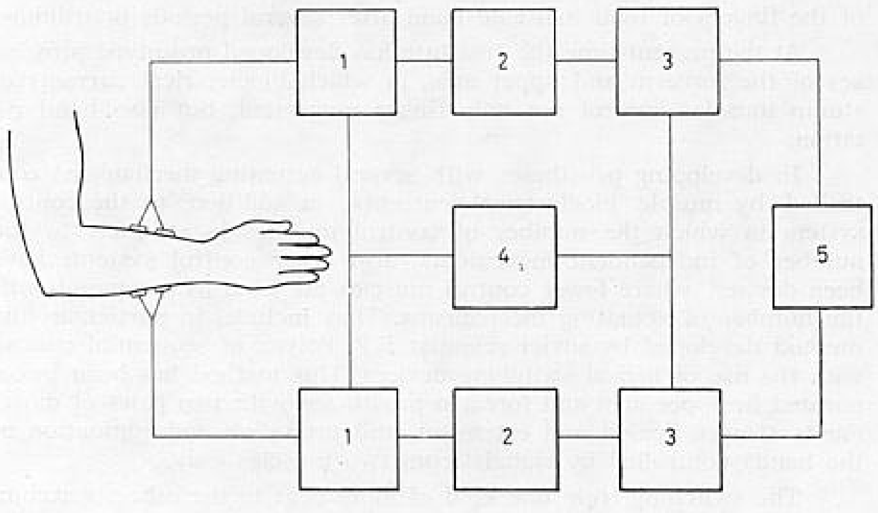

Figure 1. Block diagram of a bioelectrically controlled forearm prosthesis. 1 — voltage amplifier, 2 — rectifying device, 3 — power amplifier 4 — power pack, 5 — electrical drive for the hand mechanism

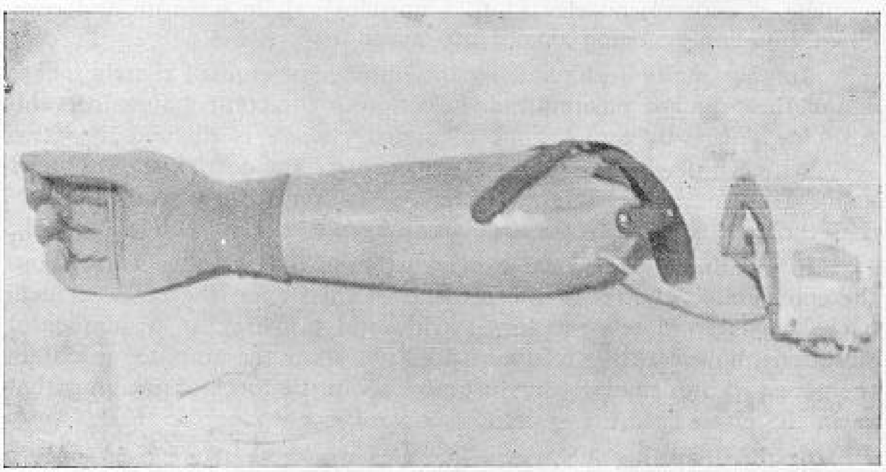

Figure 2. Bioelectrically controlled forearm prosthesis. The control unit is housed inside the prosthesis

To speed up the introduction of bioelectrical upper arm prostheses, an upper arm prosthesis with combined controls, bioelectrical and by linkages, was first developed, in which finger movement control was achieved by means of bioelectrical currents taken from the upper arm stump in any position, and the control of movement at elbow joints by means of mechanical links. The choice of control muscles and the elaboration of training procedures was preceded by continued research done by physiologists and medical specialists. Investigations and practical experience have shown that by means of bioelectrical currents taken from the upper arm stump, amputees can control the movement of the fingers of their artificial hand after several periods of training.

At the present time the Institute has developed prototype prostheses of the forearm and upper arm, in which bioelectrical currents of stump muscles control not only finger movement, but also hand rotation.

In developing prostheses with several actuating mechanisms controlled by muscle bioelectrical currents, in addition to the control system in which the number of control muscles is adequate to the number of independent movements, also other control systems have been devised, where fewer control muscles are used as compared with the number of actuating mechanisms. They include, in particular, the method developed by soviet scientist E.P. Polyan of sequential control with the use of logical switching devices. This method has been incorporated in upper arm and forearm prostheses with two pairs of movements (finger flexion and extension, and pronation and supination of the hand) controlled by signals from two muscles only.

The switching from one kind of movement to the other is accomplished by sending signals from both antagonist muscles simultaneously.

The principle of sequential control can also be examined with regard to a larger number of pairs of movement involving a limited number of control muscles (2 to 4 muscles), their separate and combined functioning being taken into account.

Another method of reducing the number of control signals makes use of the principle of amplitude selection of the control signal. In this case the entire dynamic range of signal change is divided into two sections, each of which is employed to control the corresponding movement. This method may find wide application with amputees where it is difficult to find two independent sources of bioelectrical signals.

In existing bioelectrical arm prostheses the amputee carries out the coordinated control of the prosthesis, chiefly, on the basis of feedback signals from telereceptors (vision and hearing). In a number of situations, however, this feedback does not allow the amputee to obtain the necessary information, for instance, about the force of gripping, that is, in the given case the system of control is not closed .

At the Institute, A.Y. Schneider has worked out a closed system of control which enables the amputee to exercise fine adjustment and »sense« the gripping system.

Vibratory stimuli were used as feedback signals to allow the amputee to assess the force of grip.

Comparative studies undertaken have shown it is most advisable to use frequency pulse local vibration in the feedback channel. A variable parameter of such vibratory pathway is the frequency of impulse generation, with the duration of impulses being constant. Experiments to elucidate differential thresholds of frequency impulse vibration have demonstrated that man has a very fine sense of discrimination of vibratory stimuli. This made it possible to choose such selectivity of the feedback system that the amputee could deliver the gripping force in increments of 150 to 200 grammes in the range from 0 to 1.5 kilogrammes.

Figure 3 shows a block diagram of a mock-up of a prosthesis with vibratory feedback.

Investigations have shown that the accuracy of adjustment of artificial systems approaches that of the gripping force exhibited by the fingers of a healthy hand. However, the time of control is longer, due to the increased time of processing and analysis of vibration signals.

Among technical problems of prosthesis design and construction facing scientists, great attention in the Soviet Union is paid to the problem of developing a multifunctional artificial hand for upper-extremity prostheses.

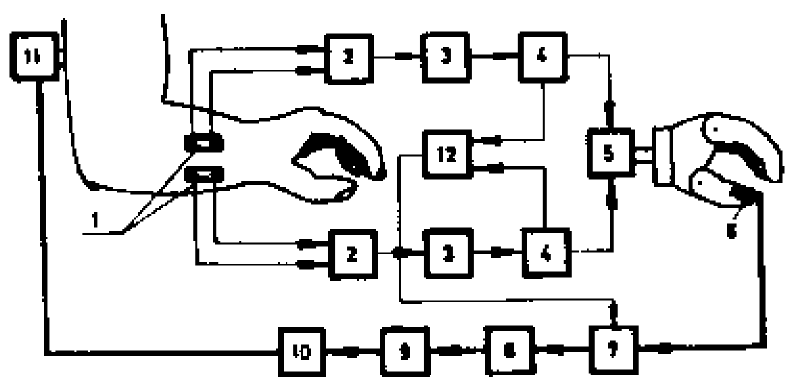

Figure 3. Block diagram of a prosthesis with vibratory feedback. 1 — skin electrodes, 2 — action potential (voltage) amplifiers, 3 — envelope discrimination block, 4 — power amplifier, 5 — electrical drive, 6 — pressure transducer, 7 — amplifier of a pressure transducer signal, 8 — block for conversion of continuous signals into pulse frequency signals, 9 — block for forming impulses of required duration, 10 — power amplifier for the vibrator, 11 — electromagnetic vibrator

Experimental prototypes of this hand have a mechanism incorporated in the palm, which ensures that each finger adjusts itself to the form of an object taken and that both finger and palm (fist) grip is possible.

The finger-adjustment mechanism makes it possible to hold tight objects and tools of most diverse form and size.

Fundamental research and practical experience of prosthesis design in the Soviet Union convincingly and graphically confirm that the ways of developing bioelectrically controlled artificial hands have been chosen correctly.