UPPER LIMB PROSTHESES WITH VARIOUS SYSTEMS OF MYOELECTRIC PROPORTIONAL CONTROL

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ABSTRACT

Below- and above-elbow prostheses using various myoelectric proportional control systems have been developed for the upper limb amputees. The below-elbow prostheses perform functions of grasp, hand open and hand rotation. The above-elbow prostheses perform the following active functions: grasp, hand open, forearm rotation elbow joint flexion-extension. Movement parameters of the prosthetic joints (grasp force, speed of elbow joint flexion-extension and of rotation mechanism) are controlled proportionally to the values of myoelectric potentials in the stump muscles. These prostheses apply the concept of sequential control of their terminal devices. The function to be performed by the prosthesis is selected by means of special commands composed either of control muscle myoelectric signals or position transducer signals, or combinations of these signals. This design of control systems enables to manufacture prostheses according to individual demands.

Electronic components of control systems include integrated microcircuits. Certain kinds of the control systems use microprocessors for processing myoelectric and position transducer signals.

Key words: multifunctional prosthesis, proportional control, grasp, hand open, forearm rotation, elbow joint flexion-extension.

The upper limb department of the Ukrainian Prosthetic Institute is developing new control systems and improving drives for the upper limb myoelectric prostheses with differential proportional control of several multifunctional prosthesis movements.

High level of amputation for the limb to be fitted requires increased reliability of the prosthesis, reduced power consumption, weight and demensions of certain components, putting forward the objective of unified alignment and design for the multifunctional prosthetic control system as well as for the whole prosthesis. Its technical complexity should be feasible for mass production by the prosthetic plants.

Increased functional range of prosthesis requires the functions performed by the prosthesis to be rationally discriminated into active and passive ones with respect to the level of amputation and medical proscription as well as the optimal organization of control for these functions. This reduces to the minimum psychophysiological efforts by the patient in control of the prosthesis and makes training and wear less tiresome.

Optimal control is considered to be the real time control of several terminal devices (TD) by the minimum number of muscles. At the same time the man-prosthesis interaction should be the easiest, providing physiological control thus keeping the good condition of the residual limb in continuous every-day use.

Easy and simple prosthesis operation with the minimum control muscles envolved is achieved by the sequential switching of the TDs.

Biomechanical analysis of the sound limb shows that there exist different ways of reaching the final objective of movement. Angular translations in the joints, speed of movement as well as the time of participation of certain limb segments in complex movements differ in different persons. Thus while attempting to simulate natural limb movements by the TD of a multifunctional prosthesis we arrive at necessity to create individual pattern of limb movements for every patient. In present industrial mass production of prostheses this task remains for future.

Switching prosthesis is the most feasible solution in fitting a wide range of amputees permitting to achieve individual control of TDs in proportion to the difference between peak myopotentials from the residual limb control muscles.

Analysis of the switching method includes both the sequence of TD switching and the selection of the switching signal.

The sequence of TD switching in control of several functions can significantly influence duration of complex movements. To study this issue we have developed a control system based on closed algorithm where simultaneous joint contraction of the control muscles perform sequential switching of the TDs: hand TD - elbow TD - forearm TD. Hand TD is energized by switching on the prosthesis power supply.

This control system was developed due to the biomechanical study of the upper limb indicating that in the above-elbow prosthesis wrist rotation is sufficiently compensated with the humeral joint movements (humeral rotation, back and forward movements, humeral abduction and adduction) permitting it to perform active but secondary part in the above-elbow prosthesis. The primary objectives are considered to be grasp-hand open and flexion-extension of the elbow.

The developed control system features (compared with the system of independent turning on of electric drives by a definite amount of simultaneous muscle contractions) 3-fold time reduction in switching on elbow TDs, and in completing one cycle of eating time is cut by 1.6 , and in drinking - by 1.7.

Switching of terminal devices may be realized by three ways: mechanical, when switching is performed by means of a muscle or a muscle group not participating in control of similar movement of the sound limb; electric, when switching uses various codes of electric signals in control muscles of the sound limb performing identical functions; and at last a combination of the above two ways may be used for switching on certain terminal devices.

The first way was analized with the above-elbow prosthesis model which included the control system generating the commands of terminal device switch over with the use of a position block. In this control system the terminal device is selected by means of a pushbutton operation with sensitive feedback of the control mechanism and patient. As before the selected terminal device is controlled by a sequence of contractions in the stump control muscles. Differentiation of the sources of signals for switch and control facilitates control of the multifunctional prosthesis while tactile sensitivity reduces errors in selection of the terminal device, thus increasing the number of patients who can wear the multifunctional prosthesis.

The second group of the switchable control systems has been studied rather thoroughly. The researchers employed different codes in switching: amplitude, speed, time and their combinations. But all of them require comparatively much time because the procedure of selecting the terminal device consumes more time than the patient's responses. The way of switching chosen for the study had to meet physiologic requirements, being not tideous, free of considerable mental efforts, demanding no continuous training and permitting to distinguish easily between the switch and control signals. So we came to the simplest code of switching: simultaneous activity of the control muscles. Switching on of one definite prosthetic terminal device corresponds to the definite number of simultaneous control muscle contractions. Starting of movements resets storage to its initial position. Control of terminal devices' movement in various directions was realized by contractions of certain control stump muscles. But even the above prosthesis control algorithm requires special training and concentration of attention to form correct command signals. Probability in control of two prosthetic functions is 0.80, though the same value for three functions requires increased time to make a decision on switching on certain terminal device.

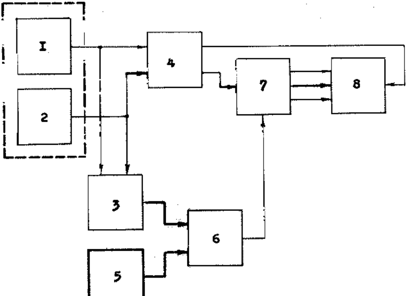
Large-scale fitting should comprise serial production of separate prosthetic units including control systems for potential manufacture of prostheses individually. The control system adaptable to the patients individually should envolve different optional methods of switching and a variety of structural arrangement of units in order to achieve the optimal combination of active and passive below- and above-elbow prosthetic functions with respect to the indications including general condition of patients, combination of limb deficiencies, level of amputation, condition of the stump to be fitted.

A variant of this system corresponding to the third method of switching is shown in figure. Change of one movement for another in such system is realized either through a pushbutton of the position block or through myopotential electrodes in other control muscles of the above-elbow stump, thus reducing time for switching of terminal devices and increasing speed of operation of the multifunctional prosthesis of the arm. Making use of various patterns of movements for initiating separate terminal devices facilitates differentiation between the switching signals and from the control signals, enhancing reliability of switchings between terminal devices.

This organization of the unified above-elbow prosthesis control system enables to arrange two versions of control for forearm prosthesis. The first one presumes the change of the active rotation drive for the passive and switching on the elbow joint terminal device by means of simultaneous signal from both control muscles of the stump. The second one, changing active rotation unit for passive permits to employ the elbow joint terminal device via single action of the position electrode.

The multifunctional forearm prosthesis serially produced in the Ukraine applies the terminal devices switched over by means of simultaneous activity of the control muscles.

The rest control systems listed above have undergone clinical trials. The results of them permitted to select for further application the system with a combination of terminal device switching due to its features appropriate for unification, fast operation, high reliability in switching over terminal devices.



I.- Initial processing of control signal (channel I);
2 - Initial processing of control signal (channel 2);
3 - Pulse signal switching; 4 - Amplifier modulation block;
5 - Position command block; 6 - Switching command storage;
7 - Commutation block; 8 - Terminal devices.

Figure. Functional diagram of the unified control system for myoelectric above-elbow prosthesis.