SOME PROBLEMS OF CONTROLLING A LIVE UPPER EXTREMITY AND BIOPROSTHESIS BY MYOPOTENTIAL

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The Modes and Possibilities of Control

The utilization of the muscle potentials creates great possibilities in the research into the biomechanics of muscles of the human extremities, programmed stimulation of muscle systems, and the construction of simulators and artificial limbs. The aim of the work being conducted is the creation of theoretical foundations for the use of muscle currents for a true control of the muscle system in a live organism and a true control of bionic mechanisms or artificial limbs by a live organism or a programming device.

The possible modes of control are shown on Figure 1. A fundamental system is one of the type (1) muscle-muscle. Another important system is (2) muscle-artificial limb, (3) muscle-orthosis, and (4) muscle-bionic instrument.

The functions of a muscle (or muscle group) may be replaced by a suitably programmed instrument equipped with memory. On Figure 1 are shown systems (5), (6), (7), and (8).

In the works hitherto conducted system (1) muscle-muscle has been dealt with in detail as the fundamental one for other systems.

The system (2) was examined simultaneously.

System (5) is in the course of examination.

Structural Model of an Upper Limb

The upper limb is a complex biomechanical system having under certain simplifying assumptions 27 degrees of freedom. The number of muscles (drives) acting on limb joints amount to approximately 50.

A complex play of muscles in the process of realizing a given movement requires determination of the correlation of the fundamental parameters decisive for the mechanism of control. A simplified structural scheme of a limb is shown in Figure 2 (a, b, and c).

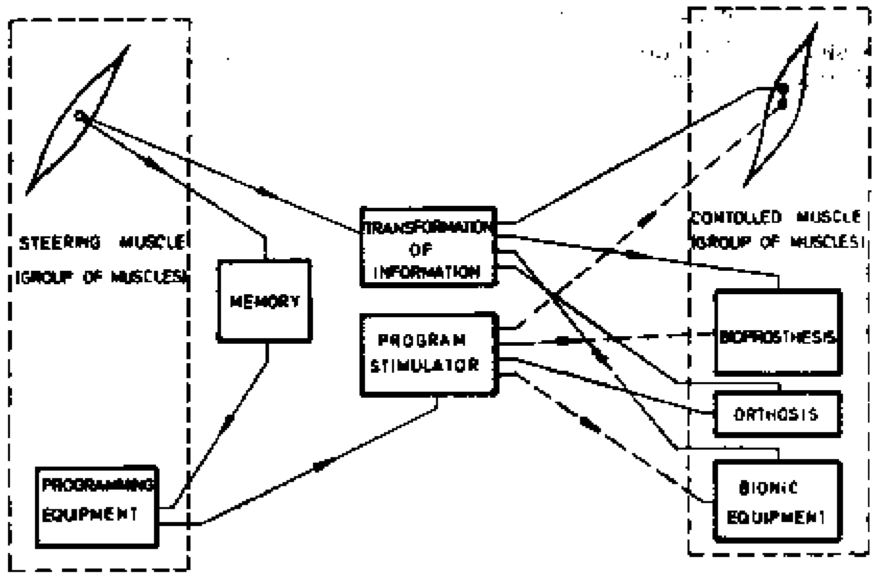


Figure 1.

In this scheme the palm was considered as one member. When considering the model of a limb on the bases of lever mechanisms it will be found that the number of mobile members equals $n = 19$, and the numbers of kinematic pairs belonging to respective classes are: $p_2 = 1$, $p_3 = 2$, $p_4 = 6$, and $p_5 = 11$.

Applying the structural formula of spatial mechanisms in order to determine the number of freedom stages, it will be obtained:

$$w = 6n - \sum_{i=1}^{6} i \cdot p_i, \quad \ldots \ldots \quad 1$$

whence

$$w = 6 \cdot 19 - 5 \cdot 11 - 4 \cdot 6 - 3 \cdot 2 - 2 \cdot 1 = 27$$

Figures 2b and 2c show special cases of the system 2a.

If we consider the forearm only (hand and arm remaining immobile), then the mobility from the formula (1),

$$w = 6 \cdot 2 - 5 \cdot 1 - 3 \cdot 1 - 2 \cdot 1 = 2$$

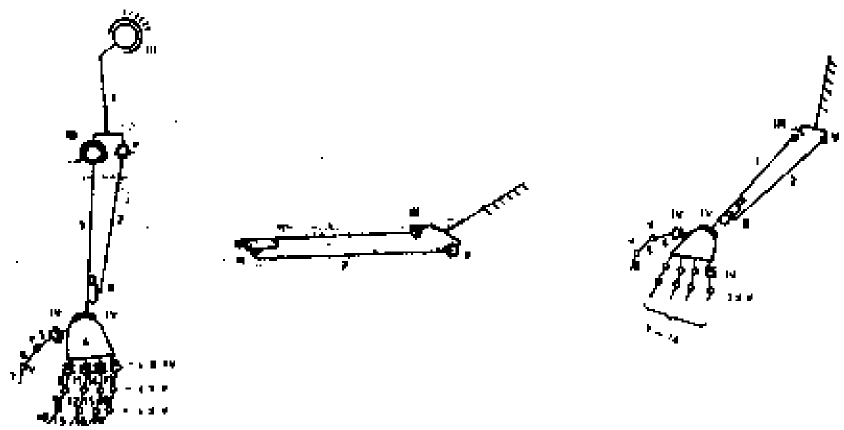
In this system the control of muscles causing flexion and extension of the forearm may be examined.

Considering now the system of the forearm and fingers (Fig. 2c) it will be obtained

$$w = 6 \cdot 14 - 5 \cdot 10 - 4 \cdot 3 - 3 \cdot 1 - 2 \cdot 1 = 17$$

The difficulty in penetrating to the deeply located muscles has induced the authors to consider in this system certain pairs of the IV-th class as ones of the V-th class.

From the point of view of the mechanical theory of machines the systems which have been considered are kinematic chains of 27, 2 and 17 freedom degrees.



a)

$n = 19$

$p_5 = 11$

$p_4 = 6$

$p_3 = 2$

$p_2 = 1$

$W = 6n - \sum_{i=1}^{5} i p_i$

$= 6 \cdot 19 - 5 \cdot 11 - 4 \cdot 6 - 3 \cdot 2 - 2 \cdot 1$

$= 27$

b)

$n = 2$

$p_5 = 1$

$p_3 = 1$

$p_2 = 1$

$n = 6 \cdot 2 - 5 \cdot 1 - 3 \cdot 1 - 2 \cdot 1$

$= 2$

c)

$n = 14$

$p_2 = 1$

$p_3 = 1$

$p_4 = 3$

$p_5 = 10$

$W = 6 \cdot 14 - 5 \cdot 10 - 4 \cdot 3 - 3 - 2$

$= 17$

Figure 2.

It is thus necessary, in order to obtain a definite movement, to equip the system with a suitable system of independent drives.

The problem, however, is more complicated. Nearly each joint is controlled by at least two antagonistic muscles (flexors and extensors). Nearly each muscle is engaged in the realization of several independent movements.

Interesting results as to the choice of the optimum number of muscles controlling a given joint are obtained by employing the programming method and the theory of graphs.

Some Fundamental Problems Decisive for the Choice of the Control System

Before proceeding with the design of a control system it was necessary to explain certain basic problems, namely, the relationships between the mechanical parameters (position, speed), stimulating parameters (the shape of stimulus, current intensity, frequency), the form of EMC, and the cooperation of muscles in the realization of a given movement.

The Measurements of Electromechanical Parameters of an Upper Limb

The measurements of the basic parameters of upper limb may be divided into two groups: the measurements at rest and during movement.

The stand shown on Figure 3 makes possible examining the relationship between the parameters of an upper limb during movement.

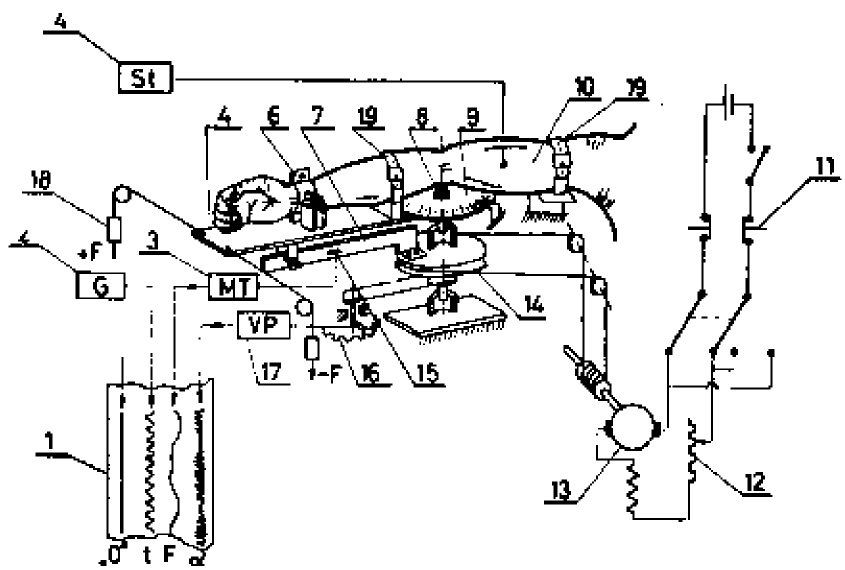


Figure 3.

The limb under test (10) is located on a special support (4) and (8), and is connected with the plate by a grip (6) and bands (19).

The drive of the limb is effected by a mobile mechanical arangement (14) resting vertically in double bearings and an electrical circuit (13) consisting of a D.C. motor with controllable speed (12) and a possibility of the reversal of direction of rotation (11).

The force developed by the muscle under test is recorded by means of a tensometric element (7) with glued resistance sensing elements (15) which is connected on one side with the tray (14) and on the other side with a lever (4).

The resistance sensing element is connected to a tensometric bridge (3). A potentiometer circuit (16) and (17) is used for the measurement of the turning angle. The measuring stand may be used either for electromyographic test with the use of weights (18) or for stimulation tests using a stimulator (5). The outputs of the force-sensing element, angle EMG, time base (2) are connected to a multichannel recorder (1), as it is required to record at least eight parameters at a time. Some results which have been obtained when conducting tests on stands (Figs. 3 and 4) are given on Figures 4, 5, and 6.

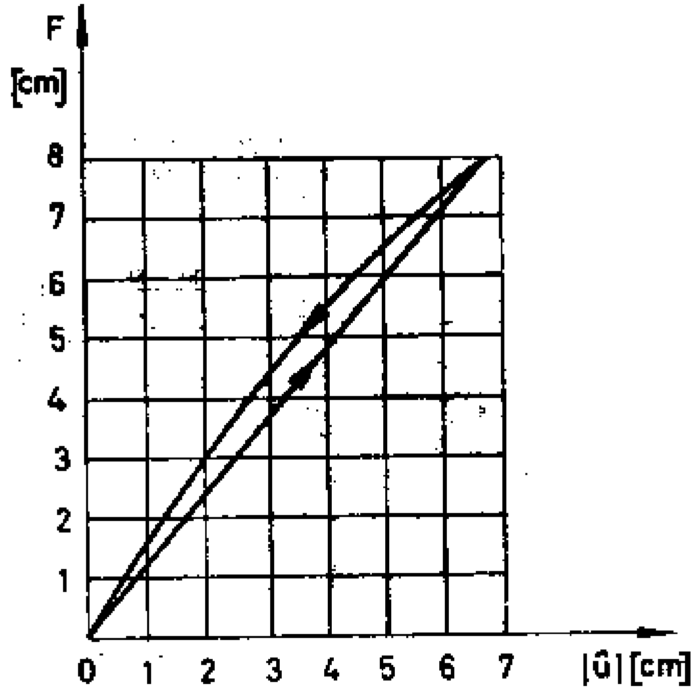


Figure 4.

In the case of measuring the relationship during movement, the relationship F = f (EMG) requires a special elaboration.

The relationship between the electromyogram thus obtained and the muscle force is given in Figure 4. As it will be seen, the relationship obtained by this method is substantially linear. The integration is effected in practice by the electronic methods. The relationship between the force developed by a muscle and the speed of contraction was tested by A.V. Hill. The relationship between the force of muscle and its length (curve 1) was tested by R. W. Ramsey and S. F. Street (1949) on an isolated muscle of a frog (Fig. 5). The authors have established the latter relationship for man's muscle in a live organism (Fig. 6) which shows the results obtained when testing the stimulation conditions, that is the force developed by a muscle as the function of the stimulus has made it possible to determine the optimum stimulation conditions for the control of the type (5), (Fig. 1). It has been found

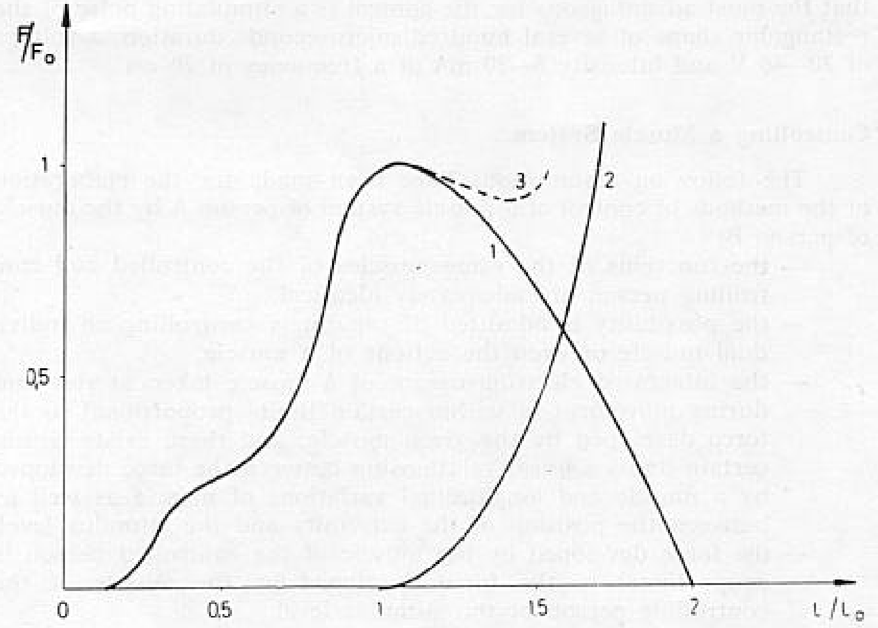


Figure 5.

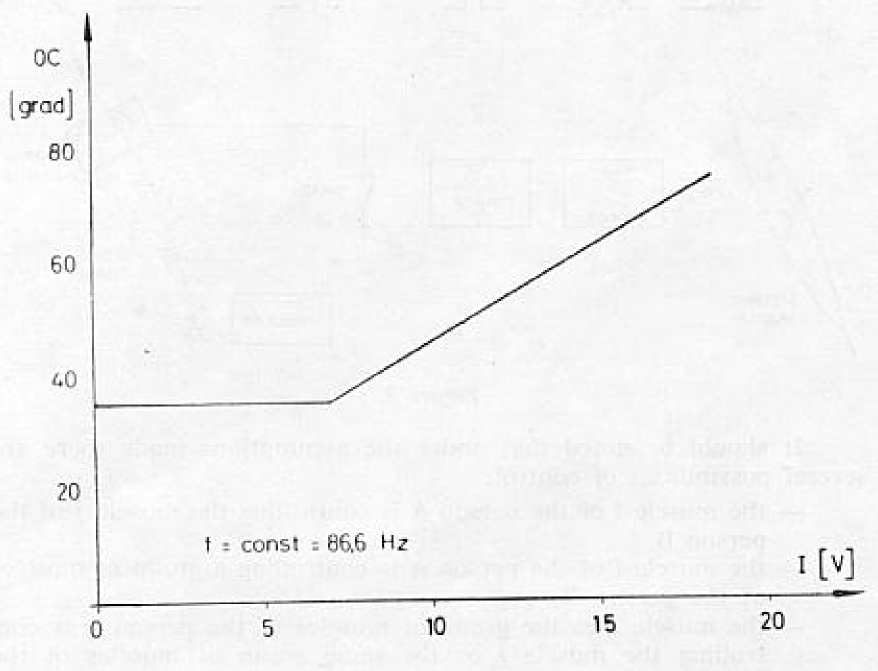


Figure 6.

that the most advantageous for the control is a stimulating pulse of the rectangular shape of several hundred microseconds duration ,a voltage of 20—40 V and intensity 8—20 mA at a frequency of 70 c/s.

Controlling a Muscle System

The following assumptions have been made for the elaboration of the methods of control of a muscle system of person A by the muscle of person B:

— the functions of the same muscles of the controlled and controlling person are adequately identical,
— the possibility is admitted of separately controlling an individual muscle or even the actions of a muscle,
— the integrated electromyogram of a muscle taken at rest and during movement is within certain limits proportional to the force developed by the given muscle; and there exists within certain limits a linear relationship between the force developed by a muscle and longitudinal variations of muscle as well as between the position of the extremity and the stimulus level,
— the force developed by the muscle of the controlled person is proportional to the force developed by the muscle of the controlling person or the stimulus level,
— the programme of muscle system control should be based on a definite value of the contribution of muscles to a given movement.

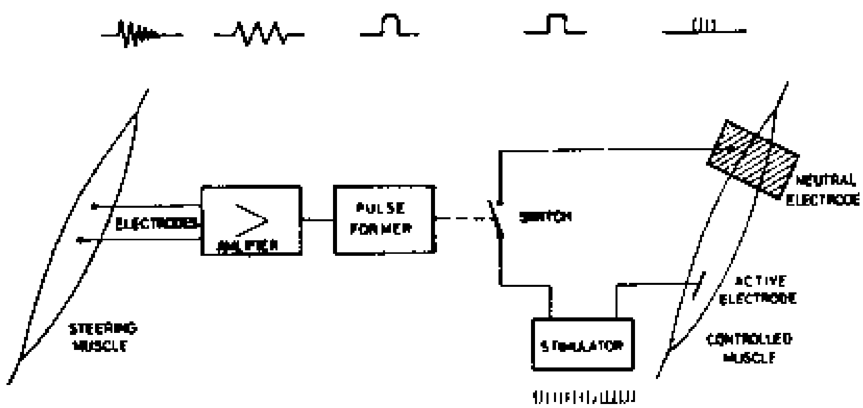


Figure 7.

It should be noted that under the assumptions made there are several possibilities of control:

— the muscle *i* of the person A is controlling the muscle *j* of the person B,
— the muscle *i* of the person A is controlling a group of muscles of the person B,
— the muscle *i* or the group of muscles of the person A is controlling the muscle *i* or the same group of muscles of the person B.

The authors have adopted for the control the third version as, in their opinion, it offers the best possibilities for true control.

The simplest system of controlling a muscle is the single-channel system given on Figure 7.

The muscle currents drawn from the muscle by means of electrodes are amplified by the amplifier and formed in an additional circuit and converted into a rectangular pulse operating the switch.

The latter is connected in series with the stimulator and the electrodes are located on the muscle to be controlled. With switch contacts closed the stimuli are transferred from the stimulator to the electrodes. For controlling a group of muscles the circuit shown on Figure 8 was employed. In this circuit one muscle of the controlling person was used for selecting, through a selector, a muscle of the controlled person and another muscle served for its operation through a stimulator.

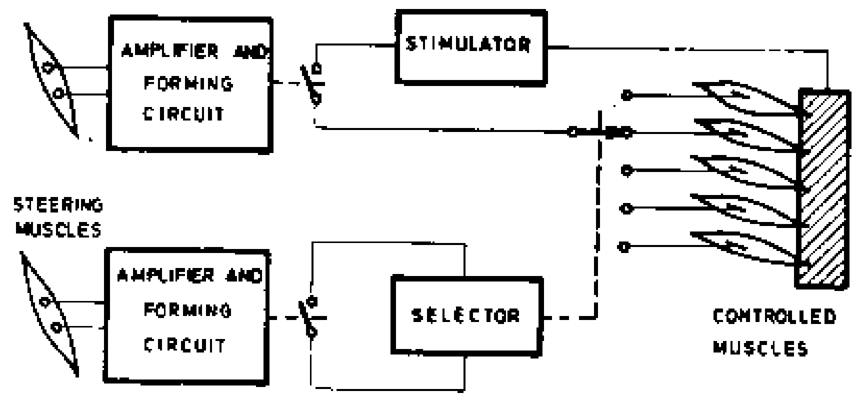


Figure 8.

The use of two-state control is, in the authors' opinion, not sufficient although it makes it possible to construct many control systems giving satisfactory performance. To achieve various force effects a discrete control of both stimuli and force may be used. This is shown in the arrangement on Figure 9. The muscle currents drawn from the surface by means of the electrode (1), after being amplified in circuit V and formed in circuit IF, are transmitted in the form of a coded pulse to the amplitude discriminators D_i of the four voltage levels P_i.

The discriminators control the switches W_i. If the coded pulse voltage exceeds the level P_i, then the corresponding discriminator D_i will cause the contacts W_i to close. The code circuit K controls the contacts of the switches W_i in a predetermined order.

The switches W_i connect the output electrodes on the muscle being controlled with the series connected stimulator resistances R_1 to R_4. In this way, if the coded myopotential pulse voltage is exceeded by the P_i levels, then stimulating pulses with I_i amplitudes are delivered. Five stimulating pulse amplitude states correspond to five coded myopotential states, in accordance with the programmed circuit characteristic.

Parallel to the works concerning the direct control of the muscle system of the person B by the muscle system of the person A, work had been conducted on the system (5), (Fig. 1).

Since the movements of the upper limb are powered by about fifty muscles, a programmed stimulator has been constructed making it possible to control various muscle combinations .

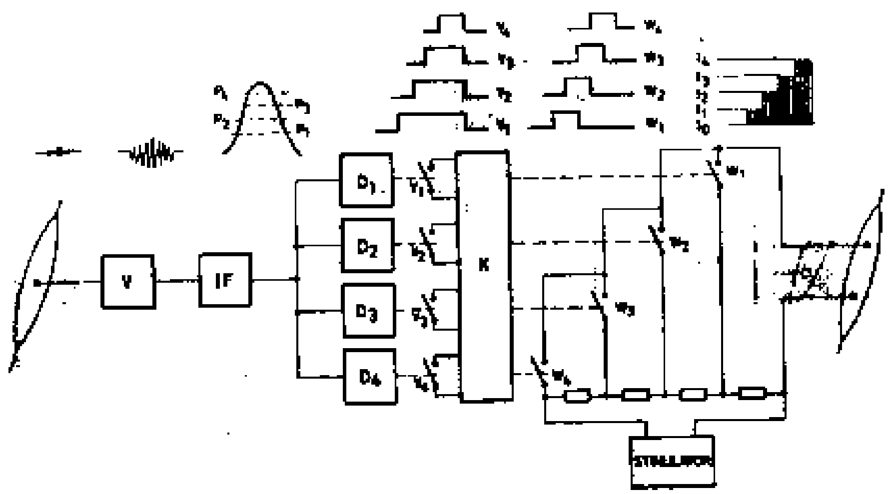


Figure 9.

A block diagram of this stimulator is given on Figure 10 and 11. It is designed to be used for the control according to three typical control schemes marked on the switch by 1, 2, 3:

1) Control is effected from a memory device of the magnetic recorder type by controlling the stimuli amplitudes.
2) Control is effected by step generator and cross fields — a fixed modulator amplitude level is set.
3) Control is effected from a 10-channel myograph with integrating circuits.

An example of controlling 17 muscles using the possibility 2 is shown on Figure 12.

By means of the equipment shown in Figure 12 the following functions were realized:

— a gripping movement with simultaneous flexion in the elbow joint,
— pronation of the forearm, gripping moment and supination of the forearm,
— gripping movement, supination and flexion of the forearm,
— extension of the fingers, pronation of the forearm and flexion of fingers.

The equipment described offered the possibility of simultaneously programmed stimulation of many muscles.

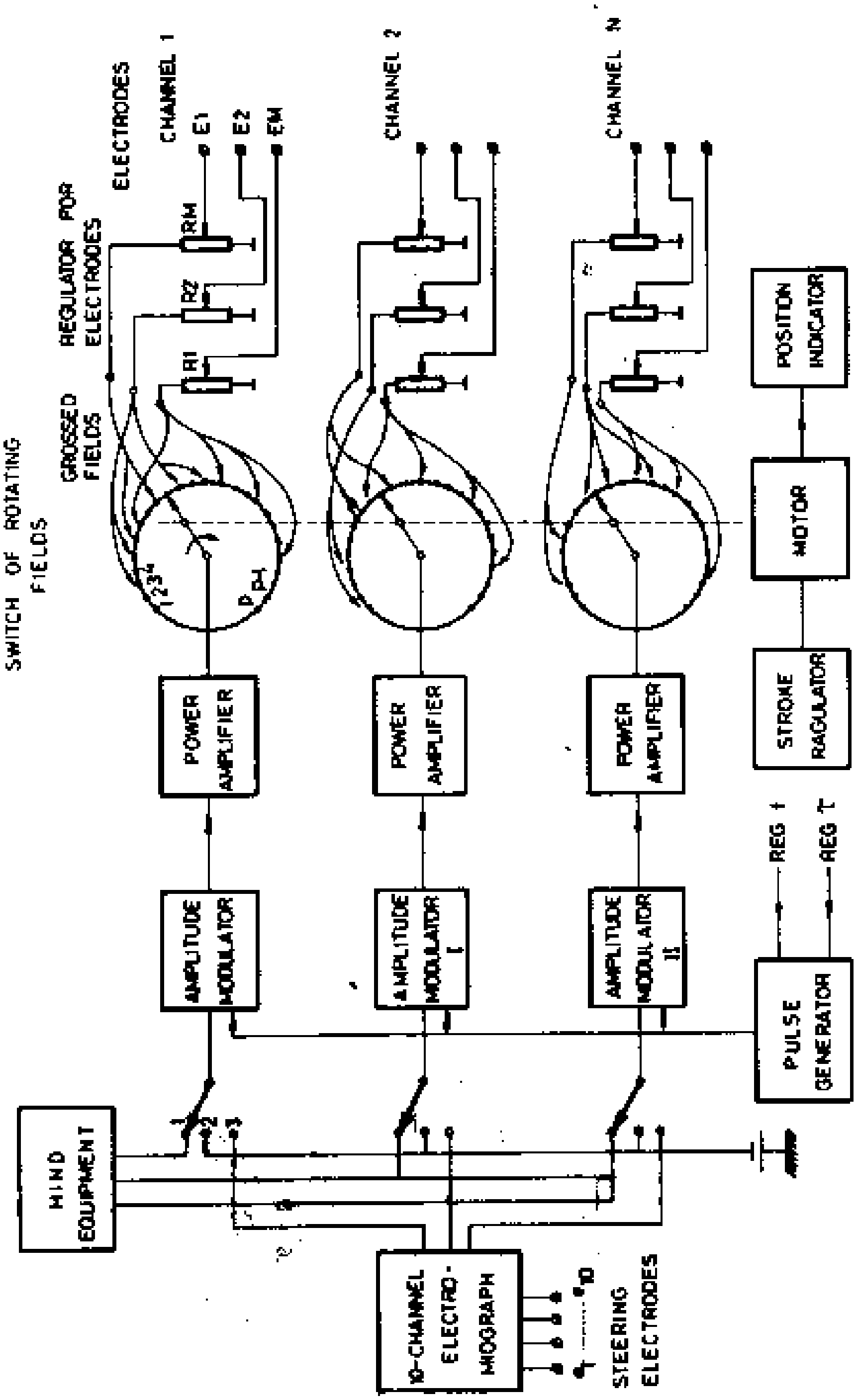

SWITCH OF ROTATING FIELDS
CROSSED FIELDS
REGULATOR FOR ELECTRODES
ELECTRODES
CHANNEL 1
E1
E2
EM
R1
R2
RM
CHANNEL 2
CHANNEL N
POWER AMPLIFIER
POWER AMPLIFIER
POWER AMPLIFIER
AMPLITUDE MODULATOR
AMPLITUDE MODULATOR I
AMPLITUDE MODULATOR II
MIND EQUIPMENT
10-CHANNEL ELECTRO-MIOGRAPH
STEERING ELECTRODES
PULSE GENERATOR
REG f
REG T
STROKE RAGULATOR
MOTOR
POSITON INDICATOR

Figure 10.

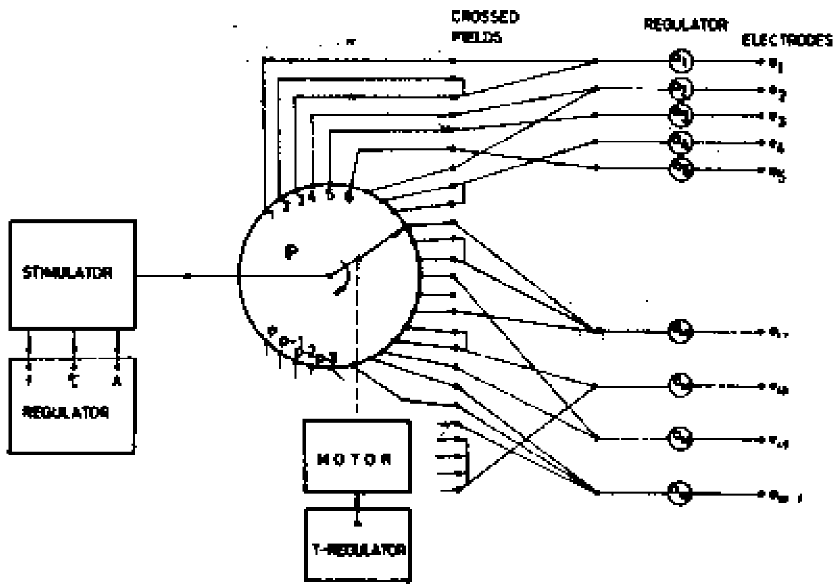


Figure 11.

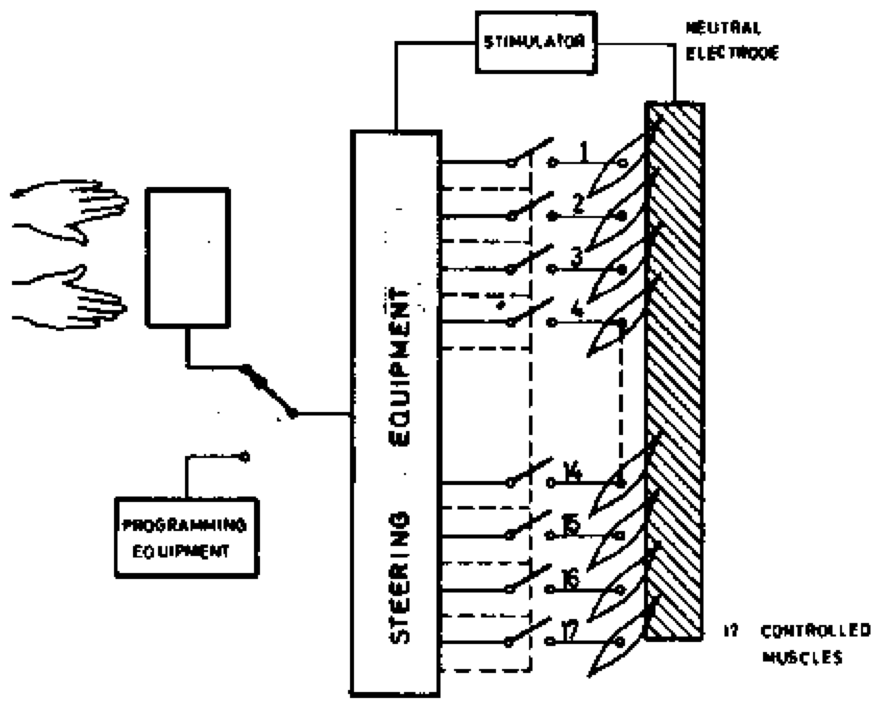


Figure 12.

Manipulators and Bioelectric Prosthesis

Problems illustrated on Figure 1 as the possibilities (2) and (6) are here considered.

Essential for elaborating the methods of control of manipulators and prosthesis by muscle currents is the choice of the type of drive. In the designs used today the drives supplied externally with compressed air or electric power are employed. The muscles of the paralyzed stump are used for the control of the drive.

In the Warsaw Polytechnic Dynamic Quantities Measurements Division an artificial pneumatic muscle developed by ing. K. Nazarczuk has been tested. This muscle develops forces of a magnitude very similar to that of forces generated by natural muscles (5—11 kg/cm^2) of the cross sectional area at a shrinkage magnitude of up to 40% length. It has a smaller hysteresis than the McKibben muscle. One of the design versions of this muscle is illustrated in Figure 13. This is a rubber tube in the walls of which along the generating lines, are placed nonflexible threads. The tube is terminated at both ends by end pieces serving for the connection of air supply. Figures 13a and 13b show respectively the muscle in the idle and the working state.

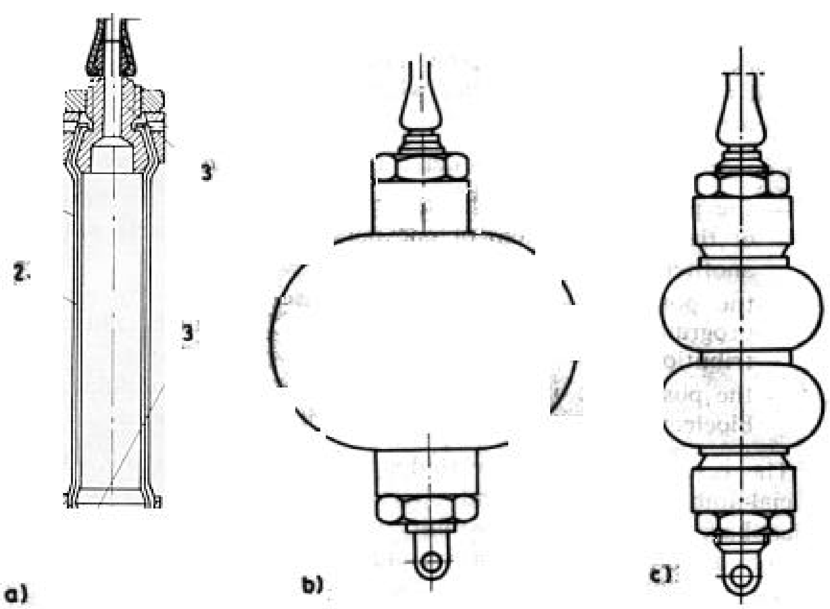


Figure 13.

In Figure 13c a version of paralel-type muscle is shown, which is advantageous with regard to the volume occupied. The acuators described have been used for driving a model of an upper limb.

A block diagram of a single-channel bioelectric prosthesis system is shown on Figure 14.

As power source a compressed air tank Z is used. A suitably amplified and U-formed muscle electromyogram control via a switch the electropneumatic valve PE-P actuating the prosthesis muscle.

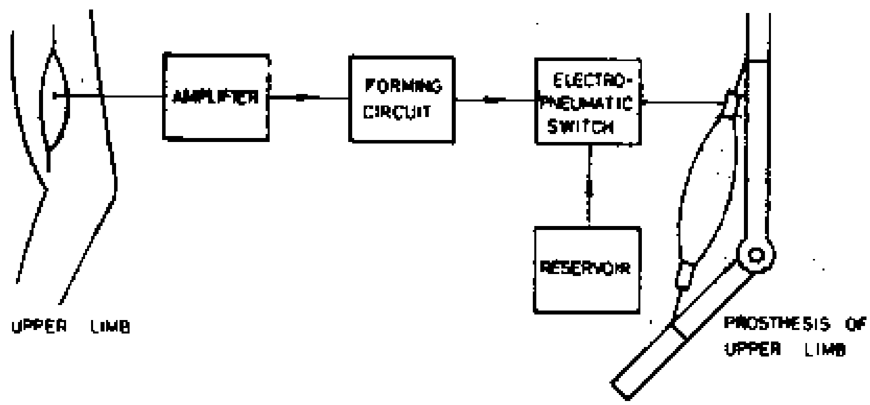


Figure 14.

Work is now in progress on bioelectric control of a prosthesis equipped with pneumatic muscles which makes it possible to perform seven movements.

Conclusion. The work conducted by the group have revealed:

— the possibility of employing muscle potentials for the control of the muscle system of one person by the muscle system of another,

— the possibility of controlling a muscle system by way of a programmed stimulation on the basis of assumed muscle contribution,

— the possibility of constructing multifunction manipulators and bioelectric prostheses based on artificial muscles.

The results obtained may find application in medicine, industry, artificial-limb construction and sports. The methods developed and applied have revealed the possibility of conducting scientific research on muscular activity directly in live organisms, and not only on isolated muscles.

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