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New conception of the hybrid system of supporting of the grasping movements.

Summary

A series of apparata for supporting lost function of upper human extremities were designed, manufactured and tested at the Team of Technical Biomechanics of the Institute for Aeronautical Engineering and Appiled Mechanics in the years 1971-76 in cooperation with Metropolitan Center of Rehabilitation, Warsaw-Konstancin/1,2/. The results obtained with the use of implanted stimulators of nerves for forcing mechanical activities of paralyzed upper extremities of a man were discussed on the example of grasping movement. Discussion of results obtained was carried out and efficiency of the method after a lapse of a long period of time from the moment of implantation was examined /3,4/. The conception of the hybrid system of supporting is presented.

The results of experimental research.

During investigations carried out in the years 1971-76, the influence of electrical stimulation of peripheral nerves on functional improvement of paralyzed hand of the tetraplegic, in cases of spinal cord injuries on the C_5-C_6 level was verified under clinical conditions.

The median nerve was stimulated with the use of implanted stimulators in order to obtai grasping function of the hand. In several cases, the radial nerve was also stimulated under the skin of the

arm or forearm of the patient, and electrodes were fastened to the epineurium of the nerve.

Fourteen tetraplegic patient were examined to whom 26 stimulators were implanted. Such cases of patients were choosen for experiments in which there was no chance of neurological improvement by means of treatment with traditioonal methods. Impulse amplitude was selected in such way as to obtain maximum contraction of flexor muscles and the opponens policis, or the amplitude was increased to degree not exceeding the threshold of pain. After the wound was healed and the thread had been removed, the localization of the elec trodes was verified by radiological method/3,4/ and systematic stimulation was begun according to the program which had been established experimentally /4/. The stimulation was performed every day for a 6 months since the operation. The daily program was performed in a period of 2 - 4 hours.

Using the discussed stimulating method in 11 examined cases, an increase of force developed by the opponens pollicis was obtained as also an increase of the time in which the maximum moment of the force during stimulation was maintained /Fig.1a and 1b/. During examinations an effect was noticed which can have great practical importance when functional stimulation of paralyzed upper extremities was carried out /Fig. 1c/. This effect cosists in possibility of active increase by the patient of the value of developed force by muscles stimulated from the stimulator. At a certain threshold basis of stimulation, which forces development of an insignificant force, patients could, on oral order, overcome resistance requiring the use of force several times higher. Measurements of observed phenomena were carried out in the period from one to four years from the moment of stopping stimulating program in three patients who came to the Metropolitan Rehabilitation Center/Fig. 1d/.

Conception of the hybrid system of supporting of the grasping movements.

The aim of this work was to design a system, for whose forces grasping movement can be realized under condition of simultaneous cooperation of the patient with the system of stimulators implanted of the nerves and with the external apparatus. This system enabled the patient to realize the functional movement useful in everyday activity /6,7/.

External apparatus is composed of the following systems:
- palm forming,
- stimulating transmitter,
- functional activity starting and ending system,
- transfirming information system from: position measuring indicator and force indicator.

Position measuring indicator assures the possibility of controllin the position of opening and closing of fingers. Force indicator makes possible, through the contact with object kept, development of force necessary for picking up or shifting the given object. Fig. 2 presents a scheme of hybrid system of supporting. Electronic part of this arrangement is composed of stimulators system, control, programming and feedback system. In the latter system, cooperating with the angular position measuring and grasping force indicators, processing of signals received from indicators is made, and command to the programming and control system is generated. This command influences directly control system which control tension of duration of stimulating signal in such a way as to have a grasp made evently and with sufficient strength. In turn, programming system controls the work of individual subsystems in such a manner that, after starting a movement by the patient, all the remaining operations run automatically as suitable time sequences.

The basic tasks of the grasping system.

Fig.3 shows the sequence of activity during the grasping movements. The whole process cosists of three phases and activities A and B.

Phase I The device is turned on and ready for operation. The flexors and extensor are not stimulated.

Phase II The hand is extended. The stimulation of the flexors is turned off. The stimulation of the extensors is turned on.

Phase III This phase consists of the sequence of two activities:

Activity A: In the result of turned on and increasing with time stimulation of the flexors, the hand encompasses an object. The system of the velocity control is turned on to co-ordinate bending of the fingers.

Activity B: An object is being lifted. In the result of dosing the stimulation of the flexors by means of the force reflecting transducer, the grasping force is adjusted to the weight of the lifted object.

To solve this problem two parallel solutions were proposed:
- the method of dial extensometer,
- the method of "artifical sensing".

In both solutions the control system for positioning /velocity/ was used.

The method of the dial extensometer

The device enables to perform motion with developed grasping force proportional to the weight of the object. The magnitude of the force depends on amplitude of the stimulation voltage. The shape of the lifted object is also taken into account. The principle of operation of the device is based on strain gauge weight. The indicators informing about the weight are locaied on the orthosisencompassed the paralyzed arm /Fig. 2-1/.

When the object is lifted the beams with attached strain gauges deflect and generate the signal proportional to the weight of the object. The system controlling the stimulation voltage, acting through the implanted stimulator, increases the level of stimulation at its the output. The level of stimulation and so the grasping force are proportional to the weight of the lifted object /Fig. 4, loop I/. The effect of the own weight of the device is taken into account. When the action of lifting is completed and the patient wants to release his hold, he sends the third controlling impulse, after which the system returns to phase I. In case the patient can not leave the object, he sends the next impulse which turns the stimulation of the flexors on, so that the hand fully opens and the object slips off.

The method of "artifical sensing".

The device coupled with the implanted stimulators utilizes the indicator of displacement located on the indexing finger /Fig. 2-1/. The device provides the smooth grasping movement of the fingers and enables to develope the grasping force proportional to weight of the lifted object. The magnitude of the force is controlled by suppying the stimulating voltage of required amplitude to the implanted stimulators /Fig.4, loop II/.

The indicator of displacement is indispensable element of the device. The indicator generates the impulse verrying information about displacement of the object relative to the hand. The signal received from the indicator, processed by proper units, is used for controlling the voltage of electro-stimulation, and enables

to perform prehension with paralyzed hand similarily to the normal hand. The essential feature of this design is in utilization of two types indicators: touch-sensor and displacement detecting ones. Both types are mounted on the grasping fingers of the hand. To make the prehension more reliable, a few touch-sensor indicators are located in various places. The touch-sensor indicators are simple snap action swiches, whose aim is to give information about the fingers coming in contact with the object. The grasping force is proportional to signals received from the deflection touch-sensor indicator. The latter consists of two parts stationary and movable. The end of the movable part /the wiper/ in the form of a plate has a large coefficient of friction. This plate, contacting the slipping object, moves relative to the stationary element.
Action of the touch-sensor indicator "freezes" the stimulation of the flexor on the level prior to that action. In this way the tentative level of stimulation is fixed and phase IIIA id completed. If the lifted object /phase III B/ slipd down, the deflection indicator comes into action and the level of stimulation is rised via the feed-back loop, so that the grasping force is increased. The feed-back system and the main control system rise the stimilation level until the object is firmly hold. If the patient wants to put the object, for example on the table, he has to send the third controlling impulse for changing the phase III into Phase I. At the same time, the stimulator of the radial nerve is turned on for a prescribed time, so that the hand fully opens. After that the system assumes phase III.

Displacement and velocity control system.

The indicator of the velocity of bending of the fingers is located on the orthosis which encompassed the patients hand /Fig. 2 - 2/. Utilization of the control system governing the speed of the prehension /Fig. 4, loop III/ enables to perform this motion in a way similar to natural i.e. at nearly constant speed.
The feed-back system comes into action if the speed of the grasping motion is either less or greater than that pre-set. The level of stimulation is adjusted by the signal generated by the control system and the grasping speed is adjusted to the required value.

The above-described action of the stimulation system fitted with the feed-back loop ensures the smooth prehension in a way similar to natural motion. The unit controlling the speed of prehension acts mainly in phase III of motion, during activity A. In case of any fading of the supply voltage the logic system will set the device in phase I /Fig. 3/.

Conclusions.

The above described investigation concerning the problems of controlling the function of paralyzed upper extremities by means of implanted stimulators shows that the proposed methods are current and useful.

The hybrid system proposed for supporing of grasping movement enabled the patients to provide the everyday activity and accelerate the rehabilitation process.

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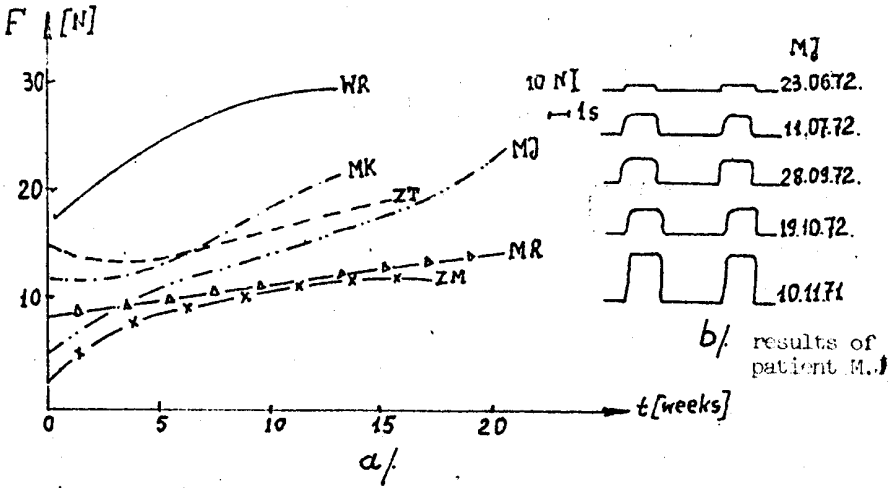
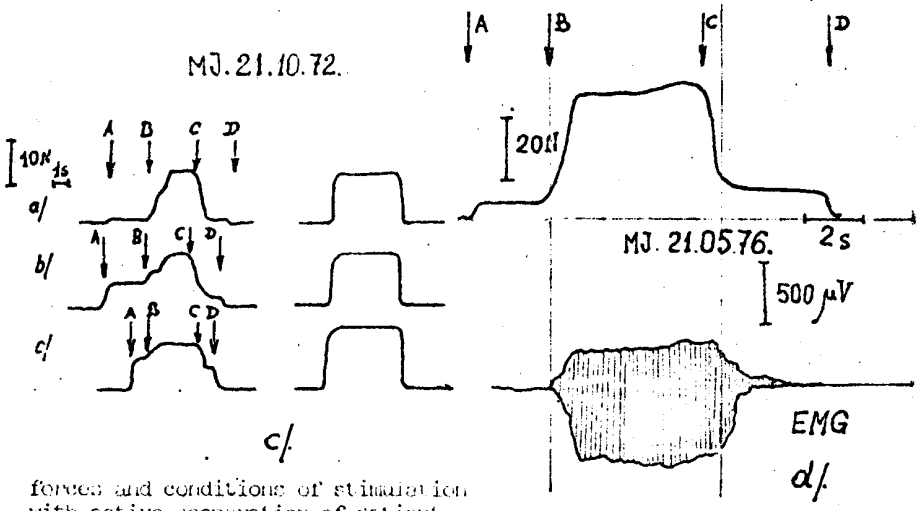


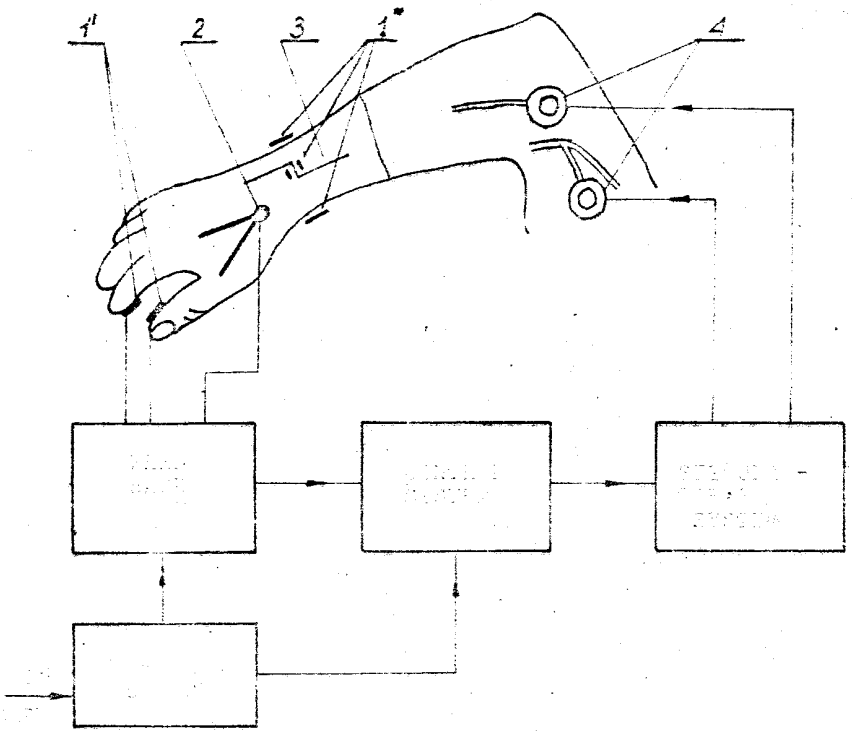
increase of force exerted during stimulation by muscle of thumb in function of time of application of stimulation programme



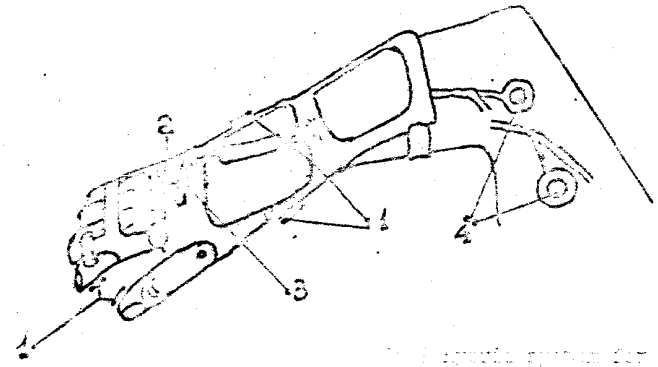
forces and conditions of stimulation with active cooperation of patient, for various stimulation levels; a/ low, b/ medium, c/ near max. level, A-beginning of stimulation, b-beginning of cooperation of patient, C-end of cooperation, D-end of the stimulation, B-maximum force

effect of stimulation after four years

FIG.1 NEUROL EFFECTS OF STIMULATION



a) block diagram



b) Array of transducers on the catheter

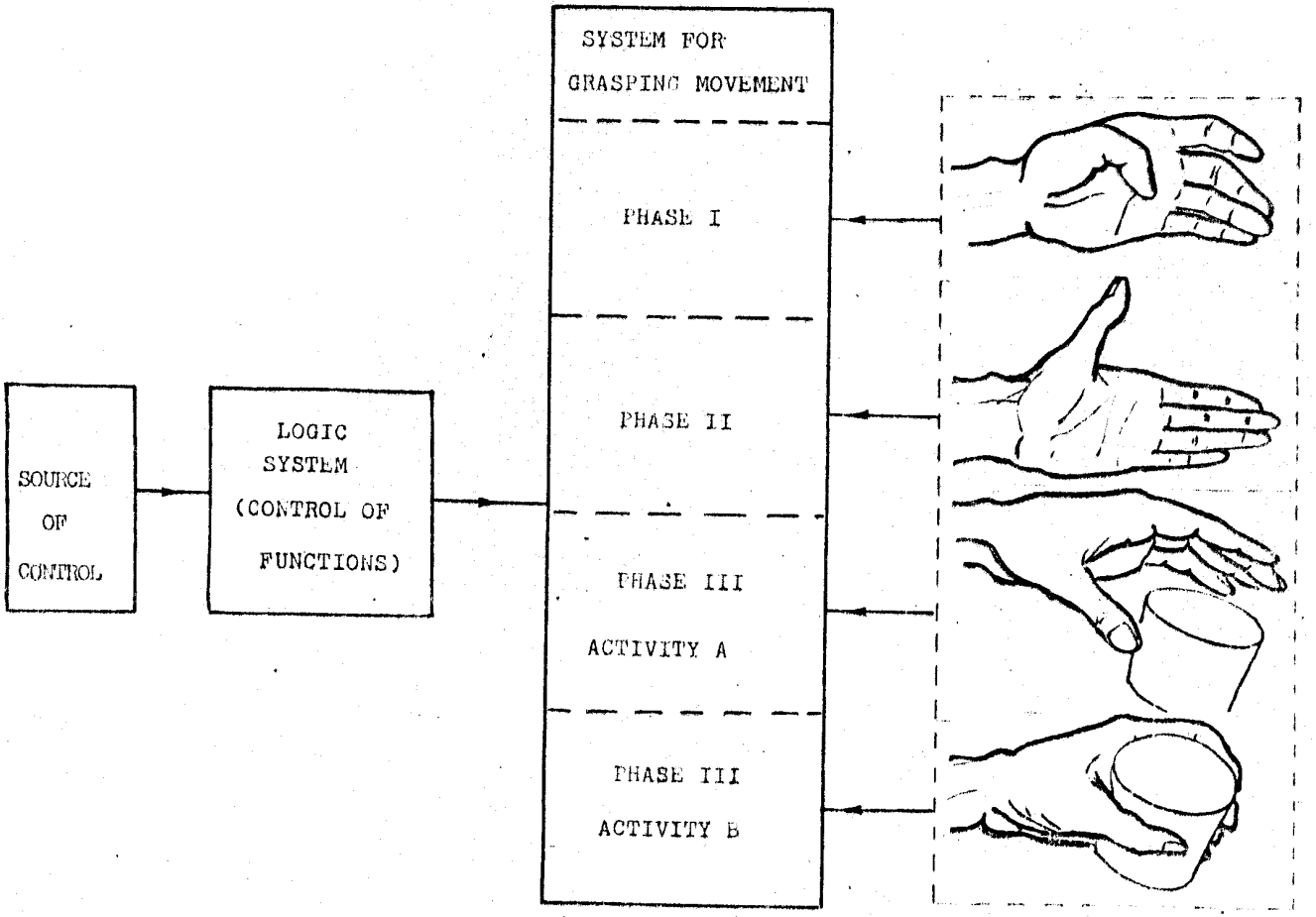


FIG. 3 THE SEQUENCE OF ACTIVITIES FOR GRASPING MOVEMENT

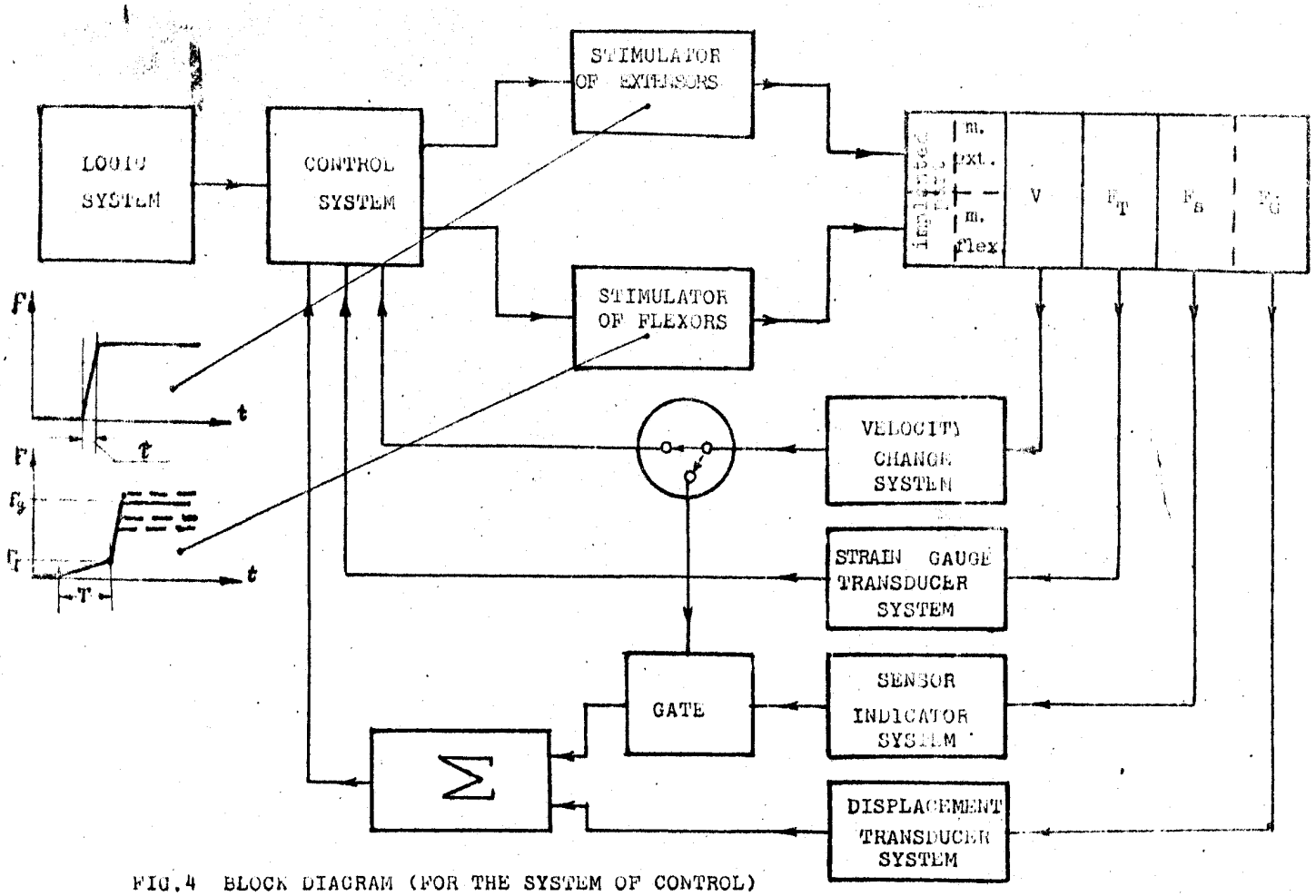


FIG.4 BLOCK DIAGRAM (FOR THE SYSTEM OF CONTROL)