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WARSAW EXTREMITY-LIKE MEDICAL MANIPULATORS x/

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Abstract

This paper describes a procedure taken in synthesis of mechanical part and control system of medical manipulators for supporting or substituting lost functions of upper extremities of a man. The results obtained for prosthetic manipulators intended for amputees with short stump are given in the first part of the work. The second part of the work gives the results obtained at testing of orthotic manipulators intended for supporting 3 and 4 motions of upper extremities of a man.

Introduction

Within a few recent years further progress has been made in design of medical manipulators of upper extremities having a few degrees of freedom and simplified supply and control systems. An invalid with above-elbow stump can use the shoulder joint only, which means that 3 out of 30 possible degrees of freedom are at disposal. Of course full replacement of the lost extremity is theoretically possible but not realised in practice. This fact is due to lack of adequate control systems. Limiting the mechanism of prehension to one degree of freedom /opening and closing/ and actively supporting flexion and extension of the elbow and wrist joints, pronation and suppination of the forearm, a manipulator can be designed with 4 degrees of freedom and 8 supported movements. Simultaneous controlling of this system calls for a few couples of antagonistic muscles or a minicomputer. One can considerably simplify the control system switching from the simultaneous to sequential controlling i.e.movement by movement. Recently extensive tests have been made on a medical manipulator having 4 degrees of freedom and performing 8 movements. Applied in this solution sequential control system facilitated 1 bioelectric or mechanic signal with 2 levels.
Sequential control system is not the best from the physiological point of view, but it can be very easily mastered by a patient. Supply system is another difficult problem as two sources of energy must be used.

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1. Prosthetic manipulator for upper extremity

1.1. The model of a manipulator and the results of its investigation

The general view of the model of manipulator for amputees above the elbow joint is given in the Fig.1a. The main technical question to consider is a type of actuator for driving artificial joints of the model. The results of analysis and considerations done by the investigators and designers turn out, that for portable prosthetic device with a high numbers of degrees of freedom, the pneumatic drive is more efficient comparing to electric or hydraulic ones. Three two-sides action actuators situated inside a forearm assembly perform three couples of movements analogically as in natural extremity. For actuating of four fingers and a thumb a two-side actuator is applied also. The fingers are mounted and connected with the phalanges by joints. The design of a thumb makes it possible to put it in nine different positions in the two perpendicular planes.
The electropneumatic selenoid valves designed by authors for operating gas actuators has been applied. Every two-sides actuator for acting in definite direction must be connected on one side with the source of gas and with the atmosphere on the other side. It demands the set of 16 electropneumatic valves for controlling of eight movements. Pneumatic actuators applied in the model give a constant pressure. For that reason question of movements control depends only on the time of filling and exhausting of the cylinders. The fundamental assumption of the control system is to perform each of the eight movements using a minimal number of signals. In binary system three bits of information are demanded for controlling eight stages device. Bioelectric or microswitch control system may be used. In the first case the bioelectric signals received from muscle by means of surface or implanted electrodes are amplified and integrated in the two stage EMG amplifier and transmitted to the logical block. The purpose of the logical block is to transform bioelectric signals obtained from muscle /or electric signal from outputs of microswitches/ to the information necessary for decoder control. This question has been solved by means of two counters /M=2 and M=4/.

It assumed that proportion between natural and artificial extremities should be preserved. After the model was completed the measurements were performed. Obtained results are as follows:

- The mass of the model m=2,030 kg /assumed data 1,26 - 1,29kg/, the mass of 16 selenoid valves and the logical block 0,842kg, EMG amplifier and CO_2 bottle - 0,5 kg. We suppose that the total mass of portable manipulator would not excess 3 kg in the future.
- To determine the

in the joints of the model are equal at teast to 60% of the angles for natural extremity.

The investigation of static characteristics curves includes measurements of torque developed as a function of angle in elbow, radii-elbow and wrist joints with different pressure were done. Some measurements were repeted after 50 000 working cycles. The static characteristics curves for all the joints and prehension are given in Fig.1b. In generally, obtained results are satisfactory, but it seems necessary to raise the force possibilities of the manipulator in the future.

1.2. The prototype of a prosthetic manipulator

Tests carried out on the model resulted in introducing many improvements both to mechanical part and the system of actuators, valves and controlling.

In practice, hand and digit systems turned out to be complicated and very often small but troublesome failures occured. These systems have been considerably simplified in a prototype. The design consisted of 3 fingers with inadjustable thumb. The system for movements of the elbow and wrist joints remained almost unchanged. In spite of considerable energy consumption, the movements of pronation and suppination of the forearm have been retained for functional reasons.

g.2 Design as a whole has been changed and is shown in Fig.2. It consists of 3 main sub-assemblies: a socket with the elbow joint axis, forearm housing differential actuators /for operating the elbow joint, pronation and suppination of the forearm/ and the hand with digits. The actuators for operating the wrist joint and prehension are placed inside the hand. Owing to the application of the two-way differential actuators the number of the valves in the design could be reduced from 16 to 8. The block
ig.3 diagram of the control system is shown in Fig.3a. The control system has the structure of the automatic device with 4 stages. The change of the states is realized by means of the signal I. The next signal of the same type I sets the automatic device in the next state. The device can change the states in predetermined sequence 1 - 2 - 3 - 4 - 1 etc. The states correspond to the determined movements of the joints. Selecting a proper state of the automatic device prepares the system for performing required movement. The movement is realized by means of the signal II. The next application of the same signal II results in performing the movement in the opposite direction. In system presented in Fig.3a the contraction of the muscle switched on the generator of impulses lasting τ_1 seconds each. Should the contraction be shorter then τ_1 = 0,7s the gate 1 generates the impuls corresponding to the next state. After the time τ_1 elapses /light signal/, the next contraction can be made, which puts the generator of the time interval τ_1 into action. Should

the contraction last longer then $\tau_1 = 0{,}7s$ /after the light signal is put out/, the generator of the impulses lasting $\tau_2 = 0{,}7s$ is switched on. If the contraction lasts less then $\tau_1 + \tau_2 = 1{,}4s$ the gate 2 generates the impuls setting the next state /from 1 to 2 to 1/ but the movement is not performed. It creates possibility to perform the movement in one direction in a few stages /intermittently/. The state corresponding to the opposite direction of the movement can be passed without realization. Should the contraction last longer then $\tau_1 + \tau_2$, in spite of change of direction the movement is performed for the whole time of muscle contraction. The general view of a electropneumatic valve is shown in Fig.3b. The general view of the set of 8 valves is shown in Fig.3c.

The manipulater is now put to the tests.

2. Prototype of portable orthotic manipulator for upper extremity of a man

Some biomechanical aspects should be considered while designing orthotic manipulator for supporting lost functions of the extremity. One of them, the type and number of supported motion, will be discussed here. Out of 8 characteristic functions of the joints of the upper extremity, 3 seems to be most important: flexion and extension of the elbow joint, pronation and suppination of the forearm, and prehension. Assuming that the patient has efficient shoulder joint, the number of possible versions of the apparata can be reduced to 4.

Schematic picture of the design elaborated by authors, with purpose to support 3 pairs of movements of upper extremity is given in fig.4a. This is model No.3 considerably improved in comparison with models designed in 1971-1973. This solution is an example of an active supporting system. Pneumatic actuators are used for opening hand, pronation and suppination of forearm and flexion in elbow joint is extended by gravitation. This solution made possible to greatly simplify supply and control systems, as well as the general arrangement of actuators. In design prehension and flexion of the elbow joint were operated by pneumatic actuators of unilateral action /1/ and /2/, while for pronation and suppination of forearm was used an actuator of bilateral action /3/. A set of 8 electropneumatic valves /4/ was similar as in prosthetic manipulator; 4 valves are used for unilateral actuators and 4 are connected with bilateral actuator. Logic system is similar to that discussed before for prosthetic manipulator. Two microswitches or two level EMG amplifier are used for controlling. The pneumatic system was supplied from Otto-Bock's bottle /6/. Logic system and EMG amplifier were supplied from 12 storage batteries /7/. Amplitudes of movements enabled patient to reach to the proximity of mouth and head. Values of torques developed at individual joints were set at 20-30% of the values of the natural extremity. Endurance tests and clinical investigations indicate high functionality of all the subassemblies. Patients learned to control the manipulator in practically no time. A short series of these appara will soon produced. The general view of orthotic manipulator is shown in the fig.4b.

Conclusion

On the basic of biomechanical and technical analysis a few model of prosthetic and ortotic manipulators, for substituting or supporting lost functions of upper extremities have been designed and manufactured. The tests proved that the mechanical and control systems as well as actuators are properly designed.

References

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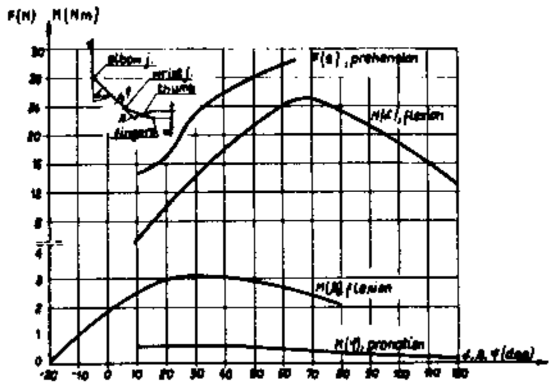
Fig. 1a



F(N) M(Nm)
elbow j.
wrist j.
thumb
fingers
F(s), prehension
M(α), flexion
M(β) flexion
M(γ), pronation
α, β, γ (deg)

Fig. 1b

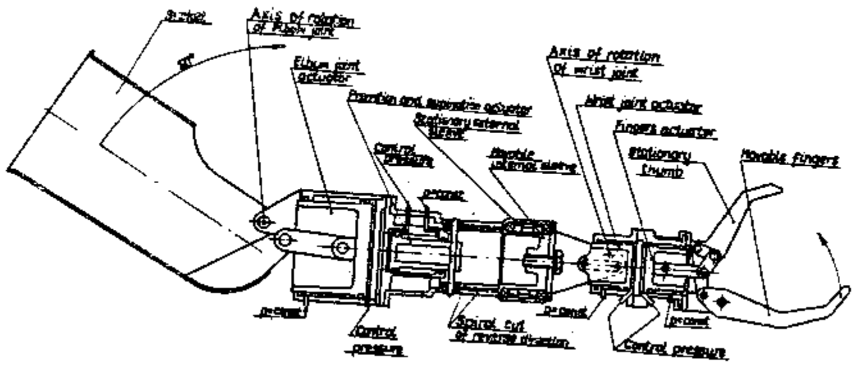

Axis of rotation
Elbow joint actuator
Pronation and supination actuator
Stationary external sleeve
Control pressure
Movable internal sleeve
Control pressure
Spiral cut of reverse direction
Axis of rotation of wrist joint
Wrist joint actuator
Fingers actuator
Stationary thumb
Movable fingers
Control pressure

Fig 2.

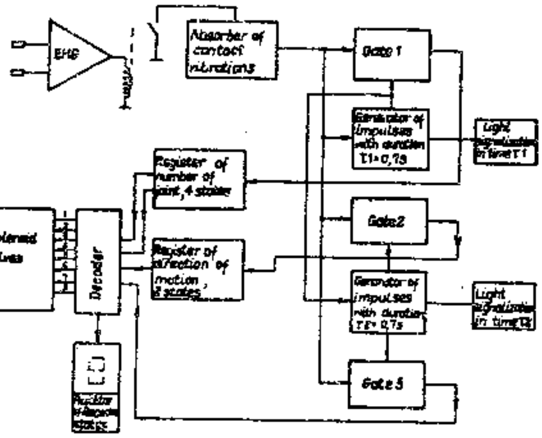

EMG
Absorber of contact vibrations
Gate 1
Generator of impulses with duration T1=0,7s
Light signalization in time T1
Register of number of joint, 4 states
Gate 2
Solenoid valves
Decoder
Register of direction of motion, 2 states
Generator of impulses with duration
Light signalization in time
Gate 3

Fig. 3a

Fig. 3b

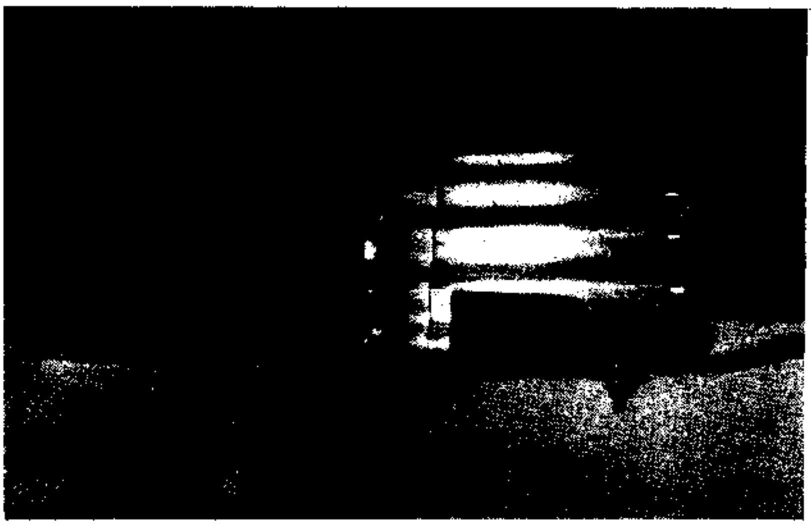


Fig. 3c

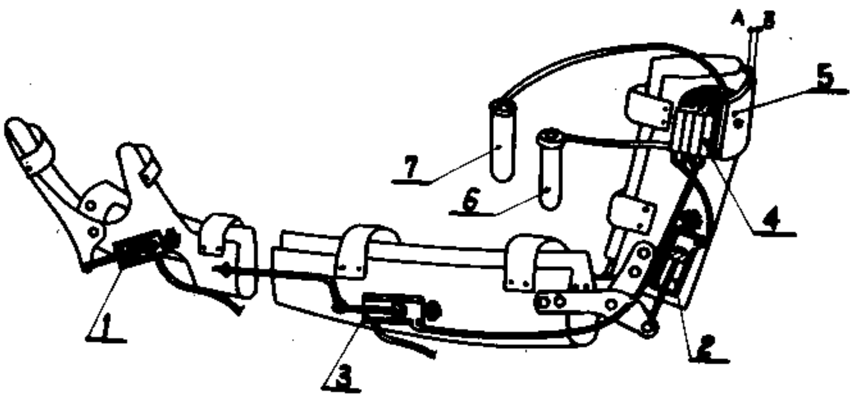


Fig. 4a

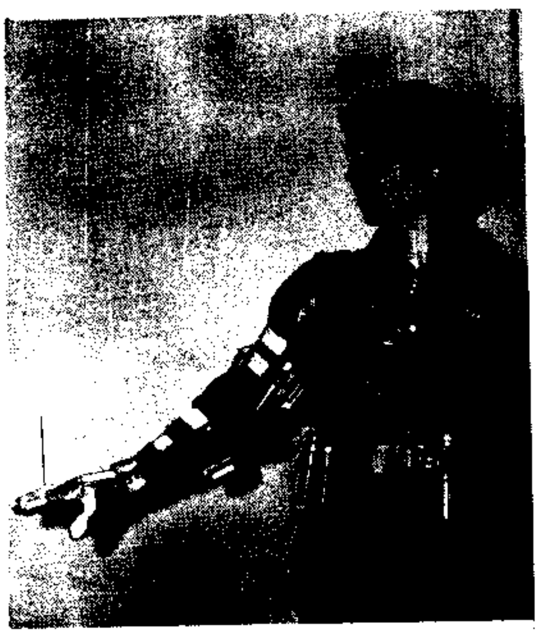


Fig. 4b

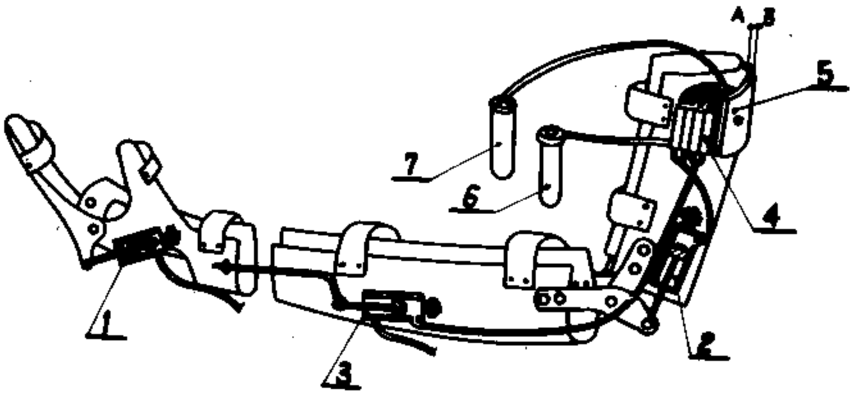


Fig. 4a

Fig. 4b