CONTRIBUTIONS TO THE SOLUTION OF DESIGN PROBLEMS OF ARTIFICIAL HANDS

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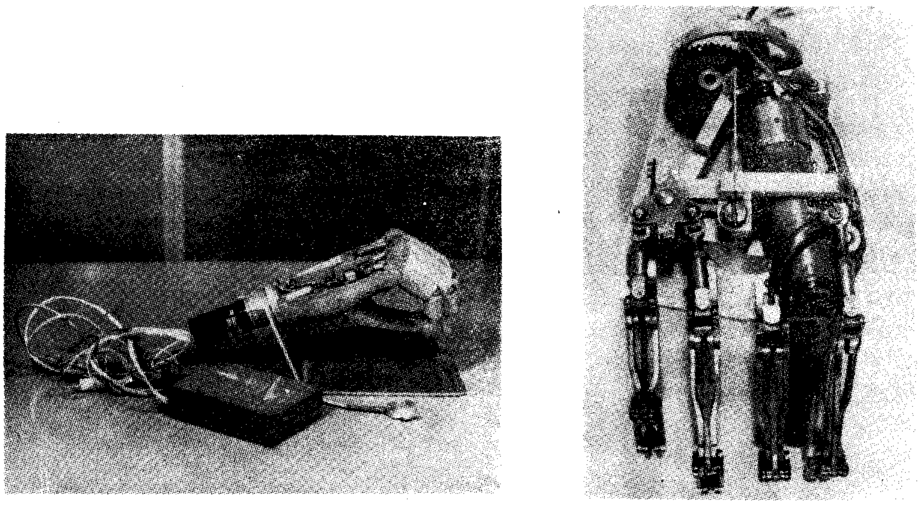
The work on the artificial hand prosthesis, known as the Belgrade Hand, has shown a series of very useful results so far, out of which we shall mention only the main ones. The first point is the multifunctionality that has been postulated as the objective with the initial development, and that has been achieved quite efficiently. There is no doubt that such a requirement brought the developer to face many difficulties, as for example, the power that is lost during the mechanism motion, especially in the fingers. Then, there were the problems of construction of the mechanism kinematics, because of the need to convert rotation into rectilinear motion. At the same time, one of the main difficulties has been to achieve the appropriate weights, and the technology of making the parts of the prosthesis, both, the mechanical one, that perform the necessary motions, and the necessary soft layer. Finally, there is the problem of control of the multifunctional operation of the artificial hand.

As far as the function is concerned, the characteristics should be as much like the natural hand as possible. This has been realized partially, with the exception of some functions, such as the movement of the thumb in all directions and horizontal movement of the fingers. However, closing of the hand into a fist has been realized quite naturally, whereby a natural squeeze of the hand, amounting to 1.5 kp/cm^2 on the tip of each finger is obtained. The pinch position has been achieved, too, that is, the squeeze between the thumb, forefinger and middle-finger, that is of particular interest for writing. The opening needed for grasping between the thumb and the fingers, amounting to about 8 cm, makes it possible to hold rather large objects. The main disadvantage in all this has been the sliding, what hindered better and more reliable grasping. This has been improved rather enough during the development in this period.

Based on the results obtained with the models of preceding years, a study has been started to develop improved mechanisms for movements with the palm and the fingers. The elementary disadvantage of the old model has been the use of castings that were inadequate. First, the form left no space for placing the soft parts. Furthermore they were to havy. In addition, this way is rather expensive due to the need for valuable tools for casting. Because of that there has been accepted a simple design for the palm in the form of a specially shaped plate adapted to carry the mechanism of the motor, thumb, and fingers, and to be connected to the adapter (Fig. 1).



(a) (b)

Fig. 1. Basic plate with the mechanism and motor
(a) previous solution
(b) the new solution

The fingers mechanism is quite different from the previous one (Fig. 2). This mechanism has been made in the form of levers to which the shell has been attached (Fig. 3).

Since the motor has to be placed inside the hand, the mechanism had to be subjected only to constructive modifications for the purpose of providing the space necessary for motor installation. All other characteristics: adaptation, lever mechanism, moving mechanism, etc., remained kinematically the same as in the old version of the hand. This means that the necessary forces and

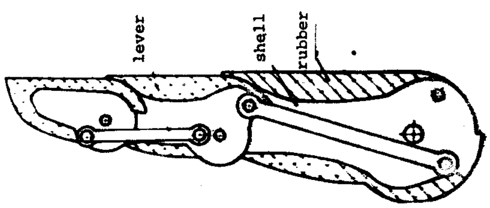


Fig. 2. Shape and mechanism of the old finger

Fig. 3. Shape and mechanism of the new finger

calculation done corresponds entirely to the forces given in the paper delivered by the author at the 3rd International Symposium in Dubrovnik (Fig. 4).

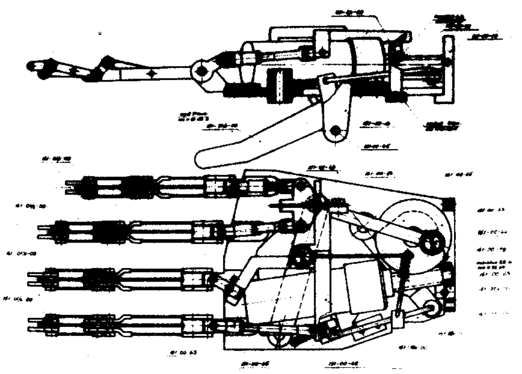


Fig. 4. New mechanism with motor placed into the hand, and fingers mechanism

To the mechanism, the soft parts have been embedded in two layers as follows: the first layer is of spongy rubber; the second one, a glove made of polychloropren (Fig. 5).

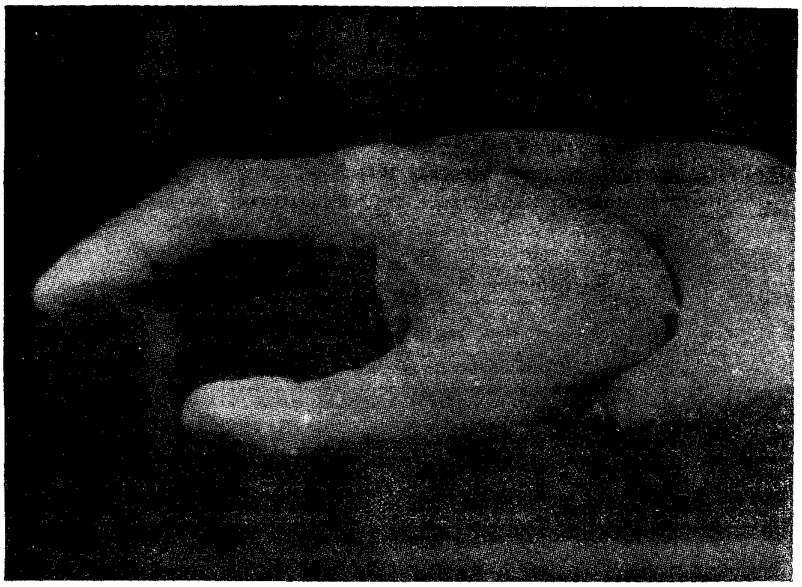


Fig. 5. Complete design of the first version of the new artificial hand prosthesis

After all disadvantages of the first design of the new artificial hand prosthesis have been recognized, a second version was design. First of all, it has been noticed as necessary to place the mechanism between two plates, one of which should be the carrying one, and the other, above it, to be in the form of a grating. The purpose of this one is to fasten those kinematic elements that are exposed to large forces during the time the artificial hand prosthesis is loaded. In this way, the worm carriers, fastened by means of consoles, and the levers should be supported at two points thus improving the rigidity and providing a better motion of the mechanism. Moreover, the thickness has been reduced, and the use of external soft parts of the palm and thumb has been made easier (Fig. 6).

The disadvantage of this mechanism is the externally motor location, what cannot be always applied. However, this same construction can be realized with the motor located internally, as was shown with the construction of the first version. We finally consider this as the definite solution for all future makes with the multifunctional artificial hand prostheses.

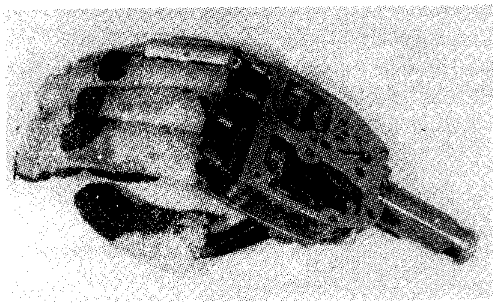


Fig. 6. Mechanism with two plates and the motor placed externally

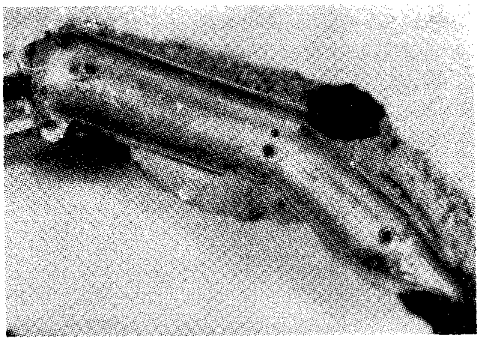


Fig. 7. New artificial finger

Experience with the first model showed that the fingers with the lever mechanism to be impractical, and thus the construction of the fingers by means of a shell has been tried. Definite shape of the finger is like the one of the shell, with the necessary carriers and levers for moving (Fig. 7). This shape is more expensive to make, but is considerably lighter than the other design. The finger made in this way weights only 21 grams.

The mechanism of the artificial hand shaped in this way with two plates and fingers in the form of a shell makes possible the placement easily of the soft parts and the glove (Fig. 8).

The appearance of the new artificial hand is the same as with the first version (Fig. 4).

The functional characteristics of this hand are exactly the same as the characteristics of the old model that was demonstrated at the 3rd International Symposium in 1969. The only thing that has been improved with its functioning is a reliability in grasping and reduction in sliding of the grasped parts because with this new version a sufficiently large soft layer has been used. The investigations show that with certain grasps, especially coarse parts, this satisfies the same technical conditions as that achieved with the natural hand.

Based on the investigations performed in the Institute for Rehabilitation in Belgrade of both the Belgrade artificial hand and other prostheses, and on the basis of the contribution by

Fig. 8. Complete mechanism of the second version of the artificial hand prosthesis

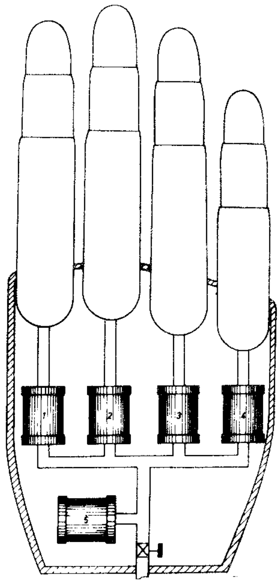


Fig. 9. Cylinders for moving the fingers and thumb

the author and Dr. Andrew Frank on the philosophy of controlling the "critical tasks" of the artificial prostheses, there has been developed one model more of the artificial hand with the new control philosophy and hydraulic drive. Namely, the artificial hand should be moved by the patient's preserved natural extremities and its movements as are legs, arms, and the others.

By its construction this model has the carrying plate and fingers the same as described in the above mentioned paper. Instead of the mechanism with the electro-motor, this prosthesis has built-in five hydraulic cylinders with a piston and membrane that move directly the fingers and the thumb (Fig. 9).

The advantage of this kind of design is that there are no rotating parts because the cylinders move rectilinearly. Also, there is no need for any adaptive mechanism since it is known that in the hydraulic system, that is being supplied from one point, the adaptation is performed automatically by the slowing down of one finger, that is,the piston in the cylinder, while the other fingers continue to move automatically (Fig. 10).

The elementary control part is a separately designed transmitter that can be built-into the heel of the shoe. This transmitter is intended to convert the force of the leg into hydraulic pressure that transfers the mechanical motion through the fluid to the cylinders of the fingers and thumb. The control itself is dictated by the man's own will and he provides such force as he considers necessary. Thus the external power supply is avoided. There are no batteries, pumps, other artificial sources. In addition, there is no need for a particular computer, or for checking the control because this is done by the man on his own

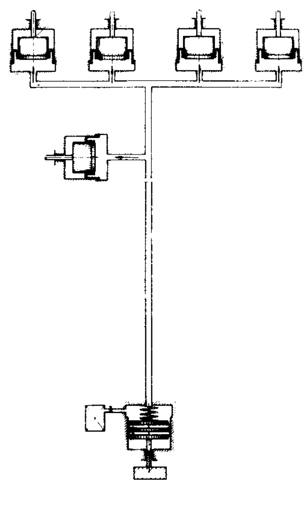


Fig. 10. Control scheme of the hydraulic artificial hand

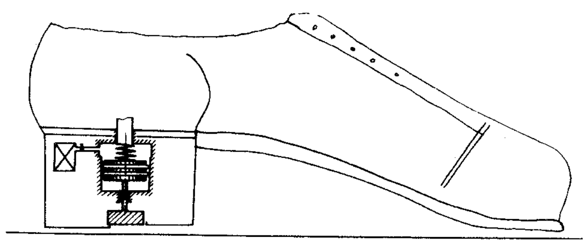


Fig. 11. Hydraulic transmitter of the artificial hand prosthesis

option. Special difficulty is encountered when constructing this transmitter with the mechanism for pressure amplification. This has been solved as follows: the transmitter consists of a cylinder with a sufficiently long travel, and the possibility for its locking, as well, in order to make it possible for the patient to walk and control slowly the system of artificial hand prosthesis at the same time (Fig. 11).

This transmitter operates so that in the cylinder, the piston under the effect of its own weight and one spring, is brought into its lower position, after the by-pass valve has been opened, through which the oil flows freely from one end of the cylinder into the other or into the tank. In this position, the transmitter is immediately ready for control after the by-pass valve has been closed. The pressure on the piston rod creates the pressure necessary for moving the fingers and thumb. This pressure has been adjusted in such a way to give maximum force of the pressure in every cylinder (10 kp/cm^2) as the case is with the electrically powered prosthesis.

In this way the forces obtained and the motion of this artificial hand are completely indentical with the two electrically powered artificial prostheses mentioned above.

Based on the up-to-date development of the Belgrade artificila hand prosthesis, very useful results can be demonstrated. The mechanism has been used on 30 artificial hands so far, wherefrom a great number has been tested in Institutes all over Europe, and a great number of it on patients. For all this time not even the smallest fault of the mechanism has been noticed. In addition, the mechanism has been subject to all laboratory tests.

Another very important result is the final solution of the shape and way of making the fingers. From all the fingers that are investigated, the one with the shell has proven to be the lightest. This form is very suitable for placing soft parts on it; it is stable in operation; and, as such, it can be considered as the best.

In constructive definite solutions there is also included the solution of the palm and the back of the hand; that is, the solution of the mechanism support by means of the gratings. This grating is very light, while at the same time it is very rigid, thus enabling safe use of the mechanism and sure motion and grasping of the fingers and thumb.

Finally, the kinematics of the mechanism for changing the position of the thumb has been solved in a very simple way. It makes possible three positions of the thumb. The streched-out thumb together with the fingers aesthetically and functionally have proven to be very good. The closing of the thumb when the fingers close to the fist makes it possible for some objects to be held safer. At last, there is the third position of the thumb for a reliable pinch.

The control philosophy with the hydraulic system can be considered as an essential result. In it man controls, by his own extremities, with only a slight force because a hydraulic amplifier has been built-into the system. Further, this solution is very simple because it does not call for a separate power supply; there are no parts to wear out so it is of long duration; and it is cheap and reliable.

It must be pointed out that all this has made it possible to obtain a very light weight hand (below 400 gr). At the same time, this design provides a smooth multi-functionality to the artificial hand. An artificial glove made of polyurethane, under which there are placed the soft parts, gives a natural appearance to the hand and a softness of grasp, similar to the human natural hand.