REPORT ON THE FURTHER DEVELOPMENT OF »BELGRADE HAND PROSTHESIS«

M. RAKIC

Introduction

The basic ideas and principles underlying the design and later improvements of the multifunctional »Belgrade hand prosthesis« have been published elsewhere[1,2,3,4,5] and it will therefore be assumed that they are known. The prototype of the hand prosthesis was tested in detail for its rehabilitation properties in summer 1964 by a group of experts. The results of these tests and accompanying comments and suggestions can be found in the published Report[6]. Early this year, the Biocybernetic Department of the Mihailo Pupin Institute started a two-year program, the purpose of which is to eliminate deficiencies which have been noted and to develop a technology which would make possible series productions of the prosthesis and its wider application. This program was prepared with a group of experts from Walter Reed Army Medical Center, Washington, D.C., U.S.A. Deficiencies of the prosthesis can be summarized as follows:

a) instability of finger joints,
b) insufficient grasping power,
c) unsatisfactory and noncosmetic movement of the thumb,
d) excessive weight,
e) insufficient cosmetic appearance,
f) impossibility of easy repetition of the same type of grasping,
g) unreliable operation of the transducers.

It is still too early to present final results of our work. We shall therefore just try to explain how we intend to eliminate the above-mentioned deficiencies and what we have done so far.

Fingers

We still adhere to the concept that fingers should have three movable phalanges, but there will be two versions of the prosthesis. In

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the first version all four fingers will be movable and the motion of the fifth and the fourth finger can be voluntarily blocked in the extended position if necessary. In the second version the index and the middle fingers will be movable while the other two fingers will be made of hard rubber in a fixed, slightly bent position.

The lever mechanisms controlling the finger motion have been slightly changed in order to attain a somewhat more favorable mutual turning of the phalanges and also to place the phalanx shafts into the middle axis of the fingers. By placing these shafts into the middle axis of the fingers we avoid undesirable openings on the phalanges, which had been inevitable earlier, and enable ball-like joints between the phalanges.

With these improvements we have made all four fingers using aluminum as basic material. Experiments with these fingers have shown that the joints of the phalanges are sufficiently stable and that the fingers can withstand a load of up to 100 kg. without any deformation.

There is another change which we intend to make in the earlier model of the prosthesis. During experiments with the original prototype it was found that in grasping with finger tips, mutual adaptation between the index and the middle finger, which permits small displacement between these two fingers, may often cause the patient to drop the object, particularly if it is thin. We wish, therefore, to introduce a better solution in the new model of the prosthesis.

Grasping Power

Repeated calculations have confirmed that the D.C. servomotor size 11 PM can provide the required pressure of 6 kg. at finger tips. The only reason why this was not achieved in the existing prototype of the hand prosthesis 1.5 excessive mechanical losses in the gearbox and the mechanism of the hand. Without making any changes in the basic principles of the existing solution, but introducing only a rotating lever, substituting ball-bearings for the sliding bearings and with more careful machining of the various parts, particularly the gearbox, it is expected that this deficiency will be eliminated. The new mechanism of the hand has not yet been completed and it has therefore not been possible to verify experimentally whether the expected results will really be achieved.

The Thumb

With the existing prototypes of the hand prosthesis we have experimented with two types of thumb motion. In the first version the thumb was initially behind the index finger and after completing the motion it was in opposition to the index finger and middle finger, thus realizing grasping with finger tips. In the second version the thumb was initially in opposition to the index and the middle finger and was moving in such a way that the tip of the thumb remained in a plane parallel to the palm.

It was found that both types of motion of the thumb were unsatisfactory both from the functional and cosmetic points of view. We want therefore to make some changes in the type of motion of the thumb. In the final version of the hand prosthesis the thumb will initially be in opposition to the index and middle finger and will move in a plane which is almost normal to the plane of the palm. In order to understand the reason for adopting such a type of thumb motion, it is necessary to explain briefly how we intend to realize various types of grasping.

Realization of Various Types of Grasping

The initial position of the hand will be such that the fingers are slightly bent and the thumb, as already mentioned, would be in opposition to the index and the middle finger. In this position the free opening between the tips of the index finger and the thumb would be only three centimeters wide. If the patient wishes to perform grasping by finger tips from this initial position, the fingers would move towards the thumb and the latter would remain in its initial position. In this way the patient will be able to grasp only smaller objects.

To realize the fist from this initial position, the fingers and the thumb would start moving simultaneously in opposite directions so that when the fingers reach the fully extended position the thumb will also be in its farthest position, realizing the greatest free space between the tips of the index finger and the thumb of about 9 cm. If the patient does not stop or change the direction of the rotation of the servomotor, the fingers would again start to bend until they closed into a fist while the thumb remained still.

With such a program of motion of the fingers and the thumb, the patient, in order to grasp bigger objects with finger tips, would first start the fist-type of grasping until the fingers and the thumb are sufficiently apart and he would then change the direction of rotation of the servomotor.

Actually, the new method of controlling the hand prosthesis imposes no limitations as to the initial position which the patient may chose. We indicated the earlier described position as initial because the prosthesis has then a shallow and cosmetic appearance and the patient can quickly perform grasping with finger tips of smaller objects which is actually the motion most frequently needed.

Cosmetic Properties of the Hand Prosthesis

Ball-like joints between the finger phalanges and between the fingers and the body of the hand have made it possible to eliminate unnatural shape of the fingers and undesirable openings in them. The thumb is also joined to the body of the hand by a suitable joint which makes it possible to avoid any openings while the thumb is in motion. These facts, together with the earlier described initial position of the fingers and the thumb and the type of their motion, have made it possible to make a hand prosthesis with satisfactory cosmetic properties.

Since such a prosthesis with movable fingers and thumb cannot be fitted with a standard cosmetic glove, we are thinking of coating the body of the hand with some suitable material.

Weight of the Hand Prosthesis

In designing the hand prosthesis we have been taking and shall continue to take the greatest care to reduce the weight of the prosthesis to the minimum without impairing the strength, reliability and durability of the prosthesis. However in this way it is impossible to achieve any considerable reduction in the total weight of the prosthesis. Analysing this problem in detail in the light of all performances an rehabilitation properties of the »Belgrade Hand Prosthesis« we have come to the conclusion that the use of an automatic hand prosthesis is justified only in the cases of high amputations of the forearm, or as part of an arm prosthesis. Taking this into account, it has been decided that the servomotor and the main gearbox should not be built into the hand prosthesis, as is the case with the existing prototype, but that they should be placed into the forearm section as close to the elbow as possible. In this way, the weight of the hand prosthesis will be greatly reduced.

Control of Motions

Experiments with the existing prototype fitted to patients have shown that further improvements in the control of the prosthesis are possible. The basic dilemma as far as the control logic is concerned was the following: should the patient be given the freedom of independently commanding the power and the direction of the rotation of the servomotor, in which case two points for voluntary command would be required, or should these two commands be connected and conditioned, in which case the number of command points would be reduced to one, but the execution of certain types of grasping would then become more complicated.

Since both solutions have certain advantages and disadvantages, it was decided to develop electronics which would make possible both types of control. The control logic would then be set up for each patient separately in accordance with his abilities and desires.

The block diagram of the circuitry for independent voluntary control of the servomotor power and the direction of the servomotor rotation with two command points is shown in Figure 1. Block diagram of the same circuitry with one command point, where the reversal of servomotor rotation is conditioned by reducing its power to zero that is, by stopping the motor, is shown in Figure 2.

In the first case (block diagram Fig. 1), by pressing voluntarily the sensitive element of relay type SR 1, the patient reverses the rotation of the servomotor and thereby expresses his desire to close or open the hand prosthesis, and also he chooses the type of grasping. By pressing the sensitive element of potentiometer type SE, the patient adjusts the power of the servomotor between zero and the maximum value. In this way he decides when the motor should start or stop, what should be the speed of the finger motion, and what should be the grasping power.

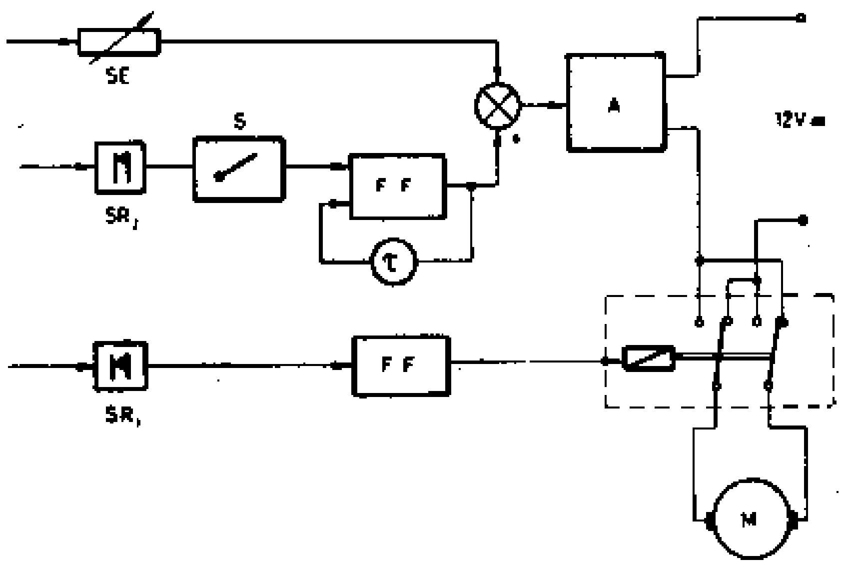

Figure 1. Block diagram of the electronics with two points of voluntary command. M — D.C. servomotor, A — power amplifier, S — switch, SR_1 — sensitive element of the relay type to command voluntarily the direction of servomotor rotation, SR_2 — sensitive elements of the relay type to control automatically the hand prosthesis, SE — sensitive element of the potentiometer type to command voluntarily the servomotor power

In the second version (block diagram Fig. 2), the sensitive element of relay type for commanding the reversal of servomotor rotation has been dropped out and the sensitive element of the potentiometer type is fitted with a sensitive element of relay type which serves as an end-point switch (SEC). Therefore the reversal of servomotor rotation is conditioned by bringing the motor power to zero, and, conversely, whenever the motor power comes to zero a reversal in the direction of rotation is effected. This is quite justified since after every closing of the hand prosthesis and grasping of an object there should usually follow the opening of the hand prosthesis and dropping of the object, and vice versa. The only difficulty occurs in the case when the patient has initiated a movement of the hand prosthesis then stops and after that wishes to continue it, or if he has grasped an object and wishes to increase the grasping power. In that case he must first slightly press the element SEC in order to change the direction of rotation of the servomotor and then continue the initiated movement or increase the grasping power.

The possibility of automatic grasping of objects, through the activation of one of the sensitive elements of relay type located in finger tips (SR 2), is foreseen only for the position in which the fingers are fully stretched, when the switch S is closed. When the hand prosthesis is in this position the pressing of any of the sensitive elements of relay type SR 2 will start the servomotor. The power which the motor then develops is approximately 75 percent of the maximum power.

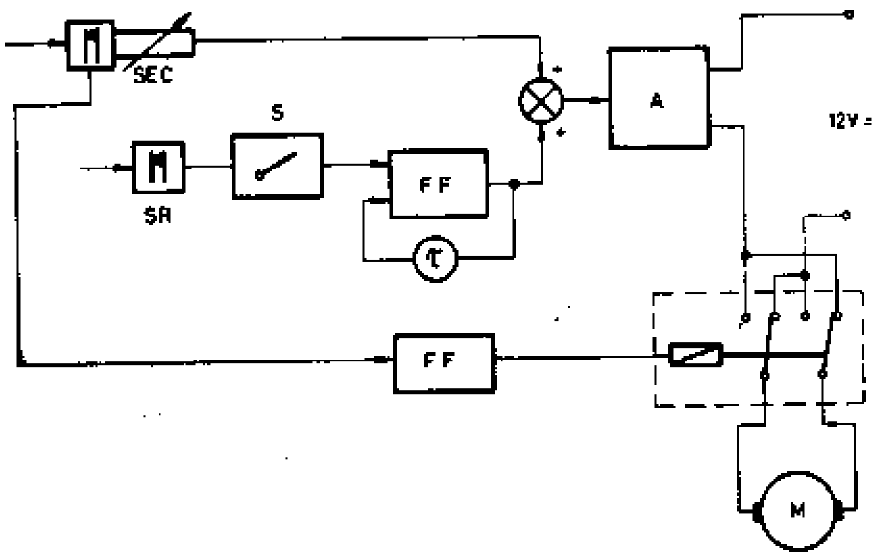

Figure 2. Block diagram of the electronics with one point of voluntary command. M — D.C. servomotor, A — power amplifier, S — switch, SR — sensitive elements of the relay type to control automatically the hand prosthesis, SEC — sensitive element of the potentiometer type to command voluntarily the servomotor power with end point switch used to control the direction of servomotor rotation

After this automatic start the servomotor is automatically switched off through a feedback path with delay time τ which is sufficiently long to enable the grasping of any type before the motor is switched off.

Sensitive Elements

Certain improvements in the technology of the manufacture of sensitive elements have been made, but we shall continue to make improvements particularly in the characteristics of the sensitive elements of potentiometer type.

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