TECHNICAL EVALUATION OF THE BELGRADE HAND PROSTHESIS

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Summary

The paper presents the tests applied in the technical evaluation of the Belgrade hand prosthesis, as well as the obtained results. General results only are given. Detailed results and their technical interpretation will be covered in a separate report. Since accepted standard tests for the technical evaluation of externally powered hand prostheses do not exist, this work deals also with questions concerning the standardization of the hand prosthesis evaluation.

Introduction

During 1966 and 1967 a multifunctional hand prosthesis known as the Belgrade hand prosthesis [1], [2], [3] was developed at the Mihailo Pupin Institute and a series of 26 units were made. To determine the performances of this prosthesis, its technical and functional evaluation was started in 1968 and continued in 1969.

Since the item in question is a prototype hand prosthesis based on a quite new concept, the problem of its evaluation created a series of questions.

The evaluation should not only determine the performances of the hand prosthesis but also indicate the drawbacks that would be corrected in further technological development.

— Alternative solutions to the design of the hand prosthesis existed and the evaluation should indicate which of these was most suitable.

— Particular attention was to be paid to the advantages imposed by the multifunctionality of the hand.

— Finally, in practice heretofore the evaluation of externally powered prostheses, and particularly of multifunctional prostheses, had not been carried out so that neither test procedure nor experiences along these lines existed.

All the stated factors show that this evaluation could not be approached in a routine manner but in itself represented researches in a definite direction. Besides, it follows that it was necessary to carry out a great number of tests to have all the questions answered.

This contribution treats the problem of technical evaluation of the Belgrade hand prosthesis done at the Mihailo Pupin Institute, Belgrad. The functional evaluation was done at the Institute for Prosthetics of Serbia, and the results of this evaluation are presented in separate papers.

The main results of the Belgrade hand prosthesis technical evaluation are given. Immediately it should be pointed out that the procedure of technical evaluation has led to a great amount of numerical data and diagrams that cannot be given completely in this paper. Therefore, a series of results is given in the form of conclusions based on many measurements, and the quantities set forth represent the mean values of these measurements.

In forming the evaluation tests the primary intent was no to come to a standard for the technical evaluation of the hand prosthesis just because of specific conditions. However, various authors are of the opinion that starting with these test procedures such standards could arise.

The test are included in the paper, and for the purpose of clarity they can be divided into descriptive, measuring, and endurance test.

Descriptive Tests

From the results of this group of tests it can be concluded that the hand prosthesis matches the shape and size of the human hand with all fingers active. The hand mechanism is of a self-locking type owing to a high reduction of the worm gearing not requiring additional power for locking and unlocking. All the parts of the prosthesis are made of low-corrosive, noninflammable material which does not cause deleterious effects on the material and colour of the glove. The mechanical system of the hand prosthesis is such that the penetration of foreign matters is reduced to a minimum.

The control system consists of standard equipment and uses the signals from potentiometers and switches activated by the patient which voluntarily determine the opening and closing as well as the proportionate power regulation of the hand prosthesis.

Measuring Tests

First, the dimensional and weight measurements were done and from these it can be concluded that the prosthesis is of the size of an average human hand and that in the ventual serial production a size above and a size below the average should be provided.

However, the hand weight of 570 gr is still above the allowed limits and it is indispensable to reduce it to one third of the present weight.

In the standard model a distance of 80 mm is needed between the hand and patient's amputation stump for location of the motor.

The measurement of the maximum hand opening indicates the largest posible dimension of an object the hand can grasp. It amounts to 70 mm.

The measurements indicate that the latero-medial displacement of the fingers is very small — maximum = 1 mm.

The relationships between the sizes, surface quality, and object weight the hand can grasp are very irregular. For this measurement the following standard objects were used:

1. Cylindric objects with diameters of 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, and 60 mm,
2. Spherical objects with the same diameters,
3. Objects with rectangular section whose width increases from 5 to 60 mm by increments of 5 mm.

For each kind of the objects two groups existed: one with smooth and one with rough surfaces. According to the obtained results in respect to the mentioned properties of the objects, the most general conclusions can be drawn as follows:

(a) The weight of cylindrical objects the hand can hold is most frequently greater for the objects with greater diameters and rough surfaces as well as for grasping by fist. It is within 0.8 — 4.5 kp.

(b) The weight of the spherical objects that can be held first increases as the diameter increases, but for greater diameters it decreases. Here, too, the roughness of the surface increases the maximum weight that can be held by about 30 per cent. The range of the weight change is 0.2—6.5 kp.

(c) The weight of the objects with rectangular section also shows great deviations at particular points but also a tendency of increase for greater widths of the objects and for a rough surface. Range of change is 0.5—9.2 kp. i. e., the maximum weight in comparison to cylindrical and spherical objects is obtained here.

The measurements of the potentiometer cable travel indicate that an excursion of 1.5 mm to 20 ± 1 mm is required with the back lash which amounts to about 1 mm not being a significant factor.

The dimensions and weight of the electronic device suffice since the same can be settled into the pocket. However, the present possibilities of miniaturizing the components allow for further reduction if needed.

The standard solution foresees the settlement of the control potentiometer on the patient's back between his shoulder blades and thus its dimensions are adapted so as not to cause ugly bulges under his clothes. The potentiometer is of the disc form with a width of 7 mm and weight of 30 p, being within the specified tolerances. Here it can also be said that further reduction is possible owing to modern miniature components. The necessary pulling force of the potentiometer active cable by the patient is within 0.5 to 3 kp. The tearing force of this cable is about three times greater than the maximum force needed for activation, but as an obligatory protection there is placed a mechanical protection against the cable tearing.

The most space is taken by the batteries which are about four times greater than the electronic logic device and about six times heavier so that they cannot be placed easily into a pocket but must be placed in a separate bag. It has been seen that tho present capacity of the batteries is in excess of need and it can be reduced to one half to satisfy a one-day hand operation without recharging.

With the electric measurements the elementary procedure was:

(a) To measure the power consumption of the electronic prosthesis as a whole and its particular components under various operating conditions;

(b) To determine the extreme values of the supply voltage at which the system is still operating well and in excess of which the system fails to function or is destroyed;

(c) To determine particular electrical characteristics of the system.

All these measurements were done and the obtained results satisfied the technical conditions set forth.

The results of these tests show that the consumption range is from 280 mW to 35 W, depending on the excitation and operating conditions. As far as the time of one battery charging lasts at a continuous discharge, it varies from 48 minutes at maximum consumption to 22 hours at minimum.

The dependence of batteries on charging and the number of cycles the prosthesis can accomplish at a minimum, mean, and maximum excitation have been measured by means of the machine for cyclic prosthesis activation. By comparing the results it can be found that the number of cycles on one charge increases with the frequency of grasping and amounts to 2700 cycles. It can be concluded that at a mean and maximum excitation it is always possible to satisfy an average number of cycles (300—500) required for one-day activity of the patient. This number can also be multiply exceeded by using only one battery. In some cases with minimum excitation, however, that is, when the system is continuously in operation for a longer time period and the movements are done relatively rarely, even one charging can be insufficient.

The time measurements of particular cycles with a minimum and maximum excitation show that the duration of particular cycles in addition to the excitation depends also on the reduction of DC motor as the actuator — with a motor with higher reduction the duration of particular cycles is within 3.5 and 33 sec, and with the lower reduction from 1.2 to 15 sec depending on the excitation. In connection with this it should be noted that the squeezing force is proportionate to the reduction, i. e. time, and thus with a slower hand 12 lbs squeezing force is achieved, and with a fast one — up to 6.8 lbs. The force of automatic squeeze is within 20 per cent to 35 per cent of the maximum squeeze.

Tests of Endurance

Since the measurements of endurance to destruction call for destroying some parts, these measurements have been done on three particular hands.

The maximum loading moment on fingers is from 2.5 to 12 kp.

Axial compressive force at the fingers is within 20 to 30 kp, while the tearing force to extension is very high, within the range of 180 to 260 kp.

The levers of the finger mechanism break only at a force of 190 to 287 kp, and the pins of the finger mechanism at 320 kp; the same thing is true with the pin bearings.

The measurements of the operating life time of the hand prosthesis have been done on the cyclic machine up to 50,000 cycles, or to the first failure of the whole system, or of particular components. It is of interest to mention that both hands endured to 50,000 cycles the operation of grasping by fingers or fist, but during the operation in cycle which includes successively both grasps, the failure appeared early — after about 20,000 cycles.

The operation of the hand prosthesis was tested in a chamber at different temperatures.

The prosthesis operated within the range of -5 to $+85$ deg. C and endured passively a range of -55 to $+85$ deg. C. Also, the behaviour of the prosthesis when exposed to vibrations and shocks was tested. The prosthesis endured the vibrations of amplitudes ± 35 mm at 55 Hz (a machine for frequencies higher than 55 Hz was not available) during a period of 6 hours, and endured 4000 shocks at an acceleration of 25 g.

With regard to the elecrical endurance the system is most sensitive to the overheating in the situation when the motor is braked and the excitation is maximum. Then the highest allowable voltage is just equal to the rated supply voltage of 12 V. At a mean excitation which gives the motor half of the maximum output, this voltage is 18 V, and at the minimum excitation — 21.5 V.

Conclusion

On the basis of the clearly defined results of the testing and taking into account that there do not exist standards with which these results could be compared, it is to be expected that some indices during further test decrease and some of them increase since they are not needed in practice. But the fact remains that the methodology of testing given enclosed can serve usefully for all the tests, both of the Belgrade hand prosthesis and the other multifunctional hands.