HAND PROSTHESES

SPECIFICATIONS FOR ELECTROMECHANICAL HANDS

H. W. Kay and M. Rakić

Introduction

Standards and specifications for artificial hands have been evolving gradually for approwimately twenty years /1, 2, 4/. Beginning with the APRL 4-C Hand attention was focused initially on hands whose functions were solely mechanical. With the advent of externally powered devices, the need for modification of earlier specifications was evident and various individuals and groups have directed their efforts to this end.

An initial approach to the writing of powered hand specifications was made in 1964 by a "Workshop Panel on External Power" established by the Committee on Prosthetics Research and Development (CPRD). These early guidelines are quite sketchy and highly empirical.

A more systematic approach to the problem was made by Leonard, Rakić and Kay in 1967 /18/. In this instance the items, format, and test procedures pertaining to the earlier APRL mechanical hand specifications were used as bases for writing standards applicable to electromechanical hands. However, in many instances values could not be assigned to powered device items because the necessary information was not then available. In these instances the place for a numerical value was left blank. It was the hope of the authors that the blanks in these requirements would be filled in as additional experience was gained.

In 1969, Leonard, Salisbury, and Colman issued a document on electromechanical hand specifications which essentially reaffirmed the 1967 statements /1/.

The period October 1968 to April 1970. was characterized by intense activity on the part of CPRD's Panel on Upper-Extremity Prosthetic Components under its energic Chairman, Dr. Edward Peizer. Out of the three workshops held during this 18-month period, significant information relating to standards for powered devices (elbow and terminal devices) emerged. These data incorporated in the reports of the meetings /10, 11, 12/.

The most recent activity contributing data and insights affecting standards for electromechanical hands was the evaluation of the so-called Belgrade Hand. In this study, conducted from 1968 to 1970, one of the present authors (Rakić) directed the engineering aspect of the evaluation, while the other (Kay) was involved as consultant in the amputee applications phase /23, 24, 25, 29/. Very interesting data have been provided also by the research work of the Institute of Medical Physics TNO, Utrecht, the Netherlands /27/.

In perspective, the development of specifications and standards for electromechanical hands has followed an evolutionary course with the specifications becoming progressively more comprehensive and precise as additional information has been obtained. Thus the present document constitutes the most recent in a series of successive approximations. Its authors freely acknowledge their indebtedness to earlier workers. Doubtless, other, even more definitive, approximations will follow.

Specifications for Electromechanical Hands

Scope

These specifications and standards cover right and left electromechanical hands which may be connected to, or disconnected from, an upper-extremity prosthesis for amputees, and which allow the amputee to control, select and maintain prehension.

Procedure for Establishing Reference Models

The manufacturer shall supply four (two left and two right) hands with required controls and power source to the Standards Laboratory, for qualifications under these specifications and upon completion of qualification tests, these controls and power sources (hand system) shall serve as standard systems for subsequent approval as to shape, finish, noise, and control characteristics. After mutual agreement has been reached, four of the systems are to be stamped "approved" and two returned to the manufacturer's Quality Control Department for reference on future production; the other two to be retained by the Standards Laboratory.

Requirements

The following standards shall be met by the electromechanical hand with glove:

A. General

1. This hand shall resemble the human hand in configuration and proportions. The hand system shall be of such rugged and substantial construction throughout that it will conform to the quantitive measurements outlined in the specifications and that it will retain its original funtional and appearance characteristics over an adequate period of normal amputee usage with minimal attention and adjustment.

2. This hand shall be designed for satisfactory operation when covered with a cosmetic glove or some other form of cosmetic treatment designed to provide a frictional surface, and the external appearance of the human hand.

3. This hand shall be of the locking type, that is, of such a design that between full opening and full closing an infinite number of locking positions shall be available to the amputee.

4. The method of attachment of this hand system shall be compatible with prosthetics applications techniques and should permit a patient to put it on and take it off by himself.

5. This hand system should be capable of attachment to a passive or active wrist joint.

6. This hand system shall be free of objectionable noises.

7. This hand shall be capable of operation by amputee-generated signals such as electromyographic signals or through the use of muscle bulges and body motions to operate switches, strain gauges, potentiometers and the like.

8. It is desirable that there be no wires connecting the patient and the hand system. If this requirement is impossible to realize, the number of cables should be minimized.

B. Appearance

1. The shape of the hand shall conform to the shape of the normal human hand as cited under general requirements.

2. The size, shape, color, finish, workmanship, shall be in accordance with the standards hand previously discussed.

3. If an inner soft glove is not part of the hand system, the external surfaces of the hand shall be flesh-colored, and shall be resistant to damage or deterioration from contact with lubricants or cosmetic gloves, and to mechanical abrasion (Test Procedures A.1 and 2, E.4, E.5, and E.6)*.

4. The fourth and fifth digits, even if they are not actively powered, shall be adequately and securely attached.

5. The fourth and fifth digits, if passive, shall be fabricated from a soft flexible material and incorporate a soft steel armature to permit variable finger positioning.

6. The position of the first digit (thumb) should be proper (lifelike) and should not increase the bulk of the hand in the rest position.

C. Prehension Capabilities

1. For those hands providing palmar prehension at least the thumb and second and third digits shall be motor driven. For those hands providing both palmar and fist prehension, all five digits may be motor driven.

2. Palmar prehension shall occur between the thumb and active second and third digits. The second and third digits shall come together laterally as they approach the thumb during closure and shall contact the thumb simultaneously. At full closure the position of the second and third digits shall be such as to permit a .100 in. (0.254 cm) gauge block to pass between their opposing surfaces at the fingertips but not permit the passage of a .135 in. (0.34 cm) thick block.

3. Maximal opening between the thumb and active second and third digits shall not be smaller than 3.5 in. (8.9 cm).

4. The angle between a plane and the longitudinal axis of the hand stud shall be between 15° - 32°, when the first, second and third digits are touching the plane with the hand fully closed (Fig. 1). This angle and the shape of finger tips should permit

---

In some modern designs, the hand has no rigid shell but has a thick inner soft glove or filler over an electromechanical construction and a cosmetic outer glove. Requirements for an inner soft glove are under consideration by the committee on Prosthetics Research and Development and, when determined, should be specified separately.

the hand to grasp cylindrical object 1.5 in. (3.81 cm) in diameter by 0.25 in. (0.63 cm) thick lying on a horizontal surface.

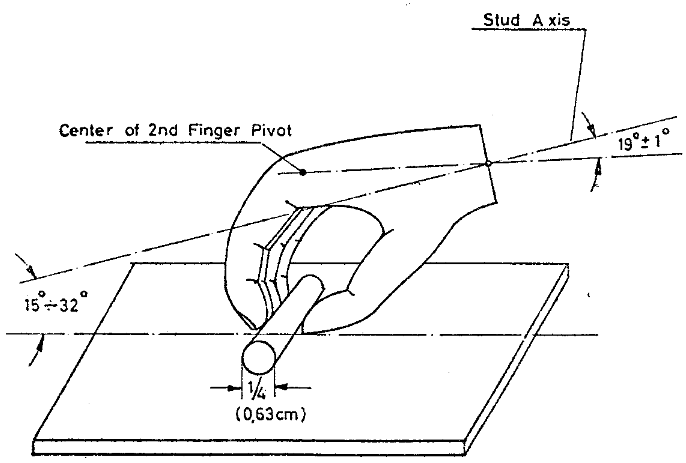


Fig. 1.

5. The hand shall be capable of grasping and lifting cylindrical and spherical object 3 in. (7.6 cm) in diameter in the crooks of the fingers; and of receiving and holding rectangular objects 3 in. (7.6 cm) in thickness between the fingertips for palmar prehension. If fist prehension is provided the hand must be capable of grasping rods of a minimum of 1 in. (2.5 cm) to a maximum of 3 in. (7.6 cm) in diameter.

6. The grasping force of the hand shall be continously variable between zero and not less than 15 lbs. (6.8 kp)* at 5/8 in. (1.6 cm) opening and not less than 10 lbs. (4.5 kp) at 3 in. (7.6 cm) opening (Test Procedure C.1).

7. For hand system with automatic control of grasp, the initial active grasping force shall not exceed 1 lbs. (0.45 kp). In lifting a cylindrical object of 5/8 in. (1.6 cm) diameter requiring more than 1 lb. (0.45 kp) pinch force but not more than the maximally available pinch force, the object shall be retained as the hand moves with an acceleration of 3 ft/sec^2 (0.9 m/sec^2) (Test Procedure C.2).

8. The maximum opening and closing velocity of the hands

kp (kgf) kilograms of force

shall be such that the time from opening to full closure (and the reverse) in palmar or fist prehension shall not exceed 1.2 seconds.*

9. After grasping an object the hand shall be locked on the object without blacklash with the motor automatically becoming de-energized. When this occurs, the idling power in the control electronics shall not exceed 0.2% of maximum consumption power.

10. Lock operating efficiency shall be such as to maintain fully the pinch force developed just prior to locking, and no more than 105% of that value after locking (Test Procedure C.3).

D. Controls

The controls for the electromechanical hand shall:

1. Provide voluntary control of opening and closing with proportional control of grasping force and, if possible, of speed.

2. If both grasping force and speed are not voluntarily controlled, the control system shall allow the amputee to override the operation (stop and/or reverse) at all times.

3. Not require any energy expenditure, either electrical or on the part of the amputee, to maintain locking.

4. Not be subject to inadverent activation.

5. Not involve the sound side or any other part of the body which will result in reduced total functioning.

6. Transducers requiring excursion but minimum force, for example, switches, potentiometers, etc., shall have a maximum excursion requirement no greater than 5/16 in. (8 mm).

Transducers requiring force but minimum excursion, for example, strain gauges, myoelectric signals, etc., shall have a maximum force requirement no greater than 1.5 lbs. (680 gr.).

Transducers requiring both force and excursion shall have maximum force and excursion requirements not exceeding those specified above.**

Opening and closing speeds less than those cited are considered to be too slow. Velocities at the other end of the spectrum, i.e., too high for patient control, have not been determined. The INAIL hand is said to open (or close) fully in 0.4 sec. without operator problems.

Detailed requirements for individual kinds of transducers: myoelectric electrodes, switches, etc., are not included within these specifications. Separate specifications should be developed for these items.

7. If the transducers which are used are not actuated by force and/or excursion but in some other way, their actuation should be well within the capability of the amputee and the minimum value of actuation should be such as to avoid inadvertent activation.

E. Structural Integrity

1. The hand shall withstand a static axial compressive force of 250 lbs. (113.40 kp), and a static axial tension force of 200 lbs. (91 kp) (Test Procedure E.1, Figs. 2a and 2b).

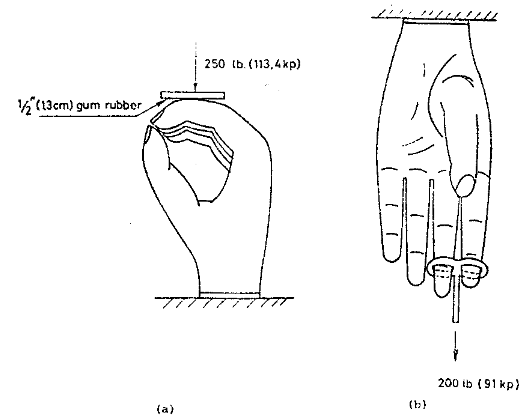


Fig. 2.

2. The hand shall withstand a torque loading of 250 lbs/in. (288 kp.cm) when applied as shown in Figures 3a and 3b. The lateromedial play in all active fingers shall be no greater than 0.050 in. (1.3 mm) prior to applying the torque as shown in Figures 3a and 3b. After application of the loads, the mediolateral

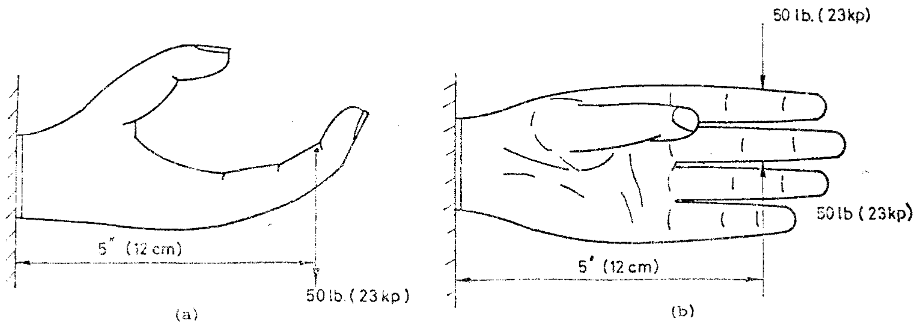


Fig. 3.

play shall be no greater than the measured original play plus 0.005 in. (0.12 mm). After the torque loads shown in Figure 3g are applied a second time to the fingers, the play shall be no greater than the original amount plus 0.007 in. (0.18 mm) (Test procedure E.2, Figs. 3a and 3b).

3. At the locking positions the hand shall be able to support a 45-lb. load suspended from the prehensile fingers without slippage, jamming, or permanent distortion of any part (Fig. 4 and Test Procedure E.3).

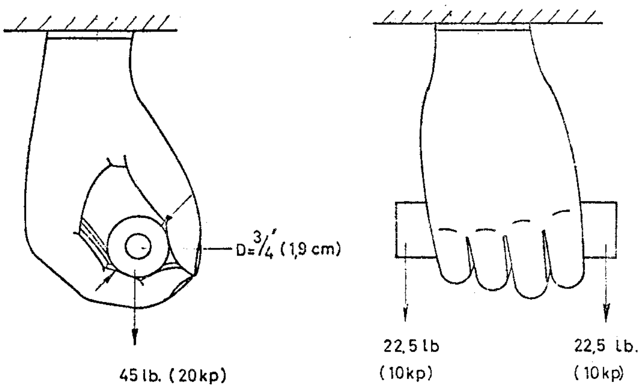


Fig. 4.

4. The hand shall be capable of undergoing 300,000 consecutive cycles without failure or undue wear. At 300,000 cycles the hand shall satisfy all the functional requirements of this specification (Test Procedure E.4).

5. The control system shall be capable of undergoing 300,000 cycles. At 300,000 cycles the transducers shall still exhibit the original characteristics with respect to force and excursion required to actuate, plus or minus 10% (Test Procedure E.4).

6. The hand system shall withstand mechanical vibrations in the interval 10 - 100 Hz without any damage and still exibit the original characteristics (Test Procedure E.5).

7. The hand system shall withstand mechanical shocks of 25 g without damage and still exhibit the original characteristics (Test Procedure E.6).

F. Design and Construction

1. There shall be no untoward physiological reaction to the materials used in the hand system, specially in the transducers,

or to the mounting or attachment techniques.

2. All parts shall be corrosive-resistant wherever practicable, free of imperfections, and of the best quality compatible with functional requirements.

3. All external surfaces, edges, or parts shall be rounded and smooth and free of burrs and other discontinuities.

4. The hand assembly shall be designed to keep the entrance of foreign matter to a minimum.

5. All electronic parts should be sealed to prevent ingress of water.

6. The hand system and prosthetic arm shall be fireproof.

7. The temperature of all exterior parts of the hand system shall be less than 95°F (35°C) in the steady state in an ambient temperature of 68°F (20°C), at normal cooling conditions and at the current required for maximum prehension.

8. The hand system shall operate in compliance with these standards at temperature between -20°F (-29°C) and 120°F (49°C) (Test Procedure F.1).

9. The hand system shall withstand temperatures between -20°F (-29°C) and 130°F (75°C) without damage (Test Procedure F.2).

10. The hand system shall withstand humidity between 0% - 100% without damage (Test Procedure F.3).

11. The hand system shall work without disturbances in harmonic variable magnetic induction field of intensity 0.1 mT* and frequency from 40Hz - 1 kHz, and exhibit the original characteristics.

12. During operation the hand system shall not produce noises greater than 50 dB**(Test Procedure F.4).

13. The hand shall be designed and assembled so that it can be adjusted, repaired, and maintained with relative ease.

T = Wb/m^2 (tesla)

Following the Eighth Workshop Panel on Upper-Extremity Prosthetics of the Subcommittee on Design and Development, Dr. Paul Newell conducted a study into nature of noise and its effect on human beings and proposed that "50 decibels represented both reasonable current standard and a maximum acceptable noise level for powered assist devices." It is proposed that beginning in 1972, 50 decibels be specified as a maximum acceptable noise level and that by 1980 or earlier 30 decibels be accepted as the standard.

14. The total weight of the hand system (hand, electronics, transducers and batteries) must not be greater than 2.2 lbs. (1 kg).

15. Overall dimensions of the hand shall be as per the following measurements (Fig. 5a, b and c)***:

Length	6.50 ± 0.0625	in.	(16.5 cm ± 0.16 cm)
Width	3.18 ± 0.02	in.	(8.1 cm ± 0.05 cm)
Thickness	3.10 ± 0.01	in.	(7.9 cm ± 0.02 cm)

(Test Procedure F.5)

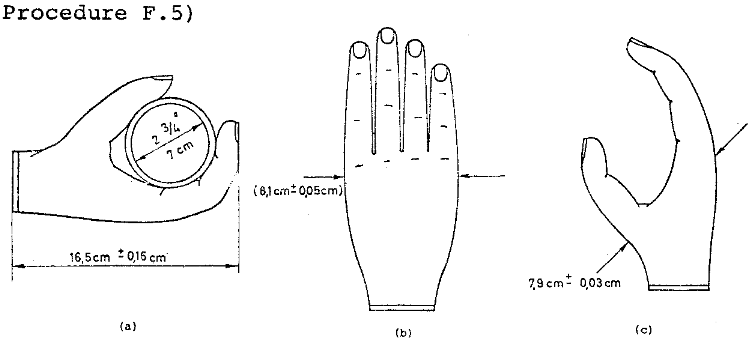
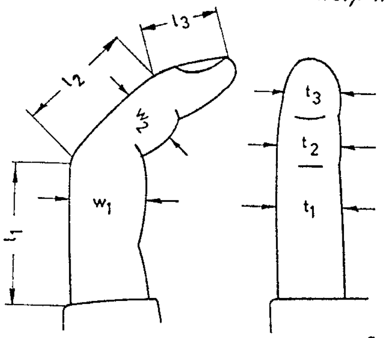


Fig. 5.

16. The dimensions of the thumb, second and third digits shall be approximately those given in Figures 6a, 6b, and 6c.

Not only must an artificial hand look and preferably feel like a human hand but also its size and proportions must be appropriate for the wearer. Moreover, its general configuration should be humanoid and take account of such factors as contours and the definition of musculature and blood vessels.
Sufficient experience has now accumulated with hand-sizing and proportions to establish that the original specifications developed by APRL /2/ are essentially satisfactory and constitute sound guidelines for present and future developers (Figs. 1, 2, and 3).
The most common hand design is the one for use by adult patients. The APRL 4-C mechanical hand was considered suitable for women and small to medium men. It is noteworthy that the AIPR (pneumatic) HAND is the same size as the APRL and the AMBRL hand is essentially the same; while the Otto Bock, Viennatone, and INAIL hands are 1/8 in. larger in length, width and depth /9/, each of these hands has achieved general cosmetic acceptance. It is on the basis of this experience that the present specification has been developed. It is beyond the scope of this paper to consider the sizing of a range of hands which would cover the entire population. Nevertheless, it is belived that adequate data to determine such sizing is avaliable in the Birdsell and DeFries reports and in the dimensions of the smaller-sized APRL and Dorrance hands that have been manufactured.

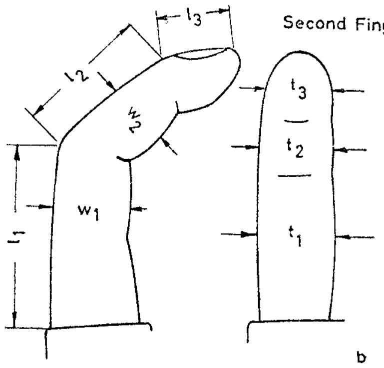
First finger



d	in	mm
l_1	1,85	47,0
l_2	1,05	26,7
l_3	0,85	21,8
t_1	0,67	17,0
t_2	0,61	15,5
t_3	0,58	14,7
w_1	0,75	19,1
w_2	0,58	14,7

a

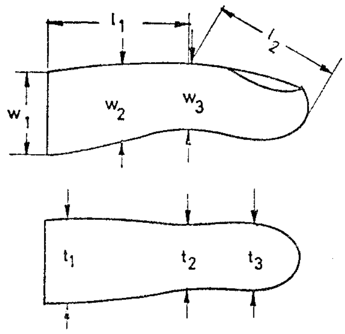
Second Finger



d	in	mm
l_1	2,00	50,8
l_2	1,25	31,8
l_3	0,90	22,9
t_1	0,67	17,0
t_2	0,62	15,8
t_3	0,57	14,5
w_1	0,76	19,3
w_2	0,65	16,5

b

Thumb



d	in	mm
l_1	1,61	40,8
l_2	1,12	28,4
t_1	1,00	25,4
t_2	0,72	18,3
t_3	0,76	19,3
w_1	1,06	26,9
w_2	0,73	18,6
w_3	0,74	18,8

c

Fig. 6.

17. The weight of the hand with glove or other cosmetic treatment shall not exceed 13 oz. (370 gr)****.

18. The hand shall incorporate a convenient means for attachment to standard wrist units. The attachment device shall be of such strength as to withstand loads imposed on the hand during use and shall in no way interfere with hand operation. The axis attachment of the device shall be at 90° plus or minus 1° to the back suface plate. A line through the center of the second digit pivot and the center of the attachment of the back plate shall be at the angle of $19^{\circ} \pm 1^{\circ}$ to the longitudinal axis of the stud (Fig. 1).

19. The hand shall incorporate a safety device which shall automatically, completely, and instantaneously (snap breakaway) open the hand from a locked position when a loading of 55 lbs. (29 kp) ± 5 lbs. (2.3 kp) is applied to the fingers as shown in Figure 2. (Test Procedure F.6).

20. In hands design for use with cosmetic gloves all fingers as well as the body of the hand shall be free of unnatural proturberances, point, and edges.

21. The control system shall not cause unsightly bulges, clothing wear, discoloration or staining.

22. The control system shall be applicable to the patient without complex harnessing or attachment techniques.

23. Maximum voltage in the hand system shall not exceed 30 volts.

24. The system should be fused at the battery at 10% above current required for maximum prehension.

25. A switch should be provided to shut off the hand system completely

26. All electric wiring shall be fastened in such a way that the possibilities of breakage are minimized.

27. All electric cables shall be connected to batteries and electronic parts with multiple connectors so that they can easily

---

If a motor or other apparatus is attached directly to the hand, i.e., on or in the distal forearm, the total weight of the hand and apparatus shall not exceed the stated limit. This standard is based on experience over the years that most amputees have found the APRL 4-C Hand (weight 13-14 oz. plus glove) to be "too heavy". No evidence exists to indicate that the weight of electromechanical (or other powered) hands is tolerated any better than that of mechanical hands.

be put in or taken out.

28. The battery shall be capable of powering the hand for 600 closures to a 5-lb. (2.3 kp) pinch force and reopening to the initial position, at a rate of 5 cycles per minute, without recharging. Total battery life should be approximately one year of 600 cycles per day or approximately 1/4 million cycles.

29. The battery shall not be heavier than 12 oz. (340 gr).

30. Each hand shall be identified by a serial number in accordance with the numbering practices and records of the manufacturer, and should be suitably lubricated, individually packed and labeled. A warranty slip shall accompany each hand indicating compliance with these standards and guaranteeing against manufacturing defects for a period of 90 days after being placed in service.

Testing Procedures*

A. General

A.1 Measurements of finger opening shall be made by using gauge blocks. Gauge blocks shall be within plus or minus .005 in. (0.13 mm) of the fractional measurements shown.

A.2 For measuring pinch force a standard Pinch Tester as described in References 1, 4, and 18 shall be used. This tester is to be calibrated to give 0.002 in. (0.0508 mm) movement per 1 lb. (0.4536 kp) of pinching force at point of load.

A.3 All tests shall be conducted at normal indoor temperatures (68^{o}F or 20^{o}C), except Test Procedures F.1, F.2, and F.3.

B. Appearance

B.1 To test the resistance of the hand to contact with an inner soft glove, the cosmetic glove, or the effect of the hand materials and finish on the glove, a glove shall be placed on a hand, using the recommended donning procedure, and allowed to remain in contact for a period of two months. After this time, the hand and glove shall be inspected for any interaction which is deleterious to function or cosmesis.

C. Prehension Capabilities

C.1 The grasping force shall be measured using a standard pinch tester adjusted to 5/8 in. (1.6 cm) opening. For the 3 in.

---

*Based on procedures described in References 1, 4, and 18. However, certain tests have been modified and others added in light of the testing of the Belgrade Hand.

(7.6 cm) use a pinch tester and 2-3/8 in. shim to give the desired opening.

C.2 For hand systems with automatic control of grasping the initial active force shall be measured by a standard pinch tester adjusted to 5/8 in. (1.6 cm) opening. Activate automatic grasping by fingertips with minimum possible force and measure pinch force while the servomotor is still excited. Let the hand grasp a cylindrical object of diameter 5/8 in. (1.6 cm) by automatic control. Move the hand vertically upward with acceleration of 3 ft/sec^2 (0.9 m/sec^2). The object shall be retained in the hand without notable slippage.

C.3 Lock operation eficiency shall also be tested with a standard pinch tester adjusted to 5/8 inc. (1.6 cm) opening. Insert the pinch tester between the thumb and the fingers and close the hand to achieve a 3 lb. (1.36 kp) pinch force. Allow the hand to lock and record the retained pinch force.

E. Structural Integrity*

E.1

a. Stabilize the hand in a suitable extensor (forearm length adaptor) with the hand in the closed position (Fig. 2a). Place a 1/2 in. (1.4 cm) thick gum rubber pad over the dorsum of the second and third digits and apply a 250-lb. (113.40 kp) static load parallel to the stud axis.

b. Mount the hand on a suitable jig (Fig. 2b). Place the hand in an open position and use a pressure sensitive tape to tape the fingers on the dorsal surface of the 2nd and 3rd finger phalanges to prevent scoring of the paint. Loop cable around the 2nd and 3rd digits at the junction of the 2nd and 3rd phalanges and bring cable down between the 2nd and 3rd digits. Position a suitable metal separater of adequate dimensions between the fingers to prevent movement of fingers relative to each other. Apply a 200-lb. (91 kp) static load to the cable.

E.2 Stabilize the fully opened hand in a horizontal position, (Figs. 3a and 3b). Determine the initial mediolateral play of each of the active fingers. Mediolateral play shall be measured as the movement of the mid-point of the third pha-

---

*If the hand has the inner soft glove, Test Procedures E.1 and E.2 shall be done without inner soft glove. Static load is applied to mechanical armature of fingers.

lange between extreme positions assumed by the finger when it is subjected to a force of 50 lb. (22.7 kp) perpendicular to the medial surface and then perpendicular to the lateral surface at the mid-point of the third phalange. Movement shall be measured using a suitable dial gauge calibrated to 0.001 in. (0.0254 mm). Apply a 50-lb. (22.7 kp) force to each of the active fingers at a point 5 in. (12.7 cm) from the wrist plate, and in the direction shown in Figure 3a, and then in the direction shown in Figure 3b, i.e., three load applications are to be made to each active finger. Remeasure the mediolateral play in each active finger as above. Reapply 50-lb. (22.7 kp) loads as shown in 3b and remeasure the mediolateral play.

E.3 Stabilize the hand in a vertical position, wrist up, with the fingers completely closed encircling a handle 3/4-in. (1.9 cm) (Fig. 4). Apply a 45-lb. (20 kp) load to the handle.

E.4 Cycling tests shall be conducted on a suitable automatic cycling machine at the rate of 5 cycles/minute ± 0.5. The hand system as received from the manufacturer shall be stabilized on the machine in a manner that will simulate service conditions. The hand system shall be programmed to close and lift 1 in. (2.54 cm) an aluminium block 1x1x6 $in.^3$ ($2.54x2.54x15.3\ cm^3$) weighted at the bottom so that a 5-lb. (2.27 kp) prehension force is required to lift the assembly vertically from the rest position. A cosmetic vinyl covering should be used on the thumb and 2nd and 3rd fingers. The assembly will then return to the rest position and open the hand. This sequence will be repeated for 50,000 cycles with battery recharging as required, at which time it shall be inspected, cleaned and lubricated. The hand system shall then be cycled an additional 50,000 cycles at which time it shall be checked for conformance to these specifications. An additional 200,000 cycles with proper maintenance at 50,000 cycle intervals shall be carried out and records made of mechanical and electrical dificiencies and coating abrasions.

E.5 Place the hand system in a standard vibration machine. Expose the hand system to vibrations with the amplitude of ±0.35 mm and variable frequency from 10 Hz to 100 Hz, 3h in horizontal and 3h in vertical direction. Take the hand system from the machine and inspect for damage or mechanical abrasion. Check to determine whether the system exhibits the original performance and characteristics.

E.6 Place the hand system in a standard machine for testing the effect of dynamic shocks. Expose the hand system to dynamic shocks under the following conditions:

- maximum acceleration 25 g const.
- shock frequency 3 Hz const.
- number of shocks vertical to the palm 1000
- number of shocks in the palm plane 1000

Take the hand system from the machine and inspect for damage or mechanical abrasion. Check to determine whether the system exhibits the original performances and characteristics.

F. Design and Construction

F.1 Stabilize the hand system on a suitable automatic cycling machine described in Test Procedure E.4. Place the automatic cycling machine with the hand system into an air-circulating thermostat chamber adjusted to the prescribed test temperature. Wait until the temperature in the chamber and of all the parts of the hand system are stabilized at $-20^{o}F \pm 2^{o}F$ ($-29^{o}C \pm 1^{o}C$). Cycle the hand system within the chamber for one hour. Inspect to determine whether the hand system exhibits the original performance and characteristics. Repeat the whole procedure on testing temperature of $120^{o}F \pm 2^{o}F$ ($49^{o}C \pm 1^{o}C$).

F.2 Place the hand system into a thermostat chamber the interior of which has been conditioned at $167^{o}F \pm 2^{o}F$ ($75^{o}C \pm 1^{o}C$). Place the hand system in the thermostat and wait for one hour so that all parts of the hand system are stabilized at the given temperature. Take out the hand system from the thermostat chamber and leave it until all parts reach the ambient termperature. Inspect to determine whether there is any damage and if the system in operation exhibits the original performance and characteristics.

F.3 Place the hand system into a thermostat chamber with humidity regulation. The chamber interior should be previously conditioned at 77°F ± 2°F (25°C ± 1°C) and to 100% relative humidity. Let the hand system stand in the chamber for 24 hours. Take the hand system from the thermostat chamber and check to determine whether there is any damage or abrasion. Inspect if the hand system operation exhibits the original performance and characteristics.

F.4 Place the hand system mounted on the forearm socket in a soundproof room or outside in a very quiet place. Operate the hand system with maximum acceleration and record the noise intensity at a distance of 1.09 yd. (1 m).

F.5 Overall dimensions of the hand shall be measured as follows: (Figs. 5a, 5b, and 5c).

<u>Length</u>: Full length when the hand grasps a cylindrical object of diameter 2-3/4 in. (7 cm).

<u>Width</u>: Maximum width of the hand shell.

<u>Thickness</u>: At the point and in the way shown in Figure 5c.

F.6 The following two steps shall be used to determine the operation of the safety overload:

a. The type of breakaway shall be determined by closing the prehensile fingers so that they encircle a 3/4 in. (1.9 cm) diameter, rigid, stabilized bar. A sharp, hard pull is applied at the stud end of the hand, sufficient to separate the fingertips and release the bar. The type of overload action shall be determined as either clean and complete, i.e., the fingers fully open (snap breakaway), or as one in which a dragging action occurs in the mechanism, only allowing the fingertips to move enough to pass the bar.

b. With the hand stabilized in a vertical position, wrist up, the fingers are completely closed, encircling a handle 3/4 in. (1.9 cm) in diameter (Fig. 4). Increasing load shall be applied to the handle until release is effected. The load is recorded.

<u>References</u>

/1/ Army Medical Biomechanical Research Laboratory, "Tentative Standards for Design and Function of Electromechanical Hands and Control Systems", Tech. Rept. 6911, WRAMC, July 1969.

/2/ Army Prosthetic Research Laboratory, "Sizing of Cosmetic Hands to Fit the Child and Adult Amputee Population", Tech. Rept. 5541, September 1954.

/3/ Army Prosthetic Research Laboratory, "Cosmetic Cloces Specifications", June 20, 1955.

/4/ Army Prosthetic Research Laboratory, "Tentative Specifications - Hand, Adult Size Mechanical Voluntary-Closing for Upper Extremity Amputees, No. IV Size", WRAMC, November 1, 1957.

/5/ Army Prosthetic Research Laboratory, "Tentative Standards, Hands, Mechanical for Upper-Extremity Amputees, Size III", WRAMC, October 1965.

/6/ Becker, Th.W., During, J., and den Hertos, A., "Artificial Touch in a Hand Prosthesis", *Med. and Biol. Eng.*, 15:1: 47-49, January 1967.

/7/ Birdsell, J.B., "A Survey to Size the 4-B Prosthetic Hand", Spec. Tech. Rept. No. 16, Department of Engineering, UCLA, August 1950.

/8/ Bottomley, A.H., and Cowell, T.K., "An Artificial Hand Controlled by the Nerves", *New Scientist*, 21:668-671, March 12, 1964.

/9/ California, University of, "Manual for Upper Extremity Prosthetics", Los Angeles, 1952.

/10/ Committee on Prosthetic Research and Development, "Report, Sixth Workshop Pane on Upper-Extremity Prosthetic Components of the Subcommittee on Design and Development", Santa Monica, California, October 21-23, 1968.

/11/ Committee on Prosthetic Research and Development, "Report, Seventh Workshop Panel on Upper-Extremity Prosthetics of the Subcommittee on Design and Development, Externally Powered Terminal Devices", Santa Monica, California, July 30-31, 1969.

/12/ Committee on Prosthetic Research and Development, "Report, Eighth Workshop Panel on Upper-Extremity Prosthetics of the Subcommittee on Design and Development, Control of Externally Powered Devices", Downey, California, March 31 - April 2, 1970.

/13/ DeFries, M.G., "Sizing of Cosmetic Hands to Fit the Child and Adult Amputee Population", Tech. Rept. No. 5441, APRL, September 1954.

/14/ Fletcher, M.J., and Leonard, F., "The Principles of Artificial-Hand Design", *Artif. Limbs*, 2:2:78-94, May 1955.

/15/ Horn, G.W., "Muscle Voltage Moves Artificial Hand", *Electronics*, 36:34-36, October 11, 1963.

/16/ Horn, G.W., "The Pick-Up of the Signal in Myo-Electric Control of Prosthetic Devices", Seminar at the Electro-Technical Institute, Roma, February 12, 1965.

/17/ Kay, H.W., and Peizer, E., "Studies of the Upper-Extremity Amputee, VI. Prosthetic Usefulness and Wearer Performance", *Artif. Limbs*, 5:2:31-87, Autumn 1958.

/18/ Leonard, E., Rakić, M., and Kay, H.W., "Tentative Design and Functional Standards for Electromechanical Hand and Control Systems", Attach. 1 to "Laboratory Evaluation of the Beograd Hand Prosthesis", Mihailo Pupin, Beograd, April 1967.

/19/ Keller, A.D., Taylor, C.L., and Zahm, V., "Studies to Determine the Functional Requirements for Hand and Arm Prosthesis", Department of Engineering, UCLA, July 1947.

/20/ Kobrinski, A.E., Bolkhovitin, S.V., Voskoboinikova, L.M., Ioffe, D.M., Polyan, E.P., Popov, B.P., Slavutski, Ya.L., Sysin, A.Ya., and Yakobson, Ya.S., "Problems of Bio-Electric Control",*IIfac Congress*, Moscow, 1960., pp. 619-623, Butterworths, London, 1961.

/21/ National Academy of Sciences, "The Control of External Power in Upper-Extremity Rehabilitation", Publication 1352, 1966.

/22/ Paul, I., and Mann, R.W., "Evaluation of Energy and Power Requirements for Externally Powered Upper-Extremity Prosthetic and Orthotic Devices", *ASME*, 1962.

/23/ Rakić, M., "Engineering Evaluation and Technical Improvement of the Belgrade Hand Prosthesis", Mihailo Pupin Institute for Automation and Telecommunications, Belgrade, April 1970.

/24/ Rakić, M., "An Automatic Hand Prosthesis", *Medical Electronic and Biological Engineering*, II, pp. 47-55, 1964.

/25/ Rakić, M., Jakšić, D., and Ivančević, N., "Technical Evaluation of the Belgrad Hand-Prosthesis", *Proceedings of the 3rd International Symposium on External Control of Human Extremities*, Dubrovnik, August 1969.

/26/ Salisbury, L.L., and Colman, A.B., "A Mechanical Hand with Automatic Proportional Control of Grasp", Technical Report 6611, U.S. Army Medical Biomechanical Research Laboratory, Washington, D.C., May 1966.

/27/ Soerjanto, R., "On the Applications of the Myoelectric Hand-Prosthesis in the Netherlands", Institute of Medical Physics TNO, Utrecht, Report 1.1.59-3, December 1971.

/28/ Taylor, C.L., and Schwartz, R.J., "The Anatomy and Mechanics of the Human Hand", *Artif. Limbs*, 2:2:22-35, May 1955.

/29/ Zotović, B., and Kajganić, M., "The Belgrade Hand Prosthesis, A Functional Evaluation", Center for Prosthetics, Belgrade, 1971.