A POWERED WRIST ROTATOR [a]

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At the First Workshop Panel on Criteria for External Power in 1964, the panel members agreed that, in their opinion, powered pronation and supination are important in the above-elbow prosthesis. It was also the consensus that the shorter the below-elbow stump the more desirable powered rotation becomes for the below-elbow prostheses (1). At the subsequent Third Workshop Panel on Upper-Extremity Components in 1965, the panel members again agreed that powered pronation and supination are important (2).

The purpose of this paper is to present the design of a component which will give the upper-extremity amputee electrically powered pronation and supination. A complete forearm for an above-elbow amputee with such a unit is shown in Figure 1. Limited clinical evaluation has demonstrated the value of such a device, especially to the bilateral above-elbow amputee.

The design criteria are to provide the amputee with active powered rotation in a unit that is compatible with current prosthetic devices and fabrication techniques. The unit is to be capable of providing enough torque to accomplish the necessary activities of daily living which require this type of rotary motion. Since there are no published data on this torque requirement, they had to be determined. Without going into an elaborate study the author felt that this torque requirement could be quickly and simply estimated. Choosing the rotation of a door knob as one of the more essential activities of a bilateral above-elbow amputee requiring this type of motion, the torque required to accomplish this was measured. For a well-fitting door the torque was found to be 65 oz.-in. For a poorly fitting door which results in the latch mechanism binding against the door jamb the torque was found to be approximately twice the above—125 oz.-in. This torque can, of course, be much higher; however, it was felt that a door fitting that poorly would probably be repaired. Since the above torques were

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determined for rather arbitrary situations to estimate the torque requirements, it was decided that the wrist unit should be capable of exerting a torque of four times the above or 500 oz.-in. The no-load speed was arbitrarily chosen to be twenty to thirty revolutions per minute which is 1.0 to 1.5 seconds per 180 deg. of revolution (full supination to full pronation).

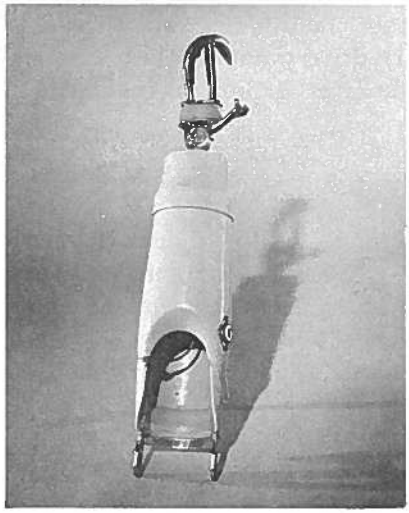

FIGURE 1.—Forearm with powered wrist rotator for an above-elbow prosthesis.

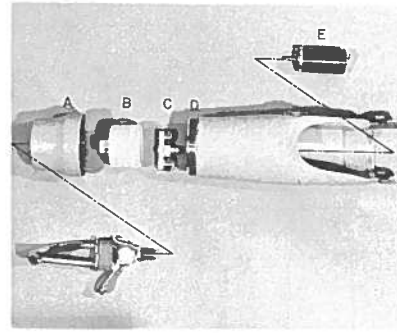

FIGURE 2.—An exploded view of the rotator showing the rigid circular spline (A), Flexspline (B), and wave generator (C) of the Harmonic Drive; the mounting plate (D), and motor (E).

DESIGN

The basic components of the unit are a d.c. permanent magnet torque motor and a "Harmonic Drive" speed reducer. The Harmonic Drive is a unique speed reducer consisting of three elements: the wave generator (Fig. 2C), the Flexspline (Fig. 2B), and the rigid circular spline (Fig. 2A) which is hidden under the cosmetic cover (3). The wave generator rotates within the Flexspline deflecting it from a circular shape into an ellipsoid shape. This assembly in turn fits within the rigid circular spline. The teeth of the two splines mesh at two diametrically opposite regions on the major axis of the ellipsoid and clear at the minor axis. The Flexspline has a smaller pitch diameter and thus fewer teeth than the rigid spline. As the wave generator rotates, it continuously deflects the Flexspline which rotates in the opposite direction to make up for this difference in the number of teeth. The speed reduction ratio is the ratio of the number of teeth in the Flex-

spline to the difference in the number of teeth between the two elements. In this unit the ratio is 80:1.

The terminal device is attached to the Flexspline with its ½ in.-20 threads and is keyed in place to prevent it from rotating on the threads. A threaded ring holds the rigid spline to the mounting plate (Fig. 2D) which is laminated to the forearm. The motor is mounted to the proximal side of the mounting plate with its shaft extending through to the distal side. The wave generator, in this case the "sun" and "planet" rollers of a friction planetary drive train, is attached to the motor shaft. This planetary drive train gives the unit an overall speed reduction ratio of 266:1.

LABORATORY EVALUATION

The unit was bench tested to determine its operational characteristics. The terminal device was replaced with a small cylinder. Dead weights suspended on a cable were attached to the drum through a pulley system to put a purely torsional load on the unit while eliminating bending forces. The results of these tests are shown in Figure 3.

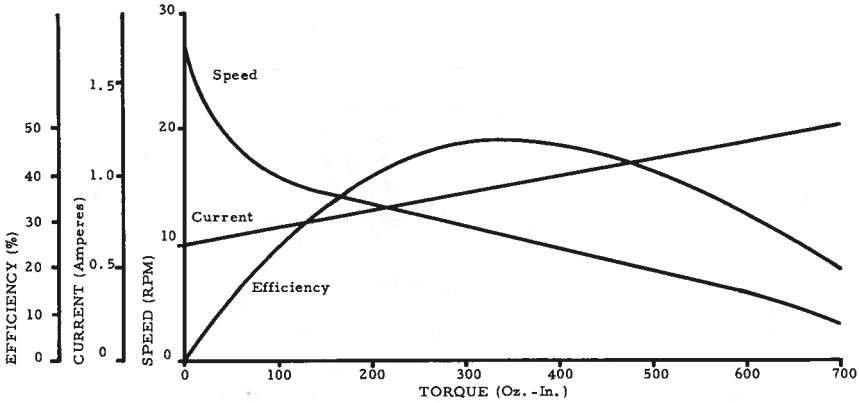

FIGURE 3.—The efficiency, current, and speed of the rotator as a function of the torque available at the terminal device.

Using the data from the above tests and the manufacturer's data (4) for the available capacity of a 500 mah. nickel-cadmium battery pack, the number of cycles per battery recharge can be estimated (Fig. 4). The battery discharge ends at a cutoff voltage of 1.0 volt per cell which is considered the end of useful drain. Operation can continue beyond this point but at gradually decreasing speeds and possibly a decrease in the useful life of the battery pack.

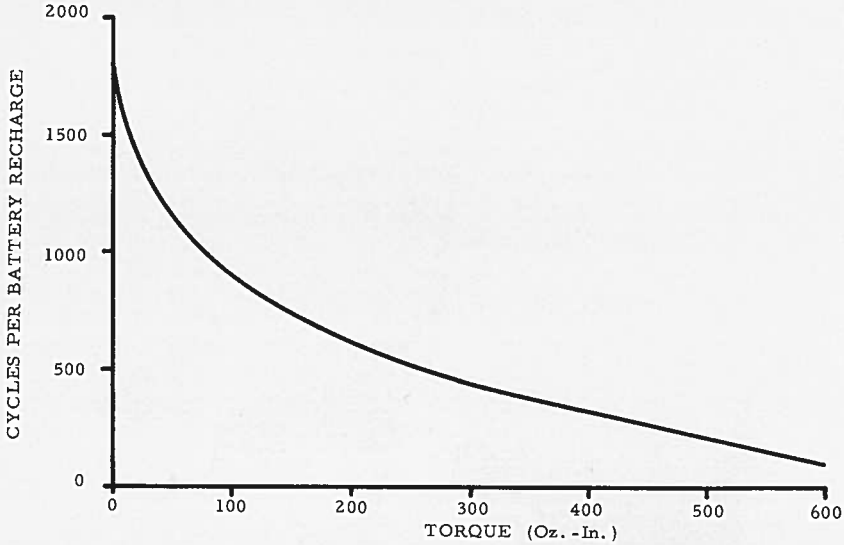

FIGURE 4.—The number of cycles of wrist rotation possible per battery recharge. One cycle is equal to 180 deg. of rotation (full supination to full pronation).

PATIENT EVALUATION

The unit has been fitted to three amputees: two bilateral below elbow and one bilateral above-elbow. The below-elbow amputees were fitted more for a mechanical rather than a functional evaluation of the unit because they were readily available and willing to participate in the evaluation (Fig. 5 and 6). After a brief training period both amputees had good control of the rotator. One amputee used the unit for 1 week with no problems and the other returned it after only 1 day for reasons unrelated to the function of the unit. Although both amputees felt that the unit allowed them more functional wrist rotation than their conventional prostheses, they were not enthusiastically willing to accept the additional weight (approximately 5 oz. additional for the rotator unit and 9 oz. for the battery pack) and the additional control motions (chest strap mounted AMBRL two-level switch or miniaturized Rancho Los Amigos lever-type switch) (5, 6).

The above-elbow amputee is shown in Figure 7. The unit is controlled by chest expansion using an AMBRL two-level switch. After a very short training and practice period of approximately 15 min. the amputee had good control of the rotator. He could easily open a door and insert and turn a key, both of which he could not do with his own prosthesis. He stated that he would accept the additional weight for the convenience of the added function. However, the control presented a problem and was the reason for discontinuing the evaluation

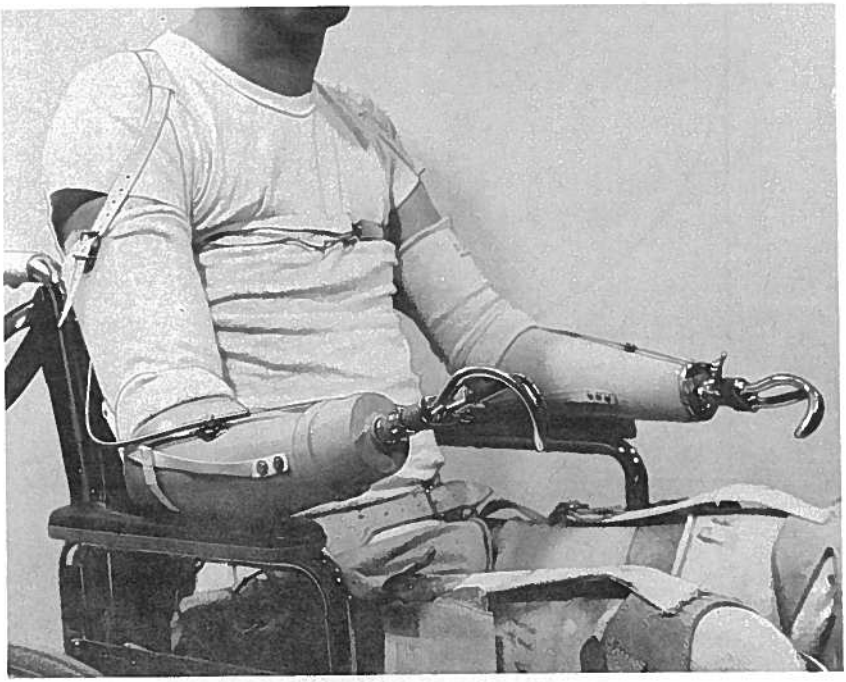

FIGURE 5.—Bilateral below-elbow amputee with powered rotator controlled by chest strap mounted AMBRL two-level switch.

FIGURE 6.—Bilateral below-elbow amputee with powered rotator controlled by chest strap mounted miniaturized Rancho Los Amigos lever-type switch. Battery pack can be seen on the chest strap.

FIGURE 7.—Bilateral above-elbow amputee with powered rotator controlled by AMBRL two-level switch. The switch and battery pack are mounted on a chest strap.

after 1 week. Although the chest strap mounted switch was adjusted to prevent inadvertent operation during breathing, other motions such as reaching and bending would cause operation. In addition to the conventional bilateral above-elbow prosthetic harness and controls, the amputee was fitted bilaterally with mechanical humeral rotators, one of which can be seen in Figure 7 just proximal to the elbow (7).

None of the amputees complained of noise; although the developer feels that the noise level of the unit is too high, they were quite willing to accept it.

CONCLUSION

Although the unit has not had extensive clinical evaluation, it has been demonstrated that powered supination and pronation are valuable to, at least, the bilateral above-elbow amputee. The noise, which is amplified by the megaphonic effect of the above-elbow forearm, can be reduced by changing materials and lamination techniques.

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