PROPORTIONALLY CONTROLLED LINEAR POWER ASSIST DEVICE FOR ARTIFICIAL ARMS

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ABSTRACT

A new prosthetic add-on device is being developed which promises to provide an economical means of adding power assist to a patient's existing conventional cable-operated prosthesis. Only minor modifications by a prosthetist would be required. Patients wearing conventional cable-operated above-elbow prostheses, who lack adequate function because they cannot generate the necessary cable excursion, are expected to dramatically improve their performance with little or no retraining. The proposed system will operate at speeds comparable to those of a conventional cable-operated prosthesis. The system will retain considerable function even if there is no power assist, and it will improve the quality of the sensory feedback normally associated with a conventional cable-operated body-powered prosthesis.

BACKGROUND

Patients wearing conventional Bowden cable-operated arm prostheses often complain of inadequate performance. This is especially
the case for the more severely disabled patient, such as the bilateral above-elbow or shoulder-disarticulation amputee. Often, this poor performance can be traced to a patient's physical inability to achieve an adequate range of motion of, and/or sufficient pull on, the Bowden cable.

Typically, conventional cable-operated prostheses utilize a combination of body motions to supply the power for their operation (Fig. 1). The basic motions used are scapular abduction (forward motion of the shoulders) and humeral flexion (raising the upper arm). The increase in dimension measured across the back between the scapulae is harnessed by axillary loops and a Bowden wire system. The anchor point for the Bowden wire housing is at the midpoint of the remaining humerus. By using both bicipital abduction and humeral flexion, sufficient cable travel is obtained to flex the elbow as well as to operate the terminal device at full elbow flexion. A total cable travel of 4 or 5 in. is normally required for this operation. Approximately 1 or 2 in. of this travel are provided by scapular abduction, while the remaining 3 in. are obtained from humeral flexion.

In practice, complications tend to arise as the level of amputation above the elbow increases. This is because the cable travel generated by humeral flexion is reduced to the point where, for a very short above elbow or a shoulder disarticulation, no excursion of the humerus is harnessable. This creates a cable travel deficiency of 2 to

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**FIGURE 1.**—Conventional cable-operated prosthesis for the AE amputee: a, photograph of the prosthesis, b, functional representation of the prosthesis.
3 in. for adequate functioning of the prosthesis. Further, in the case of the bilateral shoulder disarticulation, this deficiency is compounded and function becomes wholly inadequate. Noteworthy is

FIGURE 2.—Typical externally energized prosthesis: a. assembled pictorial view, b. functional representation.
the fact that, in nearly all cases, function cannot be improved by trading force for excursion by means of a simple mechanical lever arm, because increases in the force required to operate the cable place additional limitations on the patient's ability to make the necessary excursions.

At present, a patient who cannot achieve adequate function is forced either to accept his unsatisfactory cable-operated prosthesis or be refitted with a currently available externally energized system (Fig. 2). These externally energized systems are typically controlled by myoelectric signals or by switches operated by body movements. Present day elbow components often are damaged easily, and do not perform as well as body powered systems. In externally energized systems, the rate of movement is limited by the speed of the powered components and is typically much slower than that obtained with cable-operated prostheses. Failure of the energy source, or of any powered component, normally makes the entire prosthesis inoperable until the situation is corrected. Also, commercially available externally powered prostheses lack adequate proprioceptive, kinesthetic, and tactual feedback (2, 3). Thus, the patient does not know accurately the prosthesis position or the force being exerted on an object by the terminal device except through visual feedback. Finally, the changeover to external power requires either considerable modification of the patient's original prosthesis, or more likely, a completely new prosthesis as well as extensive retraining. The result is typically a final cost to the patient of from three to ten times that of his original prosthesis. An alternative all too often chosen by the patient is not to wear any prosthesis.

**DEVICE DESCRIPTION**

To improve the situation, a system for economically adding power assist to conventional cable-operated prostheses is being developed (Fig. 3 and 4). The new system will require only minor modifications by a prosthetist. Specifically, a linear power assist as well as a proportional controller would be attached to the patient's original prosthesis and would be operated in conjunction with a modified Bowden cable in such a way that desired cable motions would be sensed by the proportional controller which, in turn, would activate the linear power assist by means of a position servo amplifier feedback loop. Additional hardware required would include a force and excursion compensator, a controller amplifier, a power pack, and two bypass links.

Operation of the proportional control system would be as follows: As the proportional controller is extended by movement of the con-
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**FIGURE 3**—Proposed proportionally controlled linear power-assisted cable-operated prosthesis for the AE amputee: assembled pictorial view.

trol cable (caused by scapular abduction or humeral flexion by the patient), the linear power assist shortens in length in proportion to the controller position. The force and excursion compensator performs a dual function. First, it allows the excursion of the control cable relative to the excursion of the proportional controller base plate to be adjusted to an optimum value for a particular patient. Second, it allows a simultaneous reduction of the feedback force in the control cable felt by the patient and increase in the force in the power cable controlling the movement of the prosthesis joints. The net result is a reduction of the excursion and pull required by the patient to operate the prosthesis, as well as an increase in live lift capabilities. The elbow lock assembly (part of the original prosthesis) determines whether the elbow or terminal device is moved by the power assist unit and remains unchanged. Forces in the cable, resulting from limb loading or grasp pressure, as well as the cable position, are sensed by the patient in a manner similar to that used in a conventional cable-operated prosthesis. An advantage of the new system is that the amount of feedback may be adjusted to a more comfortable (lower) level by the force and excursion compensation mechanism.

Since movement of the proportional controller can be achieved with very small control cable movements, the power assist unit should be capable of at least 5 in. of movement. This would, in theory, allow complete control of the prosthesis with little or no body move-
ments. Better performance may be obtained, however, by allowing greater movement to occur in the control cable, and requiring that only deficiencies be made up by the power assist unit. Such an approach would allow greater response speeds to be realized. For certain adjustments of the force and excursion compensator, re-

**FIGURE 4.**—Proposed proportionally controlled linear power-assisted cable-operated prosthesis for AE amputee: functional representation.
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Response speeds are expected to exceed those obtained with a conventional cable-operated prosthesis.

In the event of discharged batteries or lack of power assist due to any other reason(s), considerable function could still be retained by operating the system as a conventional cable-operated prosthesis until repairs can be made. A means whereby someone could easily bypass the linear power assist device, as well as defeat the force and excursion compensator, would improve such emergency operation. One approach is to use a force and excursion compensator bypass link and a linear power assist bypass link to restore the power assisted prosthesis to a conventional cable-operated prosthesis. The two links could be mounted on a shell of the prosthesis for storage until needed, as shown in Figure 3.

At the time of this writing, much of the described system already has been developed. In particular, suitable proportional controllers, pulse width modulated servo amplifiers, and Nickel-Cadmium battery packs are 90 percent realized. The force and excursion compensator and the power assist bypass have not yet been designed, but are believed to be straightforward. Work will be next concentrated on the development of the linear power assist.

CONCLUSIONS

A proportionally controlled linear power assist add-on device for artificial limbs is being developed which, if it functions as intended, will possess the following features:
1. it will improve the performance of conventional cable-operated prostheses;
2. it will allow adequate performance to be obtained from conventional Bowden cable-operated prostheses by patients whose excursion and/or pull on the cable are limited;
3. it will provide power assist to a prosthesis by means of a system which is more rugged and reliable than previously available devices;
4. it will achieve response speeds comparable to those of a conventional cable-operated prosthesis and which greatly exceed the speeds obtainable from commercially available externally energized prostheses;
5. it will allow considerable function in the event of lack of assist (power failure);
6. it will add power assist to a conventional cable-operated prosthesis while simultaneously improving the quality of the proprioceptive, kinesthetic, and tactual feedback normally associated with such a prosthesis;
7. it will provide a means whereby power assist can be added to conventional cable-operated prostheses with the requirement that only minor modifications be necessary and that such modifications normally can be completed by any prosthetist trained in the art; 
8. it will provide a means whereby power assist can be added to conventional cable-operated prostheses with little or no retraining of the patient; 
9. it will provide a means whereby power assist can be added to conventional cable-operated prostheses at low cost; and, 
10. it will reduce the number of amputees who presently wear no prosthesis by offering them a more desirable alternative.

REFERENCES