HIGHLIGHTS OF OTHER VA RESEARCH PROGRAMS

PROSTHETICS

Edited by

Eugene F. Murphy, Ph. D., Chief

William M. Bernstock, A. M., Assistant Chief

Research and Development Division
Prosthetic and Sensory Aids Service
Veterans Administration
252 Seventh Avenue
New York, N.Y. 10001

Prosthetics, Orthotics, and Sensory Aids Research Services
Committee on Prosthetics Research and Development
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington, D.C. 20418
Colin A. McLaurin, Sc. D.

For progress during this report period see "Summary of Activities of the Committee on Prosthetics Research and Development for the Period July 1 to December 31, 1971," appearing elsewhere in this issue of the Bulletin.

Prosthetic and Orthotic Education and Information Program
Committee on Prosthetic-Orthotic Education
National Academy of Sciences
2101 Constitution Avenue, N.W.
Washington, D.C. 20418
Herbert E. Pedersen, M.D.

Because of organizational changes and the unavailability of the Executive Secretary, no report will appear in this issue of the Bulletin.

Research and Development in the Field of Artificial Limbs
Mauch Laboratories, Inc.
3035 Dryden Road
Dayton, Ohio 45439
Hans A. Mauch

An intensive effort toward improving the function and extending the maintenance-free life of the *S-N-S system* has resulted in a number of modifications in the design and assembly of this system.

In July 1971 it was found that the polyurethane O-ring on the main piston occasionally twists and then produces noises due to stick-slip friction along the cylinder wall. Roughening the chrome-plated upper side wall of the O-ring groove with a sharp carbide-tipped tool eliminated the noise.

Another modification concerns the lateral free-floating motion of the damping piston for swing-phase resistance. In several systems it was found that this free-floating motion was impeded by a ridge-like configuration on the surface of the support area for this piston, due to minor corner buildup in chrome plating. This malfunction is now prevented by flattening that chrome-plated area with a coining tool.

In August it was found that the piston rod seal will be more effective if the wiper ring is pre-compressed during assembly.

A "hooting" noise, which was caused by contact between the outside of the main spring and the inside of the cylinder, was corrected by changing the shape of the spring. This change also effected a correction of the pressure pattern at the end of the spring, which had produced a tilting moment on the annular piston, leading to wear.

In October it was found that a creaking noise, which was initially attributed to the contact area between the bottom of the dashpot and the Belleville springs on the piston rod at that location, was actually caused by dirt particles which accumulated inside the top end of the cylinder, where a Belleville spring/spacer ring combination is compressed during walking over the ball of the prosthetic foot. The noise was eliminated by making the contact area between the Belleville spring and the spacer ring so small that no particles can accumulate.

A study of the records regarding the number of systems returned from the field for maintenance purposes showed a significant decline as a result of the aforementioned modifications.

In cooperation with VAPC, New York, the length of the S-N-S system was shortened by 7/8 in. by relocation of the lower pivot in order to accommodate the standard geometry of the VAPC Multiplex setup. This change necessitated a corresponding change in the wooden setup, though there is no change in the hydraulic system as such. The changes will be applied to the next upcoming production run. The new shorter version will be called the "standard" length.

Preparations for the testing of the *hydraulic ankle* by VAPC were completed in September. Subsequently, shakedown testing in New York started and is now yielding valuable results. It appears that a number of simplifications can be applied to the ankle design without reducing

the acceptance by the amputee. Some of these simplifications may even increase the acceptance.

A third prototype system is almost completed. It will be identical with Prototypes 1 and 2. After initial amputee testing in Dayton, it will be given to an amputee still to be selected in the New York area, in order to widen the evaluation basis for the features of this system and to provide stronger evidence for whatever decisions have to be made regarding the retention, elimination, or modification of any of these features.

The manufacturing of the parts for the prototype of the *voluntarily actuated swing- and stance-control unit* is making good progress and is now 90 percent complete.

In order to avoid the problems with the mainspring reported above in connection with the S-N-S system, the design of this control system provides for the use of a cylindrical rather than tapered mainspring. Sample springs were obtained and were found to be satisfactory in every respect, including uniform pressure distribution over the top of the annular piston.

It was also established that the application of the above design principles, used to shorten the S-N-S system, will allow sufficient space for the installation of Belleville springs to provide the "double knee bend" occurring in natural legs upon heel contact, without exceeding the standard distance of 7½ in. between the knee bolt and the shank bolt in the Multiplex setup.

Stump Stress Analysis
New York University
School of Engineering and Science
Bronx, New York 10453
Leon Bennett

For progress during this report period see "Transferring Load to Flesh: Part III. Analysis of Shear Stress" appearing elsewhere in this issue of the Bulletin.

Prosthetic Research
Northwestern University, Prosthetic Research Laboratory
401 East Ohio Street
Chicago, Illinois 60611
Robert G. Thompson, M.D., and Dudley S. Childress, Ph. D.

The Laboratory participated actively in the Second Orientation Course in Upper-Extremity Powered Components which was given at Northwestern University December 15th through 17, 1971, in cooperation with PSAS. The staff of the Prosthetic Education Program at North-

western attended the course along with the VA participants as a first step in the development of educational activities in this area. Although the primary objective of the laboratory is research, it is felt that active participation in education is important during initial phases when new developments are being moved from laboratory to field use.

Research work has been continuing on the self-suspension socket for the above-elbow amputee. Preliminary results indicate that this socket has much merit. The details of cast modification are being refined as are the construction techniques. This improvement is proceeding rapidly.

Work has continued on a multi-motor-powered rotator, a power scheme for terminal devices, and a new type of myoelectric signal processor.

Preliminary work has begun on bioelectric control sites for voluntary knee control. This work is being done primarily by a Northwestern biomedical engineering student.

Dr. Childress participated in an international symposium October 6 through 8, 1971, on "The Control of Upper-Extremity Prostheses and Orthoses" in Gothenburg, Sweden, as a guest of the Swedish Board for Technical Development. A paper coauthored with Mr. Holmes and Mr. Billock was presented. In addition, research groups of the SVEN organization in Stockholm and Gothenburg were visited.

Fundamental and Applied Research Related to the Design and Development of Upper-Extremity Externally Powered Prostheses

University of California, Los Angeles
School of Engineering and Applied Science
405 Hilgard Avenue
Los Angeles, California 90024
John Lyman, Ph. D., and Amos Freedy, Ph. D.

Current work has been directed toward the application and integration of UCLA-developed techniques in powered prosthesis control into a prototype operational system. It is intended to achieve these objectives by assembling a powered prosthesis system which is controlled by transducer harness in conjunction with an adaptive control aiding technique.[a]

Over the period of this report, steps have been taken toward the realization of an operational prosthesis and control system. The following tasks have been completed: 1. construction and assembly of a pros-

[a] Both the control harness and the adaptive aiding system have been a result of earlier work and have been reported in the Fall 1971 issue of the Bulletin of Prosthetics Research (BPR 10-16), and the Proceedings of Conference Human Locomotor Engineering, September 7–10, 1971, Sussex, England (published by the Institution of Mechanical Engineers, 1 Birdcage Walk, London SWI, England).

thesis from VA-supplied components, 2. assembly of the associated electronic circuits for continuous rate and position control of the assembled prosthesis, 3. design and implementation of a mini-computer-based prosthesis control test and evaluation system. An interim report which describes the work performance in detail is now in preparation and will be published at the end of March 1972.

A. Current Work

A brief summary of the program to date in each of the areas of work is as follows:

1. The UCLA/VA Prosthesis (UVP): An experimental powered arm prosthesis was constructed and assembled from modular components. The arm has 3 deg. of freedom: hand prehension, wrist rotation, and elbow flexion-extension. The components are the Otto Bock electric hand, the Northwestern University powered wrist rotator, and the AMBRL powered elbow unit. The assembled arm will provide a means for examination of the feasibility of integrating powered components, which were individually designed, into a prosthetic system with multiple degrees of freedom having matched control capability. In its present form the prosthesis is mounted on a test frame to be used with the experimental control system.

2. Control System: Continuous rate and position control circuits for the UVP arm have been assembled. The circuits consist of a linear power amplifier and the associated summing networks. The joints of of the UVP arm were instrumented with miniature potentiometers which were integrated into the control loop. The rate/position control configuration makes the arm suitable for operating in conjunction with the adaptive aiding system. The adaptive aiding system requires both rate and position control.

3. Prosthesis control test and evaluation system: The system consists of an Interdata-Model 70 computer (newly acquired for Biotechnology Laboratory research under National Science Foundation Grant NSF GK 28896) which is interfaced to the prosthesis control system and is capable of acting as a control aiding device and an automatic on-line performance data collection unit. Various configurations of control techniques can be implemented and tested. The complete system has been designed and is currently being assembled. It is to be operational within a few weeks. The assembly involves the adaptation of the aiding system programs, formerly used on the IBM 1800, to operate on the Model 70 computer, as well as interfacing of the analog control circuits of the UVP arm to the computer.

B. Future Plans

Work in the coming period will be directed toward the completion of the construction of the prototype prosthesis system and the conduct

of experimental studies. It is planned to begin the studies by operating the UVP arm on a test frame while the subject controls it with relatively small forces applied to the lightweight transducer harness. A set of standardized manual tasks will be performed. The adaptive computer-based aiding system will participate in the control, "learning" from the subject how to control the arm, and gradually sharing control decisions, though always subject to voluntary modification by the user. In further experimentation the arm will be fitted to an amputee and tested. All technical details regarding the UVP arm and the experimental work will be provided in the coming interim report.

Design of Prosthetic and Orthotic Devices and Biomechanical Studies of Locomotion

Biomechanics Laboratory
University of California, Berkeley
5144 Etcheverry Hall
Berkeley, California 94720
Charles W. Radcliffe, Howard D. Eberhart, and James M. Morris, M.D.

A prototype of the UC-BL Four-Bar Linkage Polycentric Knee has been constructed from the detail drawings supplied to VAPC in 1971. A minor modification to the resistance control valve has yielded a significant improvement in function and ease of adjustment. Revised drawings have been forwarded to VAPC. Preparation of cosmetic covers for the device will be undertaken in early 1972.

Development of the UC-BL Six-Bar Linkage Polycentric Knee, for use by knee-disarticulation and above-knee amputees, continues. The current objective is a considerable reduction in size and weight without loss of function. Detail drawings of the third prototype are in preparation.

A new rubber return spring has been designed for the shank axial rotation device. A prototype has been constructed and fitted to an amputee. Development of this device will continue.

Preparation of the computer data acquisition system for comparative studies of prosthetic knee mechanisms is well under way. The computer itself is operational; the various measuring devices, which attach to the prosthesis and to the subject in order to provide information to the computer, are under construction.

Work continues on computer simulations of the performance of knee mechanisms and swing-phase control devices during the swing phase of walking. These simulation programs require input data which must be obtained from experimental measurements. Recent kinematic measurements have been adapted to the programs in an effort to improve the accuracy of the simulations.

Clinical trials are being conducted using spinal supports fabricated from materials with varying degrees of pliability. For the lumbosacral area, the supports are modeled after the Royalite jacket. In addition, full body supports for scoliosis patients are being evaluated preoperatively and postoperatively.

Materials from which all these supports have been fabricated include: 1. laminated polyester resin (4110) with posterior fiber glass reinforcement, 2. Prenyl, and 3. Resur.

Plastazote material has been used as a lining for increased comfort. Additional fixation at the pelvis and lower thorax, as well as increased intra-abdominal pressure, has been achieved by appropriately placed inflatable pads made of 20-gage polyvinyl chloride (PVC). These pads can be inflated by the patient to the level of comfort or maximal support.

Thus far, the results of the use of softer and more flexible materials for construction of spinal supports are encouraging, and further studies with newer materials and various combinations will be carried out.

Immediate Postoperative Prostheses Research Study
Prosthetics Research Study
Eklind Hall, Room 409
1102 Columbia Street
Seattle, Washington 98104
Ernest M. Burgess, M.D.

An extensive report covering this report period will appear in the next issue of the Bulletin.

Below-Knee Amputation for Vascular Insufficiency with Immediate Postoperative Fitting of Prosthesis
VA Hospital
4150 Clement Street
San Francisco, California 94121
Wesley L. Moore, M.D., and Albert D. Hall, M.D.

The prosthetics research project at VAH San Francisco continues to accumulate clinical data on the use of immediate postoperative prostheses with lower-extremity amputations. Data accumulated through December 31, 1971, are as follows: 71 amputations with immediate postoperative prostheses, 60 at the below-knee level, 6 knee-disarticulation amputations, and 5 above-knee amputations. In analyzing the results of this procedure with the below-knee amputation, it has been found that primary healing occurred in 87 percent of the patients, and secondary healing in 3 percent of the patients, for a combined healing rate of 90 percent. Six patients failed to heal their below-the-knee

amputations and required revision at a higher level, for a failure rate of 10 percent of that level. The rehabilitation rate of patients who were ambulatory prior to the development of gangrene continues to be 100 percent.

Research activity shows that Xenon ^{133} clearance, as a means of measuring blood flow at a proposed amputation site, continues to correlate well with healing. All patients who have had Xenon-measured blood flow clearances of the anterior skin in excess of 0.59 cc. per 100 grams of tissue per minute have healed at the proposed level. At the present time the investigators are attempting to determine whether there is a correlation with skin temperature at the site of injection with nutritional blood flow as measured by Xenon clearance. Early analysis suggests that there is only very poor correlation between nutritional skin blood flow and skin temperature.

In the period covered by this report, a two-part exhibit describing the immediate fitting program was completed. This exhibit outlined the advantages of the immediate postoperative prosthesis, together with the results of the series. In addition, there were two short film strips illustrating the operative approach used in this program as well as the application of the immediate postoperative prosthesis. The second part of the exhibit consisted of a live demonstration in the application of the immediate postoperative prosthesis. This exhibit was shown at the American College of Surgeons meeting in October 1971 at Atlantic City. The crowds were large, and the response of visitors at the booth was most gratifying. The exhibit was also shown at the meeting of the Association for Military Surgeons in Washington in December 1971. Currently an application is in progress for showing of the exhibit at the American Medical Association meeting in San Francisco in June 1972. Four months ago an abstract was submitted to the Pacific Coast Surgical Association, in which the results of a prior amputation program without immediate postoperative prosthesis were compared and contrasted with current immediate postoperative prosthesis. The abstract has been accepted for presentation at the annual meeting in February 1972. The manuscript from this meeting will be published by the American Journal of Surgery in August 1972.

Survey of Lower-Extremity Amputations for Ischemia

Harvard Medical School
25 Shattuck Street
Boston, Massachusetts 02115
Richard Warren, M.D., Ronald B. Kihn, M.D., and Leon Sheplan, M.D.

This report period has been occupied with continued and laborious collation of data in order to fulfill the objective outlined in the report

for January to June 1971. Those objectives are still the same. The "Surgical" paper is in its sixth draft. It has been accepted for presentation at the American Surgical Association meeting in San Francisco in April 1972, and will thus be published in the Annals of Surgery in the fall of 1972. It is hoped to finish by June 30, 1972, the monograph which will be offered to the Bulletin of Prosthetics Research.

Interesting revelations have emerged from the study. They include such items as: 40 percent of those below-knee amputees in whom little or no bleeding was seen at operation eventually healed; 80 percent of those below-knee amputees who had shown poor mobility prior to operation experienced satisfactory rehabilitation with prostheses; and the timing of provision of prostheses showed that this did not reach its peak until 6 months after amputation. Furthermore, 30 percent of the patients who received limbs discarded them.

Parallel to this work, Dr. Leon Sheplan has been working with Dr. G. W. Beebe of the Followup Agency to complete a report on the PM&R group. This concerns the 212 patients who were referred to PM&R services, a more favorable group for rehabilitation than the total of 427. This paper, dealing primarily with the definition of the factors affecting speed and quality of rehabilitation, is in its third, and probably penultimate, draft.

Immediate Postamputation Prosthetic Fitting
Cambridge Hospital
1493 Cambridge Street
Cambridge, Massachusetts 02139
Richard Warren, M.D.

During this report period, the number of immediate fit amputations coming under the surveillance of the team reached 66 patients.

Requests for referral have reached a level of activity which is not considered optimal. They have, in fact, decreased somewhat towards the end of the period. The October meeting of the Consultant Group, therefore, devoted some time to the future of the project. Subsequent correspondence has added to these deliberations. The decrease in referrals seems to have several ingredients: 1. oversight on the part of the surgeons because they are too busy, 2. difficulty in communications, and 3. uncertainty about the importance of the technique. Uncertainty about the technique does not mean that people feel that it is harmful, but that they feel the same objective can be reached by other means.

Useful information has been procured on the type of hospital that is prone to request services, on the most practical and appropriate "going-home" type of prosthesis, and on various technical matters. It is believed, although this is difficult to document, that an important

public awareness of rehabilitation potentials, particularly accompanied by a more liberal selection of the below-knee level, has been one of the results of the program to date. The final phase of the study will be consolidation and testing of the information procured thus far.

Interdisciplinary Development and Evaluation of Externally Powered Upper-Limb Prosthesis

Applied Physics Laboratory
The Johns Hopkins University
8621 Georgia Avenue
Silver Spring, Maryland 20910
Woodrow Seamone and Gerhard Schmeisser, Jr., M.D.

For progress during this report period see "Development and Evaluation of Externally Powered Upper-Limb Prosthesis, Summary of Research Project Activities, July 1971—December 1971" appearing elsewhere in this issue of the Bulletin.

Development of Refined Fitting Procedures for Lower-Extremity Prosthesis

University of Miami School of Medicine
Department of Orthopaedics and Rehabilitation
P.O. Box 875, Biscayne Annex
Miami, Florida 33152
Augusto Sarmiento, M.D., Joseph Infante, M.D., and William F. Sinclair

Since June 30, 1971, the VA prosthetics research effort has been attempting to overcome the problems reported in the use of methods for soft encapsulation of the stump. The bias weave nylon tubing has been obtained in a closer weave and smaller diameter. There is a slight improvement in characteristics of the new material; however, the initial problems reported (BPR 10-16, Fall 1971), such as fraying, wearability, and fiber separation, have not been improved to an acceptable confidence level.

Impregnation of the material with silicone rubber has been attempted, and one below-knee amputee has worn this prototype for over 1 month. Although the impregnated material appears improved with respect to the previously stated problems, its mechanical ability to translate vertical load into sidewall pressure is adversely affected. Evaluation of this approach is incomplete at this time.

The Medical Engineering section has been attempting to incorporate the basic concepts developed by this research into a modular, off-the-shelf, prosthetic socket. The objective of this approach is being limited in scope to a socket suitable for use in a temporary prosthesis (during

the phase of rapid stump shrinkage). A below-knee prototype has been designed and constructed with the following features: interchangeable soft suspension; a special end clamp for the tubing capable of sustaining traction forces; spring-load traction for prosthetic retention without suction or medial wedge application; and an orthotic-type structural frame designed for rapid fabrication, length adjustment, and soft-socket stabilization.

An interchangeable load-cell sandwich has been designed and fabricated to provide baseline information on load transmission during ambulation. This sandwich will be used to provide objective baseline information so that pressure transducer readings from dissimilar sockets, interfaces, patients, and alignments can be compared at similar load configurations.

The data to be obtained during this phase should determine the clinical applicability and future of this stump socket encapsulation technique.

Immediate Postoperative Application of Upper-Extremity Orthoses

VA Hospital
1201 Broad Rock Road
Richmond, Virginia 23219
Charles L. McDowell, M.D.

Since July 1, 1971, the combined clinic group, including Mr. Joseph R. Mirabella, Chief of Prosthetics Treatment Center, members of the Department of Physical Medicine, and Mr. Homer Hughes, the orthotist, has applied 17 experimental orthoses. The majority of these orthoses were designed specifically to be applied at the completion of an operative procedure and to be modified during the postoperative course, so that continued application would be maintained and so as to control the rehabilitation of the patients after tendon surgery.

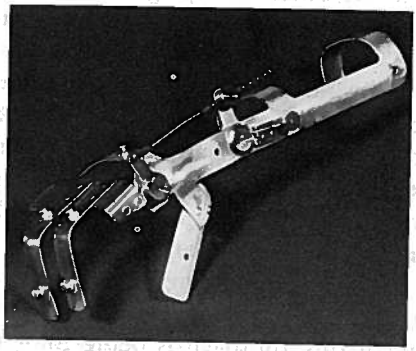

FIGURE 1

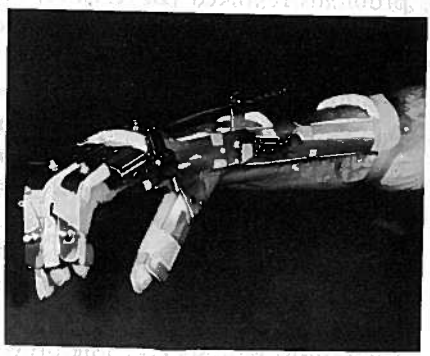

FIGURE 2

Design concepts have not changed from those enumerated in previous reports.

Review of experience indicates increasing reliance on a modified tenodesis type of brace which incorporates a control device for wrist extension and flexion and/or finger flexion and extension. This device allows the patient to move his wrist within a certain range and set his fingers at any amount of flexion that the team desires, Figures 1 and 2.

The project does not yet have enough experience to determine whether this method has reduced the period of rehabilitation time following surgery or improved the final result over that obtained using the routine cast.

The Improvement of Assistive Systems Through Research, Design, Clinical Testing, and Team Evaluation

Texas A&M University College of Engineering
Bioengineering Program
College Station, Texas 77843
Paul H. Newell, Jr., Ph. D., and Lewis A. Leavitt, M.D.

During the latter half of 1971, the research project at Texas A&M University has concentrated on the development and fabrication of a modular, endoskeletal hip-disarticulation prosthesis. An amputee has been selected, and the prototype has been fitted to this patient. This 8-lb. hip-disarticulation prosthesis is composed of new modular components. They include:

1. A lightweight hip-disarticulation girdle (socket-plus-belt), which incorporates a set of individually adjustable pressure pads that permit the amputee to adjust the girdle contours in response to minor changes in stump geometry. Furthermore, the fact that the flexure properties of the girdle vary, with maximal flexibility at the brim, provides increased patient comfort, since the top brim of the girdle will easily flex with the torso during bending.

2. A four-bar-linkage hip joint, which has been designed and fabricated to provide a mechanism to translate the center of rotation of the prosthetic hip, during swing phase, to coincide with the center of rotation of the anatomical hip. Bulkiness of the hip joint and clothing wear must be studied further.

3. A modular, endoskeletal safety knee, which utilizes the rheological properties of a dilatant fluid to provide swing control and to "lock" the joint against buckling by very high resistance to rapid knee flexion (if heel strike should occur, and knee buckling ensue), before full knee extension is accomplished.

4. The development of an improved keel for the SACH foot. A series of glass-reinforced polyester keels, that possess variable flexure proper-

ties in the toe region and modified ankle connection, have been fabricated and are being evaluated. Preliminary results indicate that these keels will mitigate the problems of bearing failure and inadequate location of toe break that are currently associated with the SACH foot.

5. The development of a self-skinning foamed cosmetic cover. An inversion casting procedure has been developed that can produce a rapid replication of the anatomical leg of a unilateral amputee.

A prosthesis has been fabricated for a selected hip-disarticulation patient, and the first clinical evaluation of the system is scheduled for February 1972.

In addition to developing the hip-disarticulation prosthesis, the prosthetics research program at Texas A&M University has become active as an industrial liaison between the Veterans Administration, CPRD, and private industry to evaluate the potential prosthetic and orthotic applications of new material systems. Presently, the industries referred to in the program include U. S. Manufacturing Co., Northrop Corporation, Jersey Enterprises, Inc., and Lord Manufacturing, Inc. In each of these cases an evaluation program has been developed and is currently being conducted.

Finally, after consultation with the project monitors and advisors, plans for future prosthetic and orthotic research activities at Texas A&M University have evolved. These projects include modifying the knee unit developed as part of this year's activities, improving the foamed cosmetic covering in the knee area, incorporating a power-assist device in the four-bar-linkage hip joint, clinically testing the hip-disarticulation prosthesis, expanding the present program to include the development of a power-assisted ankle unit to provide coordinated toe-lift, and studying the orthotics problems of quadriplegics, with special attention to control of wheelchairs and automobiles.

Control of an Artificial Upper Limb in 3 Deg. of Freedom

Department of Electrical Engineering
Colorado State University
Fort Collins, Colorado 80521
Daniel Graupe, Ph. D.

Studies on the design for a controller to provide a control in several degrees of freedom to an artificial upper limb started on November 1, 1971. The feasibility of such control has been investigated for a system whose actuation signals are provided by toe movements and are encoded and coordinated by microelectronics logic circuitry. The present design aims at providing control up to 3 deg. of freedom, namely elbow flexion, wrist rotation, and hand grasp. The controller is designed for two basic modes: one is an action mode, and the second is a hold mode where

movement is frozen. Since adequate control of toe movements at the operator's will cannot usually be achieved while walking, the hold mode is to be called for whenever the operator intends to walk. It is noted, however, that the major use of a hand, apart from a hold mode, is required while standing, sitting, or lying down and not while walking; therefore, the user of the prosthesis should not be seriously handicapped by the restriction to a hold mode when he is walking.

The electronic logic that is being designed in the first phase of the present research is to coordinate the signals provided by the toes with the appropriate movements and directions. Internal feedback taken from the controlled elements is to ascertain that the instructions transmitted by this logic are executed. The supervision of the system is obviously performed by the brain, since toe movement at will is relatively reliable, and requires little training. Although only four independent and controllable toe movements are considered, their combinations, changes in direction, and intensity can be employed to provide the flexibility required by an artificial limb.

The above design depends in its successful operation not only on solutions to the logic and control, but also on the weight of the controller and the executing mechanisms. Whereas the employment of integrated circuitry logic facilitates low weight of the logic circuity, electromechanical transduction with adequate power output is still a problem in the present and in any other controller with more than 1 deg. of freedom. Since the present design in principle is not restricted to a certain type of motor, an optimal solution in terms of available motors is to be sought.

The present design, though considering only the degrees of freedom mentioned above, can be modified to other movements as may be required by the user, including shoulder movement, etc. However, these modifications are constrained by the number of possible movements due to motor-weight considerations.