RESEARCH AND DEVELOPMENT IN THE FIELD OF ARTIFICIAL LIMBS [a]

SUMMARY REPORT

Hans A. Mauch, Principal Investigator

Mauch Laboratories, Inc.
3035 Dryden Road
Dayton, Ohio 45439

ABSTRACT

This report discusses progress from 1 July 1966 through 30 June 1967, in the development of lower-extremity prostheses, sponsored by the Veterans Administration, Prosthetic and Sensory Aids Service. Work on four items has been underway: two hydraulic knee mechanisms including development work toward an improved setup, one hydraulic ankle mechanism including lateral motion foot control and transverse rotation, and studies toward a voluntarily actuated swing and stance control mechanism. The purpose of these developments is to provide as many as possible of the lost muscle functions in the artificial joints involved, without exceeding reasonable limits regarding cost, weight, complexity, and maintenance needs.

The development of the Hydraulic Swing Control Unit (Model B) is completed except for improvements mentioned in connection with the Swing and Stance Control Unit below.

The development of the Hydraulic Swing and Stance Control Unit (Model A) has been continued. Six design improvements have been incorporated as a result of experiences gained from the clinical test units mentioned below as well as from the inspection, maintenance, and updating of seven of the former field test Swing and Stance Control Units and a number of production Swing Control Units which were returned to this laboratory during the contract year. Five of the six improvements apply to both type units, the remaining one to Swing and Stance Control Units only.

The production of fifty Swing and Stance Control Units for clinical testing by the Veterans Administration was completed early in August and the clinical tests began in October. Only one significant malfunction has come up so far (2 cases). It has been corrected.

No further work on the Foam Shank and Foam Knee Block development has been carried out during the year, because the breakthrough achieved by

[a] Based on work performed under VA Contract V1005M–1412.

the introduction of Immediate Postoperative Fitting makes a *Pylon-Type Setup* more appropriate. Consequently, a study toward the development of a pylon type, or more generally, of a non-crustacean-type setup was initiated. This setup would accommodate all our hydraulic systems including the ankle and would include all applicable improvements worked out for the foam setup, as well as features permitting alignment adjustments throughout the life of the resulting prosthesis.

The development of the Hydraulic Ankle Control Unit has been continued. This development turned out to be much more difficult than anticipated. The difficulties were not related to the design principle but were caused by design details. They concerned the reliability of the bypass control for dorsiflexion stop and toe pickup, particularly in walking downhill; the limitation and control of the leakage rate from the front chamber for toe-slap damping; the reliability and durability of the U-seal for the rear chamber; the attachment of the hydraulic unit to the foot and to the shank; the achievement of sufficient structural strength in spite of severe weight and size limitations; and the elimination of noises. Solutions for all these difficulties have been found. Amputee tests indicate high acceptance of the functional features of the unit. Work on the final production prototype has started.

Significant progress has been made in *the development of a Voluntarily Actuated Hydraulic Swing and Stance Control Unit.* A control principle has been worked out which will permit producing all the essential variations of the flexion and extension resistances of a hydraulic knee joint by a single source four-step or, preferably, gradual signal.

The use of myoelectric signals derived from surface electrodes was investigated and has been ruled out for this application. Imbedded myoelectric signal sources appear practical once they become available and are accepted by amputees.

The use of ultrasonic energy was investigated and was found to be problematical. However, audio frequency sound energy seems promising as a signal source based on measuring the degree of hardness of the controlling muscle.

PERSONNEL

Persons engaged in the work reported herein during the period covered by this report are as follows:

Hans A. Mauch—Principal Investigator
Gervais E. Murray—Design Engineer
J. Virgil Rothfuss—Sr. Engineering Technician
Willi J. Elias—Sr. Engineering Technician
Mrs. Jeanne Manley—Office Manager

The assistance of Mr. L. Morse Weimer of Dayton, Ohio, who acted as a subject for this project is gratefully acknowledged.

INTRODUCTION

The contract work is part of a continuous effort carried out by this laboratory since 1950 toward the improvement of artificial limbs, particularly for the lower extremities. Work on four items has been underway: two hydraulic knee mechanisms including development work toward an improved setup, one hydraulic ankle mechanism including lateral motion foot control and transverse rotation, and studies toward a voluntarily actuated swing and stance control mechanism. The purpose of these developments is to provide as many as possible of the lost muscle functions in the artificial joints involved, without exceeding reasonable limits regarding cost, weight, complexity, and maintenance needs.

PROGRESS DURING CONTRACT PERIOD

1. Hydraulic Swing Control Unit (Model B)

This development is completed except for improvements mentioned under 2 below.

2. Hydraulic Swing and Stance Control Unit (Model A) (Fig. 1)

The production run of the 50 Swing and Stance Control Systems for clinical tests was completed early in August. The following was learned during this phase of the project.

The first ten production Swing and Stance Control Systems (#501 through #510) which were delivered to the VA Prosthetics Center at the beginning of July were recalled at the end of the month, because it was discovered in assembling additional systems that the formerly used method of securing cylinders inside the cylinder bottoms by applying Loctite no longer worked in certain cases. The matter was taken up with the Loctite Corporation and it was learned that the original instructions which called for the use of the primer LocQuic "Q" only in cases of cadmium- or zinc-plated materials, had in the meantime been expanded to include some kinds of anodized aluminum and passivated stainless-steel surfaces. Moreover, a new type primer, LocQuic "N," had been developed for just such surfaces. That the old method worked with our previous production systems must have been due to the fact that the anodizing of the component parts at that time was done in California by a different plater who may have used a different anodizing process. A quantity of LocQuic "N" was obtained and tests proved that the new method works properly. After the recalled systems arrived, the parts were treated with the new method to secure the cylinders reliably in the cylinder bottoms and the systems were returned to the VA Prosthetics Center. The new method is being applied to all systems under production.

In the Quarterly Progress Report dated September 30, 1965, it was reported that we discontinued the application of Loctite to the shin screw.

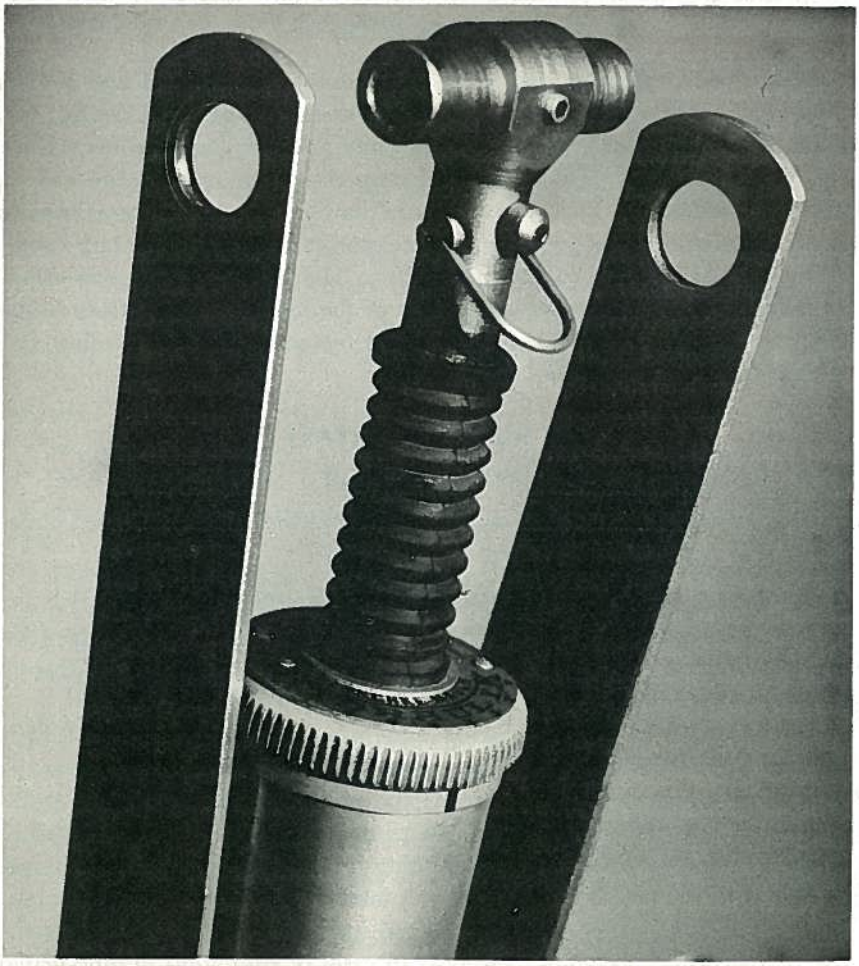

FIGURE 1.—Hydraulic Swing and Stance Control Unit (Model A) showing stance phase controls at top of piston rod.

In the above discussions with the Loctite Corporation it was learned that they have developed in the meantime a special Filled Pipe Sealant with a very high viscosity (10,000 to 30,000 centipoises). Since there is no danger with this material of its running off along the cylinder bolt and entering the cylinder bolt bearings which caused freezing of those bearings in some instances in the past, the new Loctite Sealant was adopted and used in connection with LocQuic "N" in the above mentioned ten systems. The 40 production Swing and Stance Control Systems (#511 through #550) already shipped have the Filled Pipe Sealant, however without the LocQuic

"N," which should not impair the function significantly, because the material involved (cold rolled steel) is not of a critical nature.

In assembling production systems it was found that the two "ears" which had been applied to the upper L-ring in order to facilitate turning of the control bushing by means of the cover screw, are not always helpful for this purpose unless they are very precisely calibrated to fit into the control bushing with a minimum of clearance and without interference. It was also found that only one ear is really needed because, in turning the control bushing clockwise, the upper taper of the control bushing in conjunction with the inside taper of the cover screw have the same effect the second ear has. Therefore, the latter will be eliminated from now on. As to the remaining ear, rather than adjusting its dimension for calibration purposes, it will be produced in such a way that some clearance is provided between it and the inside of the control bushing. The contact between the two elements will then be effected by slightly indenting the upper rim of the control bushing with a special plier-like tool during assembly.

A number of additional tool improvements and procedural simplifications for assembling Stance Control Systems were worked out and tested successfully during the final assembly phase of these systems.

Clinical tests by the VA involving the 50 Swing and Stance Control Systems began in October. As a first result of these tests it was learned in December that the screw cap for adjusting the swing resistances of the system turns unusually hard. Since this difficulty has been with us to a lesser degree all the time, the problem was reinvestigated. It was found that, in addition to the steps taken in the past, it would be helpful to reduce the friction between the parts involved in the adjustment motions, by replacing the interposed standard O-rings with Teflon coated O-rings. A supply of these O-rings was obtained. One each of these rings was installed between the control bushing and the dashpot and between the cover screw and the dashpot, respectively. It was found that both the adjustments for the bending as well as the extension resistance of the swing phase control were markedly facilitated by this change. In order to investigate whether the positions of the control bushing and of the cover screw relative to the dashpot will be reliably retained during walking, in spite of the reduced friction, the Teflon coated O-rings were installed in our test amputee's system for further observation early in February. By the end of March, the amputee tests had produced no evidence of slipping in 6 weeks of wear. It was decided therefore to adopt the design change. Teflon coated O-rings are now routinely used in new assemblies.

In December, clinical test system #509 including setup arrived from VA New York with a split knee block probably due to a poorly glued joint. The knee block was repaired and the setup including system was returned to New York on December 20th.

Another knee block was returned to us in February due to a fracture in the plywood layers. There are indications that this fracture occurred because of clamping the block in the slitted area in spite of the warning to the contrary stamped on the outside of the block. The block was also cut off at a level much lower than recommended in our Manual.

System #502 arrived from VA New York at the beginning of March with a malfunction of the stance control. It was found that the stance control valve was broken, probably due to a material defect. The system was repaired and returned to New York on the 14th of March.

Systems #505 and #507 arrived here at the end of April, the first one allegedly noisy on full extension and the second one because of occasional inadvertent locking. The findings could not be confirmed in bench tests. The systems were then tested by our amputee.

Nothing was found to be wrong with system #507 which allegedly had shown inadvertent lockings. The system was returned to Mr. Earl A. Lewis during a joint trip to Philadelphia on the 9th of May. At that time, we also saw the amputee whose reactions seemed to indicate that there had been inadvertent lockings. He was no longer certain and it was also found that his prosthesis was aligned in a way which made it somewhat hard for him to bend the knee at the beginning of a stride.

System #505 did have a loosely fitting strap hole which might have caused a slight noise. The condition was corrected and the system was returned to New York early in June, after having been checked out by our amputee.

System #529 arrived in the middle of May. Its boot was damaged and the snap ring holding the boot in place had been dislodged. The system was repaired and returned to New York on May 18th.

System #544, worn in the Chicago area, was found to be malfunctioning on the 12th of June. Disassembly in Dayton revealed that the malfunction was caused by the same reason that produced malfunctioning of system #502 in March in that the stance control valve was broken. At that time we had attributed it tentatively to a material defect. However, this second occurrence gave us an opportunity to investigate further. It was established that the fractures were due to overstressing the nylon of the valve proper during initial assembly when inserting the steel valve stem by means of a special tool. This tool permits, if used improperly, the application of sufficient pressure to the valve to produce cracks in the nylon. We will change the tool and we already changed the design of the valve slightly to give it more strength in the future. Mr. Earl A. Lewis will check the systems still in New York in order to find out whether any of them malfunction in a way that would indicate a broken valve. System #544 was repaired and returned to New York on June 19th.

The foregoing have been the technical findings so far from the clinical tests.

Field test systems #51, #59, #64, and #66 which were still here in July 1966 were repaired (three had broken piston rod tips) and returned to NYU in September except for #64 which was retained here as a spare system for our test amputee.

In September, Swing Control System #176 and Swing and Stance Control System #54 (the latter with a broken piston rod tip) arrived from NYU. System #176 was repaired and returned to NYU at the beginning of October; system #54 will be repaired when time permits.

System #50 worn by Mr. Y_____ was here for minor maintenance in October and arrived again from NYU on December 20th, 1966, because of noise. It was found that the noise was caused by the Belleville spring, in the top of the system, running dry. The resulting friction between the spring and the top of the dashpot produced the noise. Since we had similar experiences in some production systems it was decided to install this Belleville spring in the future with some lubricant interposed rather than to clean out that space with a solvent which had been the practice so far. The system was returned to NYU on December 28th.

Systems #51 and #56 arrived from New York University on the 26th of October with broken piston rod tips. Both systems had been worn by Mr. K_____, system #51 for only 5 days. It had been equipped with a new piston rod and hardened piston rod tip before it was installed in Mr. K_____'s leg. This amputee has broken 5 stance control units so far. Since he had been cautioned by NYU not to put unusual stresses on the unit and had apparently followed this advice, NYU suspected that a repair in the knee block carried out by a local limbfitter had produced misalignment between the knee bolt axis and the piston rod bolt axis which could have caused the fractures. It was requested that the prosthesis be shipped to this laboratory for inspection.

The prosthesis arrived at the beginning of December. Our inspection confirmed that the fracture of the knee block and the unsuitable repair of this fracture caused a misalignment between the knee bolt axis and the piston rod bolt axis of approximately 1 deg. This is 10 times the maximum misalignment permissible according to our production tolerances. There is little doubt that the fractures of the Swing and Stance Control Systems which were installed after the knee block broke were caused by this misalignment. The prosthesis was returned to NYU on December 7th.

At the end of December, system #65, worn by Mr. C_____, arrived from New York with a broken piston rod tip. Since this was the third system broken by this amputee, his prosthesis was shipped to Dayton at the beginning of April and we found that there was a misalignment of approximately five times the maximum value permitted by the tolerances in our drawings. The

knee block involved was of the old type (Superoilite bushings without Nyliners). Although there was no clear evidence which would have explained the misalignment, it seems highly probable that sometime during the life of this approximately 5-year-old knee block, one or more of the Superoilite bushings came loose and were reinstalled by a prosthetist without restoring proper alignment. The condition was corrected and the leg was returned to the amputee in April.

A tabulation received from NYU revealed that 80 percent of the piston rod fractures of the field test models occurred in systems worn by these two amputees. As may be recalled, the 50 Stance Control Systems presently undergoing clinical tests have a considerably stronger piston rod design.

Swing Control Systems #176 and #179 arrived from NYU in the middle of January. System #176 was noisy due to a dry upper Belleville spring. The condition was corrected in the usual way by lubrication and the system was returned to NYU on January 19th.

In system #179, the piston rod was broken across the threaded portion at its top end. This has happened only once before in a Swing Control System in a case where we suspected a misalignment between the axes of the knee bolt and the piston rod bolt. It is not known whether such a condition contributed to the fracture in the present case. Again, it should be recalled that the upper end of the piston rod was redesigned some time ago by relocating the thread and by using a stronger material to prevent this type of fracture in both the Swing Control as well as the Swing and Stance Control Systems. This system will be repaired when time permits and returned to NYU.

Swing and Stance Control System #57 arrived from NYU at the beginning of March because of intermittent loss of extension resistance. It was found that the upper U-cup was slightly extruded in spite of the .005 in. thick nylon washer used on the top of that U-cup to prevent extrusion. Various design changes were tried out. One involving the use of Mylar was abandoned because Mylar, although stronger than nylon within the elastic range, takes a more permanent set under stresses beyond that range. It was finally decided to continue the use of nylon but increase its thickness to .0075 in.

Since the beginning of this year, a number of production swing control systems have been returned to this laboratory to be updated and repaired. In disassembling these systems it was found that in two cases the interlocking retaining ring at the lower end of the piston rod which serves as an extension stop was broken, most likely as a result of fatigue stress which developed because the shoulder of the groove in the piston rod on which the ring rests had been deformed by the mechanical pressure. The two cases differed from the remainder of the systems in that the interlocking retaining rings had been installed with the round edges facing downward. None of the retaining rings which had been installed with the sharp edges facing

downward has been found to be broken so far. The grooves were reshaped and the replacement rings were installed with the sharp edges facing downward.

At the end of March, another Swing Control System (#136) arrived from the VA Prosthetics Center with its interlocking retaining ring broken. It could not be established in this case whether the ring had been installed with the round edges facing downward. In order to prevent similar occurrences in the future, it was decided to replace this retaining ring in systems which are here for repair and updating, with a strong steel collar fastened to the piston rod by a hardened dowel pin. However, this will not be necessary in the systems from serial number 2000 on, whose piston rods were made of a considerably stronger material.

At the present time, we have here systems #51, #54, #56, #65, and #179, all with broken piston rod tips. No further spare piston rods of the old design are available. As mentioned in past progress reports, we also have here three unassembled sets of parts for Stance Control Systems #68, #69, and #70, stemming from the field tests. These parts include three old design piston rods. However, it does not seem economical to assemble these systems using the old rods, or to install the rods in three of the four systems here for repair, because they may break again if given to particularly active amputees.

It is therefore intended to wait with the repair of the broken systems and with the assembly of the three sets of parts until we have an opportunity to install piston rods of the new design used in the clinical tests. This will probably be the case after the completion of these tests, when decisions will be made regarding the production of stance control systems.

As will be recalled from last year's Summary Report, we practically completed the development of a foam shank and were in the process of developing a foam knee block at that time. No further work has been carried out on these projects in the meantime. The original purpose of this work was to develop setups that would avoid the use of wood as a structural material. Work was discontinued due to the introduction of the technique of Immediate Postoperative Fitting which made the use of pylon-type setups particularly appropriate. While it seemed at first that these pylon-type prostheses would be used only for a limited time after the operation, there is now a distinct trend toward using them permanently and even toward retaining in the final permanent pylon-type prosthesis certain features which would permit alignment corrections throughout the life of such an artificial leg. Although it is not completely clear at present whether these ideas will eventually prevail, there was not much point in pursuing the development of a foam setup as long as the situation remains unclear.

In conjunction with our foam setup development, we had also planned to introduce certain design changes regarding the manner in which our

hydraulic systems are attached inside the setups. These changes consisted

a. In lowering the rear attachment point of the piston rod tip inside the knee block with the purpose of providing more space for longer stumps; and

b. In attaching the lower end of the hydraulic cylinder to the shank by means of a mediolateral eccentric cross bolt which would replace our present adjustable shin screw and the two side straps, with the purpose of reducing the space requirements inside the shank and the shank dimensions at mid-height in order to improve the cosmetic appearance.

Unfortunately, the delay in the development of a foam setup also delayed the introduction of these two improvements which are very desirable in order to eliminate the shortcomings of the setups we are presently using. As a result of this situation, we initiated a feasibility study for a pylon-type setup which would contain these improvements and would also meet the demands for a permanent, alignment adjustable, prosthesis to be used in conjunction with Immediate Postoperative Fitting. At the same time, we are investigating the possibilities of converting existing commercially available wood setups for our hydraulic systems by including the two improvements mentioned above.

3. Hydraulic Ankle Control Unit

This development turned out to be much more difficult than anticipated. Two facts emerged from the past year's efforts:

a. The acceptance of the functional features of the unit by amputees will be high.

b. The basic technical difficulties have been overcome in principle. However, there still lie ahead some problems involving optimizations, noise elimination, studies of wear and fatigue, debugging, and production engineering.

It must be remembered that we are developing a highly sophisticated hydraulic system capable of controlling in one way or another the ankle motions around each of three axes, the system to be located at the most distal point of an artificial leg, where it should not add more than a few ounces to the total weight, should not make any objectionable noises, and should last several years without maintenance, in spite of the extreme mechanical stresses and heavy pounding it suffers in walking and running, and in spite of the hostile environment near the ground in any weather. One must consider further that the final product will be subject to a severe cost squeeze, because it will have to compete with such simple structures as a SACH foot.

We have no doubts that we will eventually succeed and that the final result will be extremely worthwhile in that it will add to the ankle joint of an above-knee and below-knee prosthesis at least as many or more functional

benefits than the modern knee mechanisms added to the knee joint of above-knee prostheses.

The activities during the contract year included the following:

Sample castings of the housing and the vane-type piston, and a sample molding of the U-seal were received in July 1966. These samples did not fully conform to our drawings and expectations. Intensive cooperation was initiated between this laboratory and the makers of these parts in order to get satisfactory results. Acceptable castings for the housing and the vane-type piston were received at the beginning of October after several changes had been worked out with the foundries and had been included in the patterns. As to the U-seal molding, we had difficulties regarding the surface quality and an excessive need for hand-trimming. These difficulties were finally overcome in October by extensive mold changes.

Progress was made in July in the design of the elements needed for attaching the hydraulic unit proper to the prosthetic foot. Several solutions to provide adjustable toe pickup were investigated, in addition to the one reported about in last year's Summary Report. One of them consists in adjusting the vertical position of the nylon attachment plate in front of the hydraulic unit. Another one involves turning the adjustment screw for the frontal restoring springs inside the hydraulic unit through the rubber boot wall. No final decision has been made as yet. However, the first experimental foot has the design outlined in last year's Summary Report. This design is sufficiently flexible to permit experimenting with the other solutions mentioned above.

In October, the parts for the first production prototype hydraulic unit were 80 percent complete. Preliminary tests were carried out with these parts. As a result, it was decided to switch from the Air Force Hydraulic Oil to silicone fluid, for the following reasons:

a. Silicone fluid is available in various viscosities covering a wide range. By selecting a viscosity higher than the one of the Air Force fluid we can allow wider dimensional tolerances in those parts of the system which determine the leakage rate from the front chamber in toe-slap damping. This will reduce manufacturing costs.

b. The flatter viscosity versus temperature curve of silicone fluid eliminates the need for other temperature compensation means which would be difficult to include in our ankle design.

c. The two disadvantages of silicone fluids as compared with Air Force Hydraulic Oil, namely lower lubricity and higher leakage rate through sliding seals, will not cause difficulties in this application because the bearing loads inside the system are relatively low and because the system is hermetically closed.

Due to the higher viscosity of the hydraulic fluid, a control ball of higher specific gravity was needed to obtain the correct amount of damping for

the rolling motion of the ball. A ball of ceramic material is now being used instead of the Teflon ball.

In November and December, all the parts for the first production prototype hydraulic unit and the modification of the foot and shank of the prosthesis of our test amputee were completed and several preassemblies with these parts were carried out with the following results:

a. The resistance to oil flow through the oil ducts in the vane-type piston was found to be higher than desirable. The inside diameter of these ducts was increased by 25 percent which reduced the oil resistance to less than 50 percent. Similar design changes were incorporated in the relief valve and the bypass control elements in order to open up the cross sectional areas in these places. The wider oil ducts proved satisfactory now, even for oil having a viscosity of 50 centistokes which will probably not be needed.

b. With a gap of 0.010 in. around the vane-type piston, the leakage rate for oil leakage from the front chamber which determines the toe-slap damping was found to be too high. The gap was then reduced to 0.005 in., but the leakage rate of the front chamber was still too high. To produce sufficient toe-slap damping, a silicone fluid with a viscosity in excess of 50 centistokes would have been needed which would have slowed down the switching motions of the control bushing too much. Also, the effect of adjusting the resistance of the duct for bleeding oil from the front chamber and the effect of the pinch-off arrangement of the entrance hole to this duct were less than expected.

As will be recalled from past reports, it is necessary in this design to use castings for the housing and the vane-type piston which have shapes that would be much too expensive to machine to close tolerances. On the other hand, the tolerances obtainable even with precision casting methods are probably not close enough to produce the narrow gaps needed to keep the leakage rate of the front chamber at the necessary low level. In order to achieve these close tolerances it was tentatively decided, rather than to remove material by machining, to produce the castings with sufficient gap width to prevent metal contact even at the extremes of the tolerance ranges, and to close the gap to the desired minimum by adding material to the critical surfaces. For this purpose, a procedure was worked out to apply to these surfaces a sufficient amount of uncured Buna N rubber using Thixon P–4 as a bonding agent, then to assemble the piston with its mated housing whereby the Buna N is being compressed to the correct dimension, and then to vulcanize the Buna N in place in this assembled state of the unit by heating it to 300 deg. F. for 15 minutes. Prior to this procedure, the surfaces contacted by the Buna N where bonding was not desired were coated with a mold release (Fluoroglide).

For best results of this method, it was found to be essential that the ankle bolt which is attached to the housing, and the bore for this bolt

inside the vane-type piston, be located in such positions that the closest approach between the critical surfaces of these parts during rotation occurs in the fully plantar-flexed position. Since this position is also used during vulcanizing, the gaps become zero in that position, producing a "terminal deceleration." By the same token, the effect of the pinch-off arrangement of the entrance hole to the adjustable duct for bleeding oil from the front chamber is fully achieved.

The only dimension in this regard which is produced by machining is the width of the vane portion of the piston. The piston casting is made deliberately wider than the housing inside width and each piston is machined to match its mating housing with a gap of 0.003 in. on each side. To assure the lateral position of the vane piston within the housing, two Nylatron washers, one at each side of the vane-type piston, are interposed. The washers are 0.010 in. thick and they are held in recesses of the piston, each 0.007 in. deep.

The method described above was applied to the prototype system with very satisfactory results. It was now possible to get a degree of toe-slap damping which seemed sufficient in manual test, by using silicone fluid with a viscosity of 35 centistokes.

Even then the damping effect was insufficient for avoiding a metallic click at the end of the piston motion ranges. To eliminate this noise, the front and rear surfaces of the vane portion of the piston which come in contact with the inside wall of the housing at the end of these ranges were coated with a thin layer of Buna N rubber which was vulcanized in place simultaneously with the vulcanizing procedure described above.

c. The arrangement of the bypass control restoring springs had to be changed to permit full range motion for closing the bypass. This was accomplished in an improvisional manner by making rectangular the ends of the slits which house the bypass springs. Later, instead of the two bypass control restoring springs, four were installed having a somewhat reduced preload per spring, making the total resulting preload about 80 percent higher than previously. The reduced preload per spring extends the fatigue life of the springs and the higher total load helps in assuring the return of the control bushing to its neutral position.

d. To facilitate the lateral motion of the foot, the shape of the rear attachment pad of the housing which is held within the foot between two rubber washers was changed in such a way that its upper and lower surfaces are slanted sidewards to produce rooflike configurations.

After implementing all the changes described above, the total prosthesis was weighed before and after the installation of the hydraulic ankle which replaced a standard single bolt ankle joint. The resulting weight increase due to the hydraulic ankle including all accessories was approximately 3 oz.

Subsequently, the production prototype ankle was subjected to its first amputee tests early in January. Extensive functional and stress tests were carried out with very promising results. The amputee liked all the functions including the transverse rotation which had been included in the design for the first time.

These amputee tests and numerous subsequent amputee and bench tests during the time from January to May had the following technical results:

a. The piston rod was bent and slightly twisted during the first amputee tests in January as a result of deliberate excessive force application on a 25 percent incline. As an immediate remedy for the prototype production system, we reinforced the aluminum piston rod by inserting a hardened steel rod. The final remedy will consist in making the piston rod significantly thicker. The necessary change of the casting pattern has already been carried out.

b. The Rulon "A" ring which serves as a bearing around the lower end of the piston rod was extruded under the excessive pressure in the January tests. A new bearing ring was made of Nylatron. Its 45 deg. bearing surface was made slightly convex to permit easier accommodation of the various positions of the piston rod.

c. The chrome-plated steel bushing, against which the bearing ring mentioned under b above rests and which had been installed in the lower end of the wooden shank by pressing it into a corresponding hole, produced loud squeaking noises during the January tests as a result of relative motion between the bushing and the wood surface. The bushing was then installed by cementing it into its hole with epoxy which eliminated the noise.

d. The tubular rubber insert inside the attachment hole of the rear housing pad crumbled initially as a result of the lateral rocking motion combined with a vertical alternating displacement occurring at that location during walking. The rubber insert was then vulcanized in place inside its hole in the rear housing pad. This prevented crumbling, but the insert came loose again repeatedly. Its height was finally reduced to eliminate the pressure contact with the adjacent rubber washers. It remains to be seen whether this remedy is satisfactory.

e. The stops for limiting the rotation of the piston rod around its axis, provided by the shape of a nylon bracket around its top in conjunction with a leaf spring enwrapping the entire assembly, did not prove reliable enough. If maximum torque was applied about the vertical axis of the prosthesis, excessive deformation of the nylon bracket and of the enwrapping leaf spring occurred causing noises and undesirable chafing between the various surfaces. As a tentative remedy, the shape of the leaf spring was changed in such a way that a more reliable limitation of the rotational motion was achieved. It was also found that the expected "push-off" function, which we hoped would be achieved as a result of this bracket design,

would reliably occur only if the friction coefficient between the shoe sole and the ground was at least .3 which is not always the case in practical use of the leg. If the friction coefficient is less, the foot rotates on the ground instead of producing a push-off. Since even under the best conditions, the push-off will produce only a vertical lift of the amputee's body by approximately one-sixteenth of an inch, the idea to derive a push-off function from the rotation of the pelvis about a vertical axis was abandoned and it was decided to redesign the holding bracket accordingly.

In May, the redesign of this shin attachment assembly for the upper end of the piston rod was almost completed. By abandoning the push-off function it was possible to arrive at a much sturdier and potentially less noisy arrangement. It was decided to build an experimental prototype of this design and include it in the present system.

f. The toe-slap damping was still insufficient which was partially due to the use of low viscosity fluid in these tests (20 centistokes). It was decided to use higher viscosity fluid (35 centistokes) and to continue the tests with the bleeding duct from the front chamber closed completely except for the open area left between the threads of the adjustment screw.

The changes were partially successful. However, for achieving sufficient damping it was necessary to reduce the gap between the vane-type piston and the housing walls still further by coating the surface around the contour of the vane-type piston with a special bonding agent (the one we ordinarily use for vulcanizing neoprene onto metal surfaces). This reduced the gap to an average of two one-thousandths of an inch. The toe-slap damping was now satisfactory. However, since producing such a narrow gap routinely in production may be a difficult problem, the matter was investigated further. For some time we considered using a U-seal, like the one which seals the rear chamber, also for sealing the front chamber. This would have necessitated some redesign of the casting pattern of the vane-type piston. It would also have been necessary to test the wear characteristics of this second U-seal because, contrary to the U-seal for the rear chamber, it will have to seal under motion, although against less pressure. Later, this idea was abandoned. The main reason for this decision was the danger of excessive rubber wear and the possibility that rubber particles may find their way into the bypass control assembly where they may cause malfunctions. The investigations continue.

g. The function of the control bushing was quite unsatisfactory in that it did not always close the bypass reliably. After an extensive study of the situation we found that our assumption that in the original ankle unit built several years ago, this control bushing responded reliably to weight application was incorrect. It was revealed that the control bushing in that ankle unit worked reliably not so much because of vertical load application but because of a combination of additional forces produced by torque about

the vertical axis of the prosthesis and by torque about the anterior-posterior axis of the foot. Both these torques have been markedly reduced in the new ankle design by allowing semi-free rotation about both these axes.

One reason weight application alone did not produce reliable function of the control bushing was that high pressure fluid from the rear chamber on its way through the control bushing was wedging itself between the outside surface of the control bushing and the inside surface of the bore of the piston, thus counteracting the development of friction at that location on weight application. As a remedy, it was decided to relocate the bypass ports through the control bushing and the ankle bolt inside it in such a way that they are somewhat removed from the area where the weight application forces occur. As a further remedy, the upper inside surface of the bore of the piston rod was provided with a number of parallel coaxial shallow grooves to give the hydraulic fluid a chance to escape laterally on weight application in order to reduce the film thickness and the lubrication effect, thus increasing friction.

These changes helped to some degree but not enough to assure reliable operation. In addition to the changes listed we also tried various other modifications including relocation of the attachment point of the restoring springs, less spring force, more linear spring characteristics, more positive stops at the ends of the rotation of the control bushing, reduction of the bypass gap width, etc., all with only limited benefits.

Because the parts involved, namely the control bushing and the bolt inside it had by then been provided with a number of various openings which had been tried for various reasons, and because this situation may have contributed to the malfunctions, it was decided to make a new bolt and a new control bushing and include in these parts all the improvements we had found effective so far. In addition, we also replaced the bypass slit in the bolt by a row of holes in order to facilitate the movement of the control bushing in this area. Furthermore, we improved the restoring spring arrangement in such a way that the spring characteristic was much more flat and the motion limitations still more positive in both directions.

After these modifications had been carried out, the system was again tested by hand and by our amputee. It was found that the flatter spring characteristics and the more positive stops for the movements of the control bushing were definitely helpful. There was also a significant improvement in the reliability of the control functions. However, there were still instances especially in walking downhill where the dorsiflexion stop did not always work properly.

Further studies suggested the need for an even more drastic redesign of the control bushing and the bolt inside it. This redesign was directed toward such a management of the hydraulic forces between the bolt and the inside of the control bushing on the one hand, and between the outside of

the control bushing and the inside of the bore of the vane-type piston on the other hand, that the hydraulic forces between the bolt and the inside of the control bushing are in perfect equilibrium all around the bolt in all phases of walking, in order to reduce the friction at that interface to a minimum. As to the hydraulic forces between the outside of the control bushing and the inside of the bore of the vane-type piston, the new design provided that the high fluid pressure developed in the rear chamber of the housing when walking over the ball of the foot, produced forces on the surface of the control bushing at a location far removed from the place where the desirable friction-producing mechanical forces at that interface occur. The design was completed in the middle of March and the unit was ready for testing in May.

It was found in these tests that the relocation of the bypass port did make the function of the control bushing more reliable. However, it was also found that the remaining leakage rate after the bypass slits were closed was much higher than before and too high for a positive dorsiflexion stop. This higher leakage rate was found to be due to the fact that the very relocation of the bypass slits away from the place where the mechanical compression forces occur left a gap of approximately 1–2 mils open across the overlapping zone of the slits, due to the diameter tolerances of the parts involved.

In other words, we were facing a dilemma. If we put the slits in the location where the mechanical forces occur, the presence of high pressure oil counteracted the friction-producing effect of the mechanical forces and in turn, the proper functioning of the control bushing. But, if we put the bypass slits in another location we lacked the mechanical forces needed to close the slits completely in their overlapped position.

The dilemma was tentatively resolved by replacing the grooves, mentioned before, across the upper inside surface of the bore of the vane-type piston by a shallow recess extending throughout the upper 120 deg. of that bore. This had the effect that on weight application during a stride the control bushing is wedged between two surfaces 120 deg. apart which not only produces approximately twice as much mechanical friction between the vane-type piston and the control bushing, but also squeezes out the oil film in the vicinity of these weight-bearing areas and reduces the gap there to a minimum. This design change permitted placing the bypass slits back into the previous location close to the point where the maximum mechanical forces occur, because this place is very near to one of the two weight-bearing areas. This solved the problem in principle but there were still a number of unanswered questions.

h. One reason why it was so difficult to solve the control problem was the fact that the U-seal sometimes leaked in an unpredictable way and that it often was difficult to decide whether a leak was due to the U-seal or to the

malfunctioning of the control bushing discussed above. Therefore, experiments were carried out with the bypass to the control bushing plugged in order to find the reasons for the occasional U-seal leakage. One reason found was the changeover from the Air Force Hydraulic Oil to the silicone fluid. Although silicone fluid does not attack synthetic rubber, it permits leaching out of its plasticizer which leads to rubber shrinkage and to an increase in hardness. Temporarily, we bypassed this problem by keeping the immersion time of the present U-seals in silicone to a minimum. In discussions with our rubber molders we learned that the use of a so-called "dry" Buna N compound which contains no plasticizer will reduce the shrinkage in silicone fluid to an acceptable level.

The second reason for the leakages was imperfect contact between the inside of the housing and the seal's lip at the "corners" of the generally rectangular U-seal. It was found necessary to increase the corner radii of the U-seal as much as the general design would permit. Exploratory tests with increased radii carried out by filling in the inside corners of the housing with epoxy proved the correctness of this finding. Consequently, the patterns of the housing as well as the vane-type piston, and the U-seal mold were modified to have increased radii wherever desirable and feasible.

Another source of occasional leakage was the imperfect contact between the ceramic control ball and the rubber O-ring surrounding the port in the vane-type piston to be closed by the ball. This O-ring is needed to compensate for the inevitable slight misalignment between the port and the ball rolling on the bottom of the housing. The imperfect contact was caused, as in the case of the U-seal, by shrinkage and hardening of the O-ring. In this case, the remedy consisted in using a silicone rubber compound for the O-ring.

As a result of these findings, significant progress was achieved during the month of June.

a. The redesign of the modified shin attachment was completed. The prototype piston rod was modified and the attachment elements were built and bench tested. The redesign works very well. The necessary change of the casting pattern of the vane-type piston will be carried out in July.

b. The 120 deg. cutout inside the piston rod bore described above was subjected to more testing and it was found that the modified load distribution and the higher contact forces produced excessive wear. It was also found that there was still some leakage in the area of the bypass slits due to lack of full radial contact in that area when walking over the ball.

Finally, a solution for this difficult control problem was found which works well and does not seem to have any disadvantages regarding wear or complexity. The solution consists in placing the bore inside the control bushing in a slightly eccentric position (by 0.010 in.). The direction of the eccentricity is such that the forward rotation of the control bushing during

the stance phase is not only produced by friction, but is assisted by the forces caused by the eccentricity. The prototype unit was modified accordingly and tests proved the correctness of the theoretical expectations.

c. In these same tests, a problem was revealed that had so far escaped clear identification. As will be recalled, our ankle control locks the dorsiflexion motion whenever the shank moves through the vertical during the stance phase of a stride. This means that in walking downhill the dorsiflexion is locked when the foot is still plantar flexed to a degree determined by the angle of the downward slope. On toe-off and weight removal, the foot is supposed to return by itself to its normal position in order to avoid stubbing the toe during the swing phase. This dorsiflexion motion was correctly carried out by the modified system. However, there was a time delay (up to a second) between weight removal and the onset of this motion. It was found that the delay was caused by a corresponding delay in the return of the control bushing to its normal position upon weight removal. This problem was not fully recognized two years ago when we redesigned the present ankle unit. At that time we deliberately arranged the forces acting on the control bushing (weight of the foot including shoe, force of the dorsiflexion restoring spring, and the hydraulic forces acting on the vane-type piston) in such a way, that they would cancel each other at toe-off and the control bushing would return to its normal position freely without being hindered by friction forces. While this was achieved, it was not clear at that time that the contact pressure in the bypass slit area when walking over the ball would squeeze out the hydraulic oil between the adjoining surfaces to such a degree that it would take sometime for this oil to return into that space after weight removal, thus relieving the intimate contact between the control bushing and the surrounding structural elements and allowing the control bushing to return to its normal position. To speed up this process it was not sufficient to make the forces acting on the control bushing zero by canceling each other, but it was necessary to produce a load reversal that would pull the surfaces actively apart upon weight removal. Although this would ultimately produce friction again after the load reversal had its effect, there would be a short instant when the forces go through zero, during which the control bushing was free to return.

To test the theory, the toe of the existing prototype was loaded downward by attaching a weight and it was found that, paradoxically, this plantar flexing force produced instantaneous dorsiflexion upon toe-off. The necessary design changes are simple in principle but carrying them out will be time consuming because significant changes of the shapes of the casting patterns for the vane-type piston as well as the housing will be necessary. A graphic method was developed to compute the necessary changes in the location of the force vectors of the weight of the foot including shoe, of the dorsiflexion spring, and of the hydraulic forces acting upon the vane-type piston to

achieve the necessary load reversal upon weight removal. It was found that the necessary changes are feasible within the constraints of the present design.

d. The changes of the casting patterns mentioned in the previous point will be of such a nature that larger overlap areas between the contour of the vane-type piston and the inside surface of the housing can be achieved fairly easily. Advantage will be taken of this possibility in order to reduce the leakage rate from the front chamber during toe-slap damping and it is hoped that it will no longer be necessary to narrow the gap around the contour of the vane-type piston by vulcanizing rubber onto certain surfaces of the piston and the housing.

e. The changes of the U-seal mold to increase the corner radii described above were carried out and U-seal samples made of "dry" Buna N compound (without plasticizer) were obtained and tested with satisfactory results.

Preparations for a presentation of the VA PSAS R&D program to a Congressional Committee in April also included making a short movie (6 minutes) illustrating the theoretical and practical aspects of the Hydraulic Ankle Control Unit. This film was completed in time for the presentation in Washington on April 18th but could not be shown due to lack of time.

Partly for this film, but also for general use in our testing of the ankle control unit, a 10 ft. x 4 ft. replica of uneven territory, involving several slanted uphill and downhill sections, was completed during March.

Several prints of the movie were shipped to VA PSAS in Washington (one print) and New York (two prints) on May 15th and May 19th, respectively.

4. Voluntarily Actuated Swing and Stance Control Unit

Significant progress has been made in this project. One part of our efforts concerned basic studies regarding the use of a myoelectric signal for controlling the artificial leg. Since this signal will control in some way the bending resistance of the knee joint and since failure to do this may result in a fall of the amputee, it becomes clear that the reliability of such a signal in a leg prosthesis must be higher than in an arm prosthesis. As we will see further below, it is also highly desirable to have at least a four-state signal (0-1-2-3) or even a gradual—but not necessarily linear—signal over the entire range. In both cases the signal would have to progress through the range more or less reproducibly in accordance with the intensity of the myoelectric activity of the muscle. It is felt that the electrode configurations presently used for myoelectric upper-extremity prostheses may not be optimal for artificial legs.

In order to investigate the relationship of signals taken from different locations on a muscle, two electrode assemblies were constructed. Two signal electrodes and one reference electrode were used in each assembly in order to take advantage of the common mode noise rejection capabilities of a differential system. It was necessary to amplify the signals obtained from the two electrode assemblies in order to observe them on an oscilloscope. Two

integrated differential amplifiers were built, each with a differential open loop gain of about 2000. Since the small contact area of the point-electrodes used represents a high source impedance, four emitter followers were constructed to drive the amplifiers. Low noise, high gain transistors were selected for this purpose.

For convenience at this early stage the flexor muscles of the forearm were used for a signal source. The two electrode assemblies were taped to the forearm in various relative positions and the outputs of the two amplifiers monitored with a dual trace oscilloscope. In order to obtain a good signal it was necessary to add a small amount of electrode jelly to the tip of each needle.

Initially, the two signals obtained from various points on the muscle were compared by eye for any obvious wave shape similarities or patterns. Due to the complexity of the signals this is a difficult task. In order to facilitate observation the oscilloscope was connected to produce an X–Y display, i.e., the output of one amplifier was connected to the horizontal axis, the output of the other amplifier to the vertical axis. If the two signals were identical the resultant display would appear as a straight diagonal line 45 deg. from the horizontal and varying in length. If the waveforms were identical in shape, but displaced in time, the scope would display a diagonal pattern of constantly varying contour but symmetrical about a 45 deg. line.

No conclusive results were obtained from these first tests. Two essential changes were then introduced.

a. Instead of the two differential electrode assemblies used for investigating the electric activity on the muscle surface, we measured two single surface potentials relative to a common neutral electrode. Since this type measurement is much more affected by outside disturbances, we first considered building a Faraday cage but gave this up for the time being because we found locations in our building where we would reduce these disturbances to a tolerable level by turning off the fluorescent light fixtures.

b. Instead of measuring the surface potentials of the forearm muscles, we used a muscle of the quadriceps group of the thigh (rectus femoris).

In these tests, the neutral electrode was first placed on the underside of the thigh. It was found that this location introduced disturbances (probably caused by involuntary actions of the hamstring muscles) that did not influence in the same way the measuring results obtained by the two other electrodes and could not therefore be eliminated by differential methods. The third electrode was then placed midway between the two other electrodes.

The first tentative test results seemed to confirm our expectation that the muscle potentials present on surface areas spaced longitudinally along the muscle are not entirely unrelated events but show a certain correlation. This was suggested by the fact that the voltages measured between each of the two separate electrodes and the common neutral electrode, in an X–Y dis-

play, show a slanted elliptical pattern. This indicates that the two voltages contain a significant portion of common time functions that are just separated from each other by a time delay.

For a full investigation of these relationships with the aim of establishing criteria for optimal electrode arrangements, electronic signal analyzing equipment would be needed which would permit signal averaging and correlation computing in real time. This type of equipment is quite expensive and its degree of usage in our laboratory would be insufficient to justify the cost. In addition, the investigation would fall into the category of "Fundamental Research" which is not really our principal activity. It should therefore be assigned to a properly equipped university laboratory.

For the time being we are satisfied that for our specific application, the placement of the two main electrodes approximately 4 in. apart with the neutral electrode halfway inbetween, the entire group being longitudinally arranged on the surface of the rectus femoris, will yield sufficiently satisfactory results for prototype development.

Another part of our efforts concerned the question of how to utilize any kind of a muscle signal in the most advantageous way for the control of an above-knee prosthesis After a number of possibilities involving swing as well as stance control requirements had been studied it became clear that voluntary control of the extension resistance of such a leg is far less important than voluntary control of the bending resistance. Actually, there are only two instances where control of the extension resistance seems desirable: one for terminal deceleration at the end of the swing phase, and the other one for holding the leg in a bent position for lifting it over obstacles. The latter usage is rather unimportant and the former can easily be achieved without voluntary control by damping the terminal extension motion with conventional means. This reduces significantly the need for a myoelectric system involving the hamstring muscles.

As to the control of the bending resistance, there are three instances (in addition to the no resistance state) where such control is desirable. One is the moderate bending resistance which limits the heel rise at the end of the first half of the swing phase. The second is a significantly higher bending resistance to produce a moderate yielding rate under the full weight of the amputee. This state can be used for walking downstairs and downhill as well as for stumbling recovery. The third state is a full lock which can be used for a number of activities, a notable one being the so-called "double knee bend" in ordinary walking which is used by non-amputees upon heel-contact to soften the vertical excursions of the body's center of gravity.

While these four states could be achieved with a four-state signal, it would be preferable if the four states would be replaced by a continuously increasing bending resistance produced by a gradually increasing signal. It seems possible to extend the use of the myoelectric control unit, which we

obtained from Professor Scott of New Brunswick University and which produces a three-state signal, to produce a four-state signal or even a gradual signal. In either case, this signal would be applied to an electro-magnetically controlled valve or valve system associated with the hydraulic unit which would stepwise or gradually close as a result of increasing current values.

As a refinement, the valve system could be so designed that in its inactive position, it would produce a slight *extension* resistance in the leg which would make the extension motion at least partially subject to voluntary control. Another refinement would be the addition of a feedback arrangement which would signal to the amputee the relative angle between the shank and the thigh of the prosthesis.

As indicated in last year's Summary Report, we also considered the use of ultrasonic energy as a signal source.

Through the courtesy of a local doctor, we were given access to an ultrasonic tester which is used for diagnostic purposes in the ECG Department of a Dayton hospital.

The tester which was developed by Physionics Engineering, Inc. in Longmont, Colorado, and is sold by the Picker X-Ray Corporation in White Plains, New York, is based on a sonar-like principle and permits various modes of operation.

We used it in the so-called A scan mode in which a sequence of 2.5 megacycle ultrasonic low energy pulses, each lasting 1/500 of a second, is being transmitted into the body and the echo of each pulse is displayed on an oscilloscope screen which is calibrated horizontally to indicate the depth of the interface inside the body from which the echo or echoes are reflected. We applied the tester's transducer probe to the upper arm biceps.

Although the height of the reflected pulse trace is a relative indication of the amount of reflected energy and therefore an indication of the rigidity or softness of the muscle, it was soon learned that the influence of the transmission impedance on the skin surface under the ultrasonic transducer is so strong and so hard to control that intensity measurements of the reflected signal would not seem to be a reliable means of controlling a prosthesis. As a matter of fact, the only way of achieving a transducer/skin impedance having a tolerable level and a reproducible value would be the one used for diagnostic purposes in the hospital, namely the application of ECG jelly to the skin, which, of course, would not be feasible on a permanent basis inside the socket of a prosthesis.

However, it was found that the degree of the muscle's rigidity is indicated on the oscilloscope not only by the echo intensity but also by the echo pattern in that a larger number of echoes seem to be returned from various interfaces inside the rigid muscle as compared with the relaxed muscle. These were rather preliminary findings and more studies seemed necessary to assess their value for our purposes in more details.

On the 25th of April, the Dayton Office of the Hewlett-Packard Company received a demonstration model of their newly developed Diagnostic Sounder, and we were given an opportunity to carry out some tests. The tests were more extensive than the ones previously carried out with the ultrasonic tester in the hospital. The results confirmed the former findings but were less encouraging. It was found that the high directionality of the high frequency ultrasonic sound made the signal very sensitive to small changes in the location and orientation of the piezoelectric probe.

As a result, it was decided to abandon ultrasonic frequencies and to carry out tests with frequencies in the audio range. It is expected that this approach will result in a much more reproducible and stronger signal. The design of an electro-dynamic vibrating probe is partially completed. Essentially, it will measure the energy dissipation and hardness of the muscle in its various states of tension or relaxation. The probe is so designed that it can be used as a tool for finding optimum frequencies, amplitudes, and dimensions.

5. Miscellaneous

On October 10th and 11th, 1966, Dr. Eugene F. Murphy, Chief, R&D Div., PSAS, VA, New York, visited this laboratory to discuss the status of our development program.

From October 15th through 20th, H. A. Mauch attended the AOPA Convention in Palm Springs. A great deal was learned from the papers given and the personal discussions regarding the impact of Immediate Postoperative Fitting on prosthetics design, and regarding the state-of-the-art of myoelectric control of upper-extremity prostheses.

From December 1st through the 3rd, H. A. Mauch attended the Seminar on Immediate Postoperative Fitting given by the University of Miami School of Medicine in order to obtain additional information on this new type of surgery and prosthetics management.

On January 25th and 26th, Mr. Earl A. Lewis from the R&D Div., PSAS, Veterans Administration, New York visited this laboratory to discuss technical aspects of the clinical tests of the Swing and Stance Control System. In addition, three instruction pamphelts (Stance Control Adjustment, Swing Control Adjustment, and Training Procedures) used during these tests, were thoroughly reviewed and partially revised.

Dr. Eugene F. Murphy, Chief R&D Div., PSAS, VA, New York, visited Mauch Laboratories on February 27th, 1967. Dr. Murphy was informed about the present status of the ankle development. In addition, we discussed with him the myoelectric control project and preparations for a demonstration of our development items to be included in a presentation of the VA PSAS R&D program to a Congressional Committee in April.

From March 6th to March 10th, H. A. Mauch participated in CPRD panel meetings on Lower-Extremity Orthotics and Upper-Extremity Pros-

thetics in Santa Monica, California. The meetings were very informative. The opportunity was also used for discussions with other participants regarding our present and future work. These discussions were very fruitful and will definitely influence the direction of our work.

During the stay in Los Angeles, H. A. Mauch, together with Dr. E. F. Murphy, visited the local VA Hospital which is carrying out the clinical tests of our Swing and Stance Control System on three amputees. The three amputees and the local prosthetists involved were also present. Much was learned about the first experiences in fitting this system and training the amputees.

From April 16th to 18th, H. A. Mauch was in Washington, D.C. for discussions of our projects and for assisting in the preparation of a presentation of the VA PSAS R&D program to a Congressional Committee. This presentation included a number of our development items which were well received.

On May 8-9, H. A. Mauch met with Mr. Earl A. Lewis in Philadelphia in order to attend a presentation at the local VA Hospital of four amputees wearing our Swing and Stance Control System as part of the clinical tests.

On May 9-10, H. A. Mauch was in New York where our artificial limb program was discussed with VA officials with particular emphasis on the ankle development and on our present studies regarding the voluntary control of artificial limbs by electro-dynamic measurements of the energy dissipation and hardness of a muscle in its various states of tension or relaxation.

On June 12-13, H. A. Mauch traveled to Chicago and Atlanta to meet with Mr. Earl A. Lewis, and to attend presentations at the local VA Hospitals in the two cities, by a total of seven amputees wearing our Swing and Stance Control System as part of the clinical tests. The ensuing discussions proved very fruitful and informative.

FUTURE PLANS

1. Hydraulic Swing Control Unit (Model B)

Since this development is complete and production of the unit is underway, no further work is planned. However, improvements of the swing control mechanism which may result from our work on the Swing and Stance Control Unit (see 2 below) will be included in the design of the Swing Control Unit at suitable intervals.

2. Hydraulic Swing and Stance Control Unit (Model A)

Assistance will be given whenever necessary to the clinical tests of the Swing and Stance Control System presently underway. Any modifications of the design which may be found necessary will be carried out, and units received after such an event will be updated if this seems desirable. Findings regarding the swing control mechanism will be included in the design of the Swing Control System as stated above under 1.

As agreed with NYU and following the procedure established at the end of the field test of our Swing Control System, we will continue servicing the Swing and Stance Control Systems used in the NYU field test. This service which has helped us considerably in improving our design will continue until Swing and Stance Control Systems will become generally available.

In preparation for the production run of this system to be expected after the completion of the clinical tests, we will bring all the drawings and specifications up-to-date.

Development work toward an improved setup will be continued.

3. Hydraulic Ankle Control Unit

After completion of the modifications of the casting patterns presently underway and after having received satisfactory sample castings, we will build a revised production prototype unit which will include all the improvements developed during the past year. After bench testing and debugging, this unit will be installed in the prosthesis of our test amputee for extensive amputee tests. After successful conclusion of these tests, six shakedown test models will be built to be evaluated by the Veterans Administration in New York. This work will represent the most important effort during the coming contract year.

4. Voluntarily Actuated Swing and Stance Control Unit

Work on this problem will represent the second major effort during the coming contract period. The ultimate goal of these studies is the application of voluntary control principles to a lower-extremity prosthesis for swing as well as stance functions. The development will parallel the efforts going on in the upper-extremity field toward the application and control of external power. Although in lower-extremity prostheses external power for joint manipulation is not contemplated, the voluntary control of the dissipation of the energy created in the joints during the locomotion process is similar to the upper-extremity problems in many respects.

We are no longer sure that the myoelectric control system with skin electrodes developed for upper-extremity prostheses can be adapted successfully to the control of lower-extremity prostheses. It seems likely that a sufficiently reliable, *gradual,* reproducible myoelectric signal for lower-extremity prostheses can only be obtained from an imbedded myoelectric signal source. A development of this nature lies outside our province because we lack clinical facilities. We also feel that it will take quite some time until amputees will accept surgical procedures as a necessary prerequisite for prosthetic control.

On the other hand, we are hopeful that our present experiments with an electro-dynamic signal source which measures muscle hardness from the outside through the skin, will work. We intend, therefore, to continue work-

ing on this device which may also prove useful for the control of upper-extremity prostheses.

In addition, we will design and build a prototype of a hydraulic knee system whose swing and stance functions can be controlled voluntarily and gradually by either our electro-dynamic signal source or by any myoelectric gradual signal source which may become available. This prototype knee system will also provide voluntary terminal deceleration at the end of the swing phase and a feedback informing the amputee about the position of the prosthetic shank relative to the thigh.