PHYSICAL RESPONSE OF SACH FEET UNDER LABORATORY TESTING

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PURPOSE OF STUDY

Durability is one of the important features of a SACH (Solid Ankle Cushion Heel) foot. The subjection of commercially available feet to controlled but vigorous testing would indicate the effects of design and materials on durability, would identify weaknesses or faults, and hopefully would lead to improvement of design.

It is acknowledged at this time that durability is only one criterion of a functional SACH foot. Also, amputee requirements vary considerably according to their weight, level of amputation, and level of activity. These latter factors require clear elucidation and further study. Although durability is important for economy—patient time, prosthetist time, and cost of replacement—it is stressed that the results in this paper must be interpreted with a degree of caution, as other parameters of quality are not included.

TEST APPARATUS

Detailed descriptions of the durometer test and cycle test apparatus are given in previous publications (2, 3). For convenience this equipment is described briefly.

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Cycle Tester (2)

As shown in Figure 1, two SACH feet may be tested simultaneously on the cycle tester. The load cycle is controlled by timed cams cycling the air pressure within the pneumatic cylinders in relation to the walking cycle. At heel contact, which occurs 20 deg. before the shaft of the footholder reaches the vertical position, the foot is loaded rapidly by an injection of high pressure air into the air cylinder. By means of the timed cam arrangement, the pressure within the cylinder is switched to a reserve tank (shown below the force plate in Fig. 1) having a controlled pressure to maintain a relatively constant load until unloading, prior to “toe-off.” Toe-off occurs 35 deg. past the vertical.
The cycle load is calibrated and controlled by means of a cantilever beam located at each corner of the force plate. Each cantilever beam has two strain gages (one mounted on top, the other on the bottom) wired in a Wheatstone half-bridge circuit, to provide individual vertical-load signals to a d.c. amplifier chart recorder via a switch and balance unit and a strain indicator. By the use of calibration curves for each beam, recorded strains are converted to measurement of vertical load in pounds. A two-chart recorder was used in this application. The first channel records each strain level, while the second channel records the time period (angle) of the cycle by method of a photoelectric interrupter module. A light interrupter disk mounted on the shaft which provides the rocking action to the foot gives precise photolight interruptions every 10 deg. The recorded blips caused by the photolight interruptions give accurate correlation between load and time or load and foot angle.

Durometer Tester (3)

Physical details of the durometer testing equipment are shown in Figure 2. Forces are applied to the foot by an electric motor which drives the vertical column up at a constant rate of 7.2 in./min. Various rates of loading were attempted prior to establishing the given rate. It was found that rates slightly higher or lower than the established rate resulted in minimal changes in the curves obtained.

The load cell located just below the force plate on top of the vertical column supplies voltage readings to the Y axis of an X-Y recorder in direct proportion to load. Linear travel of the vertical column is also converted into a voltage signal, which is recorded on the X axis of the recorder. Consequently, a continuous load versus deflection curve is recorded on the X-Y chart for the entire test. The recorder chart is calibrated for 1 in. deflection in the X direction to equal 0.25 in. travel of the vertical column, and for 1 in. deflection in the Y direction to equal 25 lb. of load. As described in reference 3, the point in travel of the vertical column, at which the chart recorder commences to record in the X direction, is preset and maintained in the same position for the entire cycle test sequence as a specific reference point. From this reference point the distance to the “touch point,” or the instant at which the load is applied to the foot, was automatically recorded. Consequently all permanent deformation during cycling is recorded as the result of the touch point moving further along the X axis.

X-Ray Equipment

The X-ray equipment used in analyzing the feet was a Picker Model
6500S special hospital unit for tuberculosis control and Fuji RX 100 film. The feet were mounted in the appropriate position at a distance of 60 in. from the film cassette. Normal power setting on this equipment for the X-ray was 60 kV., 25 ma., with an exposure time of ¼ sec.

**Figure 2.—Durometer tester.**
Although modifications in the design of equipment and additional techniques were included, the test procedure was based on the criteria outlined by the Veterans Administration Prosthetics Center, New York, in its "Standards and Specifications for Prosthetic Foot/Ankle Assemblies" (1).

The following is a summary of the test procedures employed: An X-ray is taken of each foot in the condition as received from the manufacturer. Immediately following, individual load versus deflection (durometer) for heel and sole was recorded in both the loading and unloading sequence by method of the durometer tester (Fig. 2). The feet were then mounted on the cycle tester (Fig. 1) at a fixed angle of 5 deg. to simulate normal toe-out when attached to a prosthesis. Socks and shoes were applied to the feet in order to simulate normal wear during the cycling process. The standard "Hush Puppy" shoe manufactured by Greb Shoe Company was used in all tests.

Starting from lower load values, the loading cylinder air pressures, reserve tank pressures, and timing cams were adjusted to subject a cyclic load onto the test feet to simulate vigorous walking of an active amputee weighing approximately 200 lb. or 100 Kg. Calibration and control of the cyclic load was achieved by use of the strain gage and light interrupter recordings (Fig. 2). Figure 3 shows a plot of the average load of all tests versus time, while Figure 4 illustrates the average load versus foot angle. The upper and lower limit plots shown in the figures are the maximum and minimum average loads encountered during the whole range of tests.

Due to most changes in durometer occurring early in the cycling program, durometer tests were completed at 5,000, 10,000, 20,000 and 50,000 cycles. Additional tests were completed at 100,000 and at every additional 100,000 cycles. In view of the durometer changes in the foot, it was necessary to recheck the cyclic load at every 100,000 cycles employing the strain gage-light interrupter technique. The averages of these recorded loads are plotted in Figures 3 and 4.

RESULTs

To date the results of testing nine various types of SACH feet for durability are complete. The results for each individual foot are given in graphical form as exact superimposed reproductions of the original graphs obtained using the durometer tester.

The graphs "Durometer Test Results After Cycle Testing" show the permanent deformation and changes in resistance as related to the
AVERAGE LOAD vs TIME DURING CYCLE TESTING

TIME, Sec.

LOAD, LB.

FIGURE 3

AVERAGE LOAD vs FOOT ANGLE DURING CYCLE TESTING

FOOT ANGLE, DEG.

LOAD, LB.

FIGURE 4
Veterans Administration Prosthetics Center, New York, specifications. Note that the specified curves are superimposed with the original “touch point” as the zero load, zero deflection point on the VA charts.

As stated in reference 3, the hysteresis curves are an indication of the ability of the SACH foot to recover from deformation. It was also found that the area between the loading curve and the unloading curve (the amount of lag as the result of reversing the loading) is directly related to the degree of permanent deformation and/or changes in resistance expected as the result of cycle testing. In general, the larger the area, the greater the change in resistance and/or permanent deformation. In the graphs included in this report, the final hysteresis curves have been superimposed over the original curves with the original touch point as a common reference. Note that the loading curves on the hysteresis graphs correspond to the curves shown on the graphs of durometer test results.

Photographic reproductions of the X-ray negatives prior to and subsequent to testing are included to show any internal breakdown which may have occurred. A plan X-ray view of each of the feet is given to show the various methods used to attach the belting to the keel.

**Permanent Deformation**

Prior to an interpretation of the details of the graphs for each of the feet, the progressive permanent deformations as the result of cycling are given in Tables 1 and 2 for each of the heels and soles respectively. In the columns “Increments to Touch Point” are measured from the edge of the graph or base reference point at which the chart recorder has been preset to commence recording. The permanent deformation is measured from the touch point established at 0 cycles.

**DISCUSSION OF RESULTS**

**Otto Bock—Type 1537**

*Heel Resistance* (Fig. 5 and 6)

With reference to Figure 5, the original heel resistance curve as compared to VA ratings is on the extreme borderline of the firm range. Most change in resistance for the entire loading cycle occurred prior to the completion of 5,760 cycles. Although there was a slight reduction in resistance when subjected to loading, the superimposed hysteresis curves shown in Figure 6 indicate little or no change in the encompassed area as the result of cycle testing.
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<th>Manufacturer Type</th>
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<th>Otto Bock IS10</th>
<th>Kingsley High Profile</th>
<th>Kingsley Standard</th>
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*Increments to Touch Point. Note each increment equals 0.025 in.*
Table 2.—Permanent Deformation of the Soles

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<th>Otto Bock IS37</th>
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*Increment to Touch Point. Note each increment equals 0.025 in.*
DUROMETER TEST RESULTS
AFTER CYCLE TESTING
OTTO BOCK (SIZE 29)
137 HEEL

DEFLECTION, IN.

LOAD, L.B.

TOUCH POINT
'0' CYCLES

Figure 5

HYSTERESIS CURVES
OTTO BOCK (SIZE 29)
137 HEEL

DEFLECTION, IN.

LOAD, L.B.

TOUCH POINT
'0' CYCLES

Figure 6
DUROMETER TEST RESULTS
AFTER CYCLE TESTING
OTTO BOCK (SIZE 29)
IS37 SOLE

Figure 7

HYSHERESIS CURVES
OTTO BOCK (SIZE 29)
IS37 SOLE

Figure 8
**Sole Resistance** (Fig. 7 and 8)

The initial sole resistance curve falls slightly below the VA recommended range. Most permanent deformation and changes in resistance occurred prior to the first durometer test at 5,760 cycles. However when the curves at 5,760 and 500,000 cycles were moved back to the original touch point, the resistance in both instances for the entire loading cycle is almost identical to the original curve. This is clearly shown in Figure 8 for both the loading and unloading phase of the durometer test. The narrow encompassed area between the curves should be noted.

![Figure 9](image1.png)

**Figure 9.**—Otto Bock 1S37 before cycling.

![Figure 10](image2.png)

**Figure 10.**—Otto Bock 1S37 after cycling.
Construction and X-ray Analysis (Fig. 9, 10, and 11)

A three-piece foam construction with a softwood keel and single belt is used in the Otto Bock foot. In lieu of double belting to obtain required sole resistance, the forefoot and upper half of the toe area consist of a high density foam. The sole of the foot is formed using a lower density resilient foam. Heel wedges of varied durometer provide the range of firmness required.

Due to the softwood keel used in all Otto Bock feet, it was necessary to add a flat metal plate over the attachment face of the keel during cycle testing. The metallic insert around the attachment bolt hole shown in the X-ray figures is provided by the manufacturer. Of note is the neat attachment of the single belting to the keel and the excellent positioning of the belting. The keel shape in itself with the well-rounded corners and consistency with the outer shape is noteworthy. No physical breakdown was observed by X-ray.

Otto Bock—Type 1S10

Heel Resistance (Fig. 12 and 13)

The resistance curves for the heel of the Type 1S10 foot are almost identical to those of the newer Otto Bock Type 1S37. Consequently the same comments are applicable.
DUROMETER TEST RESULTS
AFTER CYCLE TESTING
OTTO BOCK (SIZE 29)
ISIO HEEL

Figure 12

HYSTERESIS CURVES
OTTO BOCK (SIZE 29)
ISIO HEEL

Figure 13
DUROMETER TEST RESULTS
AFTER CYCLE TESTING
OTTO BOCK (SIZE 29)
ISIO SOLE

FIGURE 14

HYSTERESIS CURVES
OTTO BOCK (SIZE 29)
ISIO SOLE

FIGURE 15
**Sole Resistance** (Fig. 14 and 15)

Due to the thicker cross-sectional area at the toe break, the initial resistance curve falls well within the VA specified range. For comparison, with reference to Table 2, the permanent deformation is reduced by 0.075 in. in comparison to the Type 1S37. The curves in Figure 15 indicate a slight softening of the materials due to cycling, interpreted as follows: For loads up to 25 lb. there is more deflection (less resistance) in the final test. As the load is increased, the softer material is compressed more readily against the keel causing the curves to rise at a steeper angle. However, the resiliency of the sole is reasonably maintained, as indicated by the almost identical areas between the curves and only slight change in the durometer.

**Construction**

Although the shapes of the 1S10 and 1S37 feet differ, the construction is identical. No physical breakdown was observed by X-ray.
Kingsley High Profile

Heel Resistance (Fig. 16 and 17)

The permanent deformation of the Kingsley heel is higher than that of the Otto Bock feet. Also, the heel section shows reduction of resistance to load commensurate with cycle testing. With reference to Figure 17, the resilience of the heel section is maintained regardless of the reduced resistance to load as indicated by the almost equal encompassed areas.

Sole Resistance (Fig. 18 and 19)

With reference to Table 2, the permanent deformation of 0.350 in. is double that of the Otto Bock foot. However, the excellent initial curve form is maintained throughout the cycle testing. Due to the permanent deformation this curve falls outside of VA specified limits after 5,000 cycles. Resilience is maintained as shown by the comparative hysteresis curves (Fig. 19).
DUROMETER TEST RESULTS
AFTER CYCLE TESTING
KINGSLEY HIGH PROFILE (SIZE 27)
SOLE

UPPER LIMIT

TOUCH POINT '0' CYCLES

LOWER LIMIT

DEFLECTION, IN.

LOAD, LB.

FIGURE 18

HYSTERESIS CURVES
KINGSLEY HIGH PROFILE (SIZE 27) SOLE

TOUCH POINT '0' CYCLES

FIGURE 19
A three-piece foam construction with a hardwood heel and single belt is used. As opposed to the Otto Bock sole, resistance to load is maintained primarily by a high density sole. The foam used in the forefoot and toe area is of lower density. Heel wedges of varied durometer provide the range of firmness required.

The Kingsley feet have a hardwood keel and consequently are not vulnerable to the disadvantages of requiring additional metallic components when subjected to vigorous testing or walking. Although the basic attachment of the belting to the keel is good, the final position of the belt within the foot is poor (Fig. 20). No physical breakdown was observed by X-ray.
Kingsley Standard

Heel Resistance (Fig. 23 and 24)

Aside from the Kingsley Standard heel being more resistant to greater loads or slightly firmer than the Kingsley High Profile Type, the two feet are identical in terms of heel performance.
'ole Resistance (Fig. 25 and 26)

With the VA limits as a reference, the foot is less resistant to load at the lower levels and more resistant at the upper limits than the High Profile sole. Reference to the comparative hysteresis curves (Fig. 26) reveals a definite reduction of encompassed area between the original and final curves. The larger encompassed area between the original loading and unloading phase, shows a marked lag between the recovery of the materials as the result of reversed loading. The final hysteresis curve indicates a softening of materials at lower load levels, with definite compacting of the foam against the keel when higher load levels are reached. The reduced encompassed area in the final curves may be accounted for by considering the final permanent deformation of 0.475 in. It appears that the foam in high pressure areas has been compacted, resulting in the high permanent deformation.

Construction and X-ray Analysis (Fig. 27 and 28)

The basic construction of the Kingsley Standard and High Profile feet is identical. No physical breakdown was observed by X-ray.
HYSTERESIS CURVES
KINGSLEY STANDARD (SIZE 27) SOLE

DEFLECTION, IN.

LOAD, L.B.

TOUCH POINT
'0' CYCLES

UPPER LIMIT

LOWER LIMIT

0
0.25
0.50
0.75
1.00
1.25
1.50
1.75

2.00

DEFLECTION, IN.

FIGURE 25

FIGURE 26
Winnipeg Mk 1

Heel Resistance (Fig. 29 and 30)

The permanent deformation and changes in resistance in the heel of his foot are the highest recorded for all the feet tested. With reference to Figure 30, note the large encompassed area of the original hysteresis curve indicating substantial lag in the material’s response to reversed loading. The final hysteresis curve shows a definite compacting and breakdown of the foam cells within the material by reduced resistance to load and narrowed area between the two curves. This observation is verified by Figure 29 which shows the permanent deformation as being .225 in.
DUROMETER TEST RESULTS
AFTER CYCLE TESTING
WINNIPEG MK I (SIZE 27) HEEL

FIGURE 29

HYSTERESIS CURVES
WINNIPEG MK I (SIZE 27) HEEL

FIGURE 30
Sole Resistance (Fig. 31 and 32)

Figure 31 shows marked decrease in resistance to load within 5,000 cycles of testing. The final loading curve (500,000 cycles) indicates minimal resistance to load until such time as the material becomes compacted against the keel. The deflection after 50 lb. of load is reduced to almost zero indicating complete compacting against the keel. With reference to the hysteresis curves (Fig. 32), a poor response to reversed loading is observed in the original curves. Almost complete loss of resistance to load of the belting-foam is shown by the final hysteresis curve.

Construction and X-ray Analysis (Fig. 33, 34, and 35)

This foot uses a single foam system having a hardwood keel with belting attached to the upper and lower positions at toe break. The dual belting system is required to give adequate toe resistance as the result of one material used for both heel and toe function. Consequently, the material density in the toe break area is dictated by the resistance requirements of the heel. The belting is positioned too close to the bottom of the foot causing poor pressure distribution under load at toe off. The concentrated pressure causes the foam to stretch beyond its limits resulting in loss of resistance and eventual breakdown. Note the
permanent deformation of the belting by comparing Figure 34 to Figure 33. Also, delamination of the foam from the keel between the belting is evident in Figure 34. Delamination of the foam from the keel is avoided in the heel area by keeping the extreme back of the heel at the attachment face close to the outer rim of the foot. Upon loading the heel, compressive forces will be predominant. The shearing effect is thus reduced to a minimal amount. With the exception of the attachment face, the entire keel is roughened and slotted to insure good bonding of foam to wood.
Heel Resistance (Fig. 36 and 37)

The performance of this heel as compared to the others tested is rather unique in that there is less deflection per unit load up to 20 lb. and above 80 lb. Minimal permanent deformation and changes in resistance occurred up to 5,000 cycles. Table 1 shows the permanent deformation to be progressive over the entire cycle period. Figure 37 shows that the final hysteresis curve is reduced in area indicating slight compacting and breakdown of the foam cell structure. However, the resilience within the material was maintained and the final resistance curves fall more readily within the VA specified curvature than the original curves.
DUROMETER TEST RESULTS
AFTER CYCLE TESTING
WINNIPEG MKII WITH INSERT
(SIZE 27) HEEL

![Graph of Durometer Test Results](image1)

HYSTERESIS CURVES
WINNIPEG MKII WITH INSERT
(SIZE 27) HEEL

![Graph of Hysteresis Curves](image2)
Sole Resistance (Fig. 38 and 39)

The final permanent deformation of the sole was the minimum of all feet tested. Figure 29 shows the encompassed areas of the two comparative hysteresis curves to be almost identical with minimal changes in resistance. All loading curves fall within the VA specifications (Fig. 38).

DUROMETER TEST RESULTS
AFTER CYCLE TESTING
WINNIPEG MK II WITH INSERT
(SIZE 27) SOLE

Figure 38

HYSTERESIS CURVES
WINNIPEG MK II WITH INSERT
(SIZE 27) SOLE

Figure 39
Construction and X-ray Analysis (Fig. 40 and 41)

A hardwood keel with dual belting is used. However, the construction of this foot differs from other feet in that the heel wedge is molded directly to the keel. The wedge and keel is then molded into the final foot shape in an additional process, thereby eliminating adhesives. The keel and belting is identical to the Winnipeg Mk 1. X-ray analysis (Fig. 41) shows slight delamination of foam from wood occurring between the belts and just above the staples attaching the upper belt to the keel.

U.S. Manufacturing

Heel Resistance (Fig. 42 and 43)

The response of the heel in terms of resistance is very similar to the Otto Bock and Kingsley feet. The final hysteresis curve shows a slight compacting of the foam and reduced resistance to loading.

**Figure 40.**—Winnipeg Mk II before cycling.

**Figure 41.**—Winnipeg Mk II after cycling.
125 DUROMETER TEST RESULTS AFTER CYCLE TESTING U.S. MANUFACTURING (SIZE 27) HEEL

FIGURE 42

HYSTERESIS CURVES U.S. MANUFACTURING (SIZE 27) HEEL

FIGURE 43
Sole Resistance (Fig. 44 and 45)

The original resistance curve falls below the VA specified range on the first durometer test (Fig. 44). Although the original hysteresis curve (Fig. 45) indicates a relatively resilient combination of materials, similar responses were noted after cycle testing of some of the other feet. With the VA specifications as a guideline, there is a definite lack of resistance at toe break for lower loads due to the combination of a low density material, and reduced cross-sectional area as specified by the VA. The final hysteresis curve implies almost complete breakdown in terms of resistance, resulting in most of the load being taken by the keel.

Construction and X-ray Analysis (Fig. 46, 47, 48, and 49)

A hardwood keel with a single belt stapled and screwed to the heel forms the core of the foot. Aside from varying durometer heel wedges, a single foam system is used. The keel shape is very thick in cross section on the heel position, to provide adequate backup and stability to the foam (Fig. 46). With reference to Figures 47 and 49, severe delamination of the foam from the keel has occurred as the result of cycle testing. In addition, the front staple at the toe break is sheared (Fig. 47). Delamina-
ion in the fore-foot is caused by the very smooth keel having no fixation ridges. The visible delamination in the posterior portion of the foot (Fig. 19) is caused by the lack of firm backing of the foam during heel strike. This problem could be eliminated by extending the keel posteriorly thus replacing the shear forces with compressive forces.

**Figure 46.**—U.S. Manufacturing before cycling.

**Figure 45.**—Hysteresis curves.

- **Hysteresis Curves**
  - U.S. Manufacturing (Size 27)
  - **SOLE**
  - **LOAD, LB.**
    - 125
    - 100
    - 75
    - 50
    - 25
  - **DEFLECTION, IN.**
    - 0
    - 0.25
    - 0.50
    - 0.75
    - 1.00
    - 1.25
    - 1.50
    - 1.75
    - 2.00
  - **TOUCH POINT 'O' CYCLES**
  - 500,000
  - 0
Laurence

Heel Resistance (Fig. 50 and 51)

Figures 50 and 51 show the heel resistance to be relatively constant for the entire cycling procedure. Some compacting and breakdown of foam is indicated by the reduction of encompassed area in the final hysteresis curve.

Sole Resistance (Fig. 52 and 53)

The original durometer curve (Fig. 52) shows good resistance of the sole with respect to the VA specifications. However, the original hysteresis curves (Fig. 53) show an excessive lag in the response of the sole when the loading is reversed. Directly related to the poor response is the marked loss of resistance within 5,000 cycles of testing. The final durometer and hysteresis curves show almost complete breakdown of
the sole with most resistance obtained by the material compacting against the keel.

\[ \text{FIGURE 49.—U.S. Manufacturing—delamination of posterior portion of the foam from the keel.} \]

\text{Construction and X-ray Analysis (Fig. 54, 55, and 56)}

A single foam construction with a hardwood keel and dual belting is used (Fig. 54). The top belt is approximately half the width of the bottom belt (Fig. 56). Note the delamination in the top belt as the result of cycling (Fig. 55), accounting for most of the loss in sole resistance.
DUROMETER TEST RESULTS AFTER CYCLE TESTING, LAURENCE (SIZE 27) HEEL

FIGURE 50

HYSTERESIS CURVES LAURENCE (SIZE 27) HEEL

FIGURE 51
**Figure 52**

DUROMETER TEST RESULTS AFTER CYCLE TESTING
LAURENCE (SIZE 27) SOLE

**Figure 53**

HYSTERESIS CURVES LAURENCE (SIZE 27) SOLE
Figure 54.—Laurence before cycling.

Figure 55.—Laurence after cycling.

Figure 56.—Laurence X-ray plan view.
Heel Resistance (Fig. 57 and 58)

The permanent deformation of the heel (0.200 in.) was the second highest in this range of tests. In spite of the excessive deformation, a large encompassed area was maintained for the entire test cycle (Fig. 58). Note in Figure 57 the consistent general form of the loading curve. Apart from the permanent deformation, the change in resistance to load is comparable to other feet tested.

Sole Resistance (Fig. 59 and 60)

Excessive permanent deformation (0.775 in.) of the sole resulted from the cycle testing. However, as with the heel resistance, apart from deformation, the change in resistance to load was within reasonable limits as shown in Figure 59. The hysteresis curves show a definite lag in response to reversed loading (Fig. 60). Due to the compacting of foam in the forefoot and stretching of the foam to the ultimate limit in the sole, the load resistance is increased with cycling.
HYSTERESIS CURVES
WAGNER (SIZE 27)
HEEL

DEFLECTION, IN.

TOUCH POINT
'0'
CycLes

500,000

DEFLECTION, IN.

Figure 58

DUROMETER TEST RESULTS
AFTER CYCLE TESTING
WAGNER (SIZE 27)
SOLE

LOAD, LB.

UPPER LIMIT

LOWER LIMIT

TOUCH POINT
'0'
CycLes

500,000

DEFLECTION, IN.

Figure 59
Construction and X-ray Analysis (Fig. 61, 62, and 63)

The construction of this foot differs from others in that a double fixed layer of belting is attached to the bottom of a hardwood keel. A single foam system is used. Aside from the severe permanent deformation noted in the X-ray analysis (Fig. 62) no other physical breakdown was noted.

Figure 61.—Wagner before cycling.
CONCLUSION

On the basis of the results obtained by testing the nine SACH feet four conclusions may be drawn. In analyzing the results, limitations in terms of equipment and applied techniques must be realized.

1. The specifications on resistance requirements outlined by the Veterans Administration Prosthetics Center, New York, provide a basis for functional evaluation in terms of durability.

2. The initial encompassed area in the hysteresis curves can be related to the amount of permanent deformation and/or resistance changes to be expected with the following qualifications: For the sole resistance, if the initial curve falls markedly below the minimal VA specified resistance, regardless of resilient response indicated by the initial hysteresis curve, unacceptable permanent deformation and resistance change may be anticipated. In the heel section, significant reduction of the encompassed area of the hysteresis curve within 5,000 cycles give reason to expect unacceptable permanent deformation and/or resis
ance changes. Generally, a large encompassed area between the initial curves indicates poor response of the materials to load changes leading to premature breakdown of the foam or foam and belting used.

3. Adequate resistance in the sole (toe break) cannot be maintained by reinforcing low density foams with additional belting. A high density, resilient foam or combination of foams is necessary to maintain a relatively consistent level of resistance during the entire period of active use of the SACH foot.

4. Reduced cross-sectional areas of material at the toe break, such as specified shape by the VA, accentuate the problem of creasing and reduced resistance.

RECOMMENDATIONS

1. Detailed studies with recommendations to determine the functional requirements other than durability of artificial feet should be undertaken immediately. One set of standards cannot be assumed as appropriate for all levels of amputation and activity. The suggested studies should take into account patient comfort, including gait analysis, to produce functional resistance curves correlated to physical evaluation of manufactured feet. Obviously, other types of laboratory test equipment would have to be designed to correlate recommended functional requirements.

2. Durability should be evaluated on the basis of dynamic durometer testing in both the loading and unloading phases. Specifications as to acceptable limits of lag in response are impossible using incremented static tests.

3. Durometer (resistance) ratings on the SACH feet should be on the basis of resistance to load after initial walking trials. With reference to figures 64 and 65, note that the major permanent deformation of the durable SACH feet occurs within 5,000 cycles of testing. By referring to the charts in the section “Results” on the same feet, it is noted that all major changes in resistance have taken place within this period.

4. For quality control in setting of standards, cycle testing of all SACH feet may be terminated at 5,000 cycles or less. As previously shown, major deformation and changes in resistance occur prior to 5,000 cycles. Figures 66 and 67 show the results of 10 sequential durometer tests. Note the marked changes in durometer and encompassed area of the hysteresis curves as the result of the sequential loadings. The 5,000 cycle figure is quoted on the basis of being the first durometer test recorded after cycling in this test program.
COMPARISON OF PERMANENT DEFORMATION

(HEELS)

5,000 CYCLES and 500,000 CYCLES

FIGURE 64

COMPARISON OF PERMANENT DEFORMATION

(SOLES)

5,000 CYCLES and 500,000 CYCLES

FIGURE 65
1. A high density resilient foam is required in the toe break area to maintain adequate resistance for the expected duration of the artificial foot. It is impossible to maintain the toe break resistance with belting and the density of foam dictated by the requirements of resistance to loading at heel contact.

2. Single belting to maintain the bond of the toe section to the keel is recommended. The dual belting (attached proximally and distally at the front of the keel) used to gain added resistance tends to delaminate in itself and/or shear the bonding with the foam; that is, the major toe break resistance should be obtained by the use of dense resilient foam materials. The resistance differential between a rigid belting and flexible foam combination is too great if used to maintain the tensile and compression shear required to maintain adequate resistance. Placement of a single belt in the central section of the toe break area reduces these forces to a minimum.

3. The cross-sectional dimensions at the toe break should be increased to the limits dictated by the dimensions of standard shoe lasts, particularly in the dorsal-plantar dimensions within cosmetic limitations. By means of an increase in this dimension, the tensile-compressive forces may be reduced to within the elastic limit of the foam during normal walking, thereby reducing permanent deformation and breakdown of the foam.

**Figure 66**

TYPICAL DURAMETER RECORDINGS
(HEEL)
'0' CYCLES and '10' CYCLES

<table>
<thead>
<tr>
<th>DEFLECTION, IN.</th>
<th>LOAD, LB.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>25</td>
</tr>
<tr>
<td>0.25</td>
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<td>1.75</td>
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<tr>
<td>2.00</td>
<td></td>
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</tbody>
</table>
4. A hardwood keel should be used in all SACH feet, particularly with the increase in popularity of modular prosthetics.

The keel should extend posteriorly to within a minimum of 3/16 in. from the outer configuration of the ankle attachment face to provide adequate backup to the forces applied at heel contact. Two problems are eliminated by the posterior extension of the heel. In the first, shear stresses tending to delaminate the foam from the heel are converted to compressive forces. In the second, the tendency of the foam in the heel section to push any cosmetic restoration upward (particularly when modular foam rubber covers are used) is eliminated.

5. A good bond between the foam and rigid members of the structure must be insured. A smooth keel and belt delaminates quickly unless bonding agents are applied.

**SUMMARY**

The results of testing nine different commercially available SACH feet have been reported for purposes of improving testing techniques and standards of durability. Further studies are required to adequately define and correlate the function(s) of artificial feet, as related to levels of amputation and levels of activity, to provide the ultimate in the amputees' comfort and gait.
REFERENCES

