STEP UP PROSTHETICS

IN-HOUSE MANUFACTURING SOLUTIONS

Step Up Prosthetics Lab Testing Manual

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Introduction:

Step Up Prosthetics Goal Statement:

Our mission is to increase access to quality prosthetic care for adolescents in low-resource areas by empowering clinics to fabricate our low-cost, durable, high-energy devices. We are committed to creating and sharing sustainable solutions that promote independence, dignity, and well-being.

Goal Statement for Testing:

By testing the Step Up Design in a lab setting, the team will be able to collect data to satisfy ISO 10328 standards and be able to predict the correlation between the amount of steps, weight, and frequency of use to failure in a lab setting vs. real life trial.

General Definitions:

ISO 10328:	"During use, a prosthesis is subjected to a series of load actions, each varying individually with time. The test methods specified in this International Standard use static and cyclic strength tests which typically produce compound loadings by the application of a single test force. The static tests relate to the worst loads generated in any activity. The cyclic tests relate to normal walking activities where loads occur regularly with each step. This International Standard specifies fatigue testing of structural components. The tests specified do not provide sufficient data to predict actual service life." [1]
Static Proof Testing:	"The material is mechanically loaded up until the point it reaches a predetermined deformation level or the point at which the sample completely fails." [2]
Ultimate Strength Testing:	"Max amount of stress a material can bear before failure" [3]
Cyclic Testing:	"Loading cycles are designed to simulate fatigue initiation and propagation over time rather than isolated overload events that would cause immediate failure." [4]
Energy Return:	"..can capture and store some of the collision energy normally dissipated at foot contact and then transfer it to the forefoot just prior to toe-off, may increase prosthetic push-off work" [5]

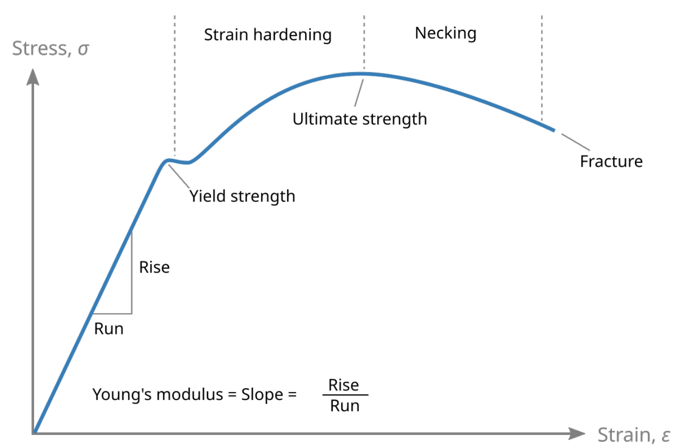

Figure 1: Stress Strain Curve for Reference [6]

Testing Information:

Data Standards:

Shoe Size of Current Step Up Prosthetics Foot:	Men's US 5.5
Max Weight of User:	150 lbs
Average Child Walking Speed (age 12.65±2.16) [7]:	1.39±0.22 m/s
Average Child Running Speed (age 12 50th percentile) [8], [9]:	2.755 m/s
Average Weight of a 12 Year Old Child (50th percentile) [10]:	88 lbs (40 kg)
Average US Shoes Size for Women at Age 12 [11]:	Women's US 7
Average US Shoes Size for Mens at Age 12:	Men's US 8
Ground Reaction Forces for Walking [12]	1.5 Body Weight
Ground Reaction Forces for Running	2.9 Body Weight

Testing Criteria:

User Characteristics:	150 lbs (68 kg)
Loading Condition:	K3-K4 (General outdoor use to high impact use)
Walking Speed:	1-1.6 m/s
Running Speed:	2-5 m/s
Frequency of walking [13]	1 Hz
Frequency of running	2 Hz

Material List:

Step Up Prosthetics Foot

Pyramid Adaptor

20° Angle Wedge

-15° Angle Wedge

Landmark Servohydraulic Test System

Adaptor to Connect from Landmark to Pyramid Adaptor

Figure 2: Prosthetic foot and Landmark System set up

Figure 3: Foot Connection to Landmark Testing System

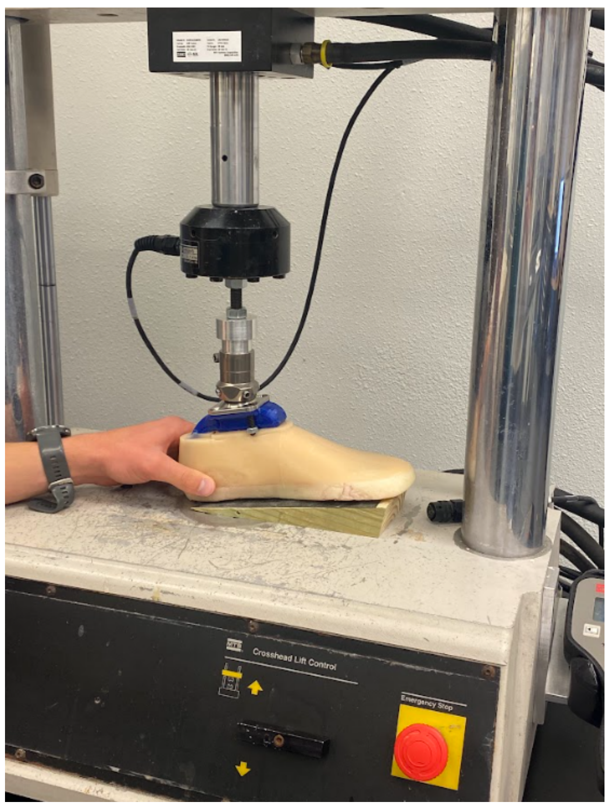

Figure 4: Example of how -15° angle wedge is placed

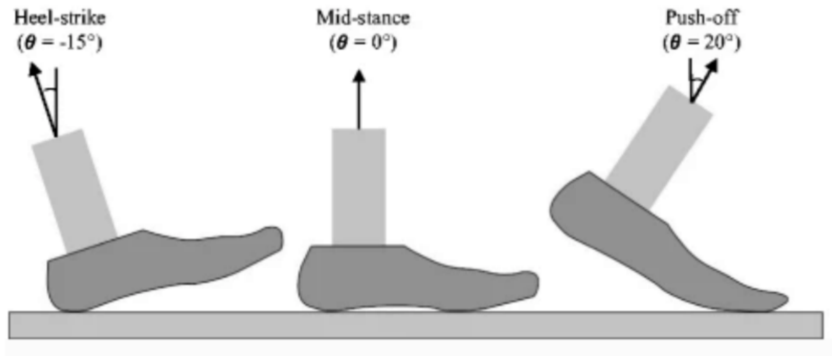

Figure 5: Foot Angle Reference [14]

<u>Failure Criteria:</u>

Testing till failure will be defined as the following:

- Part is visibly deformed and does not return to initial form
- If prosthetic deforms more than 4.4 mm will also fulfill failure criteria. This value is based on previous years of experimentation. The Freedom Maverick is the current closest competitor and the goal is to stay within range. Figure 7 shows data collected from 2023-2024

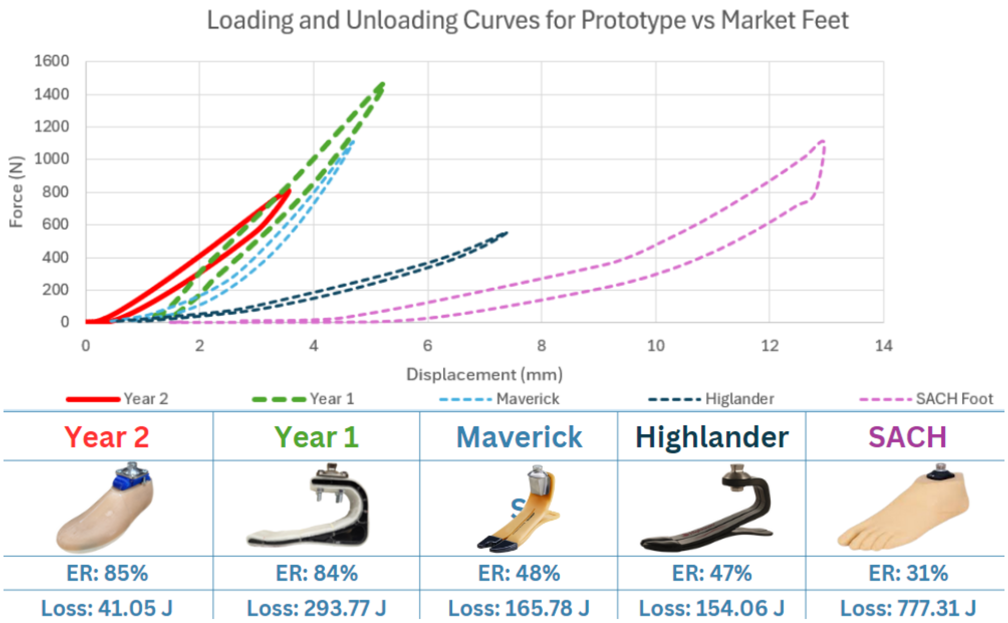

Figure 6: Lab Data Reference for Failure Criteria

Testing:

Initial Set Up:

1. Check Step Up prosthetic foot for any major flaws.
2. Check that the pyramid adaptor is connected flush to the top of the prosthetic foot, leaving no room for the pyramid adaptor to move in any direction.
3. Connect prosthetic to Landmark testing system through the adaptor
4. Confirm that the system will only move in the intended direction and will not shift.
5. Follow directions below based on specific test being done.

Static Proof Testing:

- Load the system to 1,333 N (300 lbs) at a rate of 1 mm/s
- Hold for 60 seconds
- Unload at a rate of 1 mm/s back to 0 N
- Record load vs. displacement

Ultimate Strength Testing:

- Simulating acute prosthesis overload of four times body weight (600 lbs)
- Load to 2,667 N (600 lbs) by hand
- Once load value is reached, immediately unload back to 0 N by hand
- Record load vs. displacement

Cyclic Walking Test:

- Load to 1,000.62 N (225 lbs, 1.5x bodyweight) at a frequency of 1 Hz
- Run test till failure
- Record load vs. displacement

Cyclic Walking Test at Push Off Angle (20°):

- Place a 20° angle wedge (reference figure 5) between prosthetic foot and ground
- Confirm that system is stable and will move in the designated direction
- Load to 1,000.62 N (225 lbs, 1.5x bodyweight) at a frequency of 1 Hz
- Run Test till failure
- Record load vs. displacement

Cyclic Walking Test at a Heel Strike Angle (-15°):

- Place a -15° angle wedge (reference figure 5) between prosthetic foot and ground
- Confirm that system is stable and will move in the designated direction
- Load to 1,000.62 N (225 lbs, 1.5x bodyweight) at a frequency of 1 Hz
- Run Test till failure
- Record load vs. displacement

Cyclic Running Test:

- Load to 1,934.532 N (435 lbs, 2.9x bodyweight) at a frequency of 2 Hz
- Run test till failure
- Record load vs. displacement

Cyclic Running Test at a Heel Strike Angle (20°):

- Place a 20° angle wedge (reference figure 5) between prosthetic foot and ground
- Confirm that system is stable and will move in the designated direction
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Data Processing:

The goal of data processing is to calculate energy return percent and energy loss. The Landmark Servohydraulic Test System collects data at a rate of 50 Hz (every 0.02 seconds), and data collected includes displacement and force. The following steps will help process the data given.

Equations Used to Process Data:

Viscoelastic materials (material that experiences spring and fluid-like reactions to force) tend to load and unload along the different curves, creating a hysteresis curve type curve seen in figure 7.

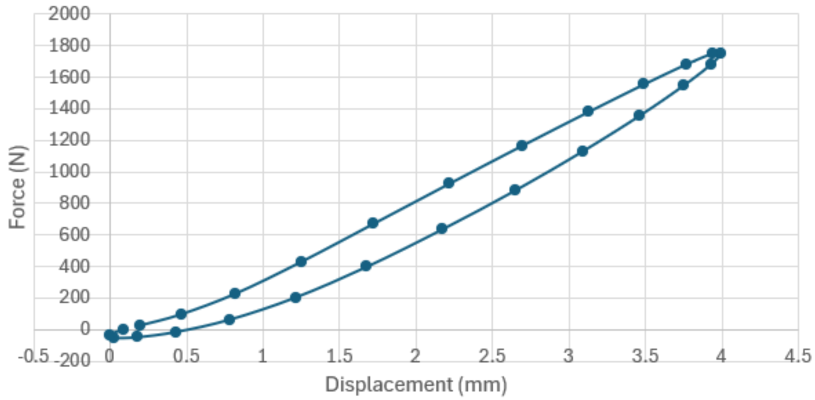

Figure 7: Sample Data That Shows Hysteresis Curve

Energy return is found by calculating the area under the loading curve and the unloading curve, and obtaining the ratio between the two. Equation 1 shows this relationship.

$$Energy\ Return\ Percent\ = \frac{\int_{x_1}^{x_0} F_{unload}dx}{\int_{x_0}^{x_1} F_{load}dx} * 100 \qquad (1)$$

Energy loss is then calculated by subtracting the area under the loading curve by the area under the unloading curve. Equation 2 shows this relationship.

$$Energy\ Loss\ = \int_{x_0}^{x_1} F_{load}dx - \int_{x_1}^{x_0} F_{unload}dx \qquad (2)$$

Transferring Data From Testing Equipment To Excel:

1. Data will be transferred from the Landmark Servohydraulic Test System onto a flash drive. The key file collected from the flash drive is the specimen.dat, all other files are not needed for this data processing. This file can be opened on a notepad type app on the computer. This data can then be transferred to Excel. Note: depending on the test every ten seconds the data will be relabeled with the seconds, displacement, and force titles. This should be deleted because it will interfere with further steps.

Setting Up Time, Displacement, and Force Columns:

1. The ram of the testing system has its origin above the material being tested, so most displacement and force values will be negative. For the sake of appearance in the force displacement graph it is best for the data to appear in the first quadrant instead of the third. For this reason two columns are added to "fix" the data, which gives the appearance that displacement and force are generally positive. This is done by dividing the value by -1. This will not affect any data processing, but helps the viewer understand the application of the data better. Figure 8 shows the set up used in this process.

	A	B	C	D	E	F
1	Time (s)	Displacement (mm)	Force (N)		"Fixed" Displacement	"Fixed" Force

Figure 8: Excel set Up for "Fixed" Displacement and Force

Calculations for Trapezoidal Numerical Integration:

1. Trapezoidal numerical integration was employed to calculate area under the curve for energy return and energy loss, which can be seen in equation 3. To make this easier, each section of the equation is placed in a different column. Figure 9 shows the set up used to organize the process.

$$\int_a^b f(x)dx \approx (b-a)\frac{f(a)+f(b)}{2} \tag{3}$$

	G	H	I	J
1	Energy Return Calculations	b-a	(f(a)+f(b))/2	Total

Figure 9: Excel Set Up for Energy Return calculations

Table 1 gives meaning to each variable.

Table 1: Equation Variables

a	Lower bound displacement value
b	Higher bound displacement value
f(a)	Lower bound force value
f(b)	Higher bound force value

In trapezoidal numerical integration the “a” value will be the first deflection data point, and the “b” value will be the next deflection data point. This will continue step by step until the end of the data. Meaning that at each step the “b” value will become the “a” value and the next deflection data point will become the next “b” value. This same concept will apply for the force values. To follow the format within the Excel spreadsheet, equation 4 and 5 will be used to calculate the area under the curve.

$$a\text{-}b = E3\text{-}E2 \tag{4}$$

$$\frac{f(a)+f(b)}{2} = (F2+F3)/2 \tag{5}$$

From there you can auto-populate the rest of the column using this format.

2. Once these two columns are auto-populated the two columns can be multiplied together. As seen in figure 8 this total will be placed in column “J”. This has completed the steps for calculating the trapezoidal numerical integration.

Setting Up Cycle Count, Sum Loading and Unloading Curves, Energy Return, and Energy Loss Columns:

1. From here the following columns will be set up and further details about the columns will be described in the Visual Basics Application Coding section. Figure 10 shows the set up for cycles, sum of the area under loading and unloading curves, energy return and energy loss columns.

	K	L	M	N	O
1	cycle number	Sum Load	Sum unload	Engery Return	Energy Loss

Figure 10: Set Up For Cycle Count, Sum Loading and Unloading Curves, Energy Return, and Energy Loss

Setting Up General Information Square:

1. The final step in the set up is to create a square for recording general data from the testing session. Figure 11 shows the general setup.

	P	Q
1		
2	Test Date	12/6/2024
3	Testing Location	OBRL
4	rate (Hz)	
5	Max Force	
6	Max Force Goal	
7	Max Displacement	
8	Energy Return	
9	energy Loss	
10	cycles	

Figure 11: Recording Space For General Data

2. All values will have to be manually put in. For the max force,max displacement, and max cycles equations 6, 7, and 8 can be used. This will take the max value of each respective column. Note that for the cycle count the first cycle is considered "cycle 0", so to get an accurate cycle count you can add one to equation 8.

$$\text{Max Force} = \text{MAX(F:F)} \tag{6}$$

$$\text{Max Displacement} = \text{MAX(E:E)} \tag{7}$$

$$\text{Max Cycles} = \text{MAX(K:K)} + 1 \tag{8}$$

3. To Find average energy return and energy loss use equation 9 and 10.

$$\text{Energy Return} = \text{AVERAGE(N:N)} \tag{9}$$

$$\text{Energy Loss} = \text{AVERAGE(O:O)} \tag{10}$$

Setting Up VBA Coding in Excel:

1. The next step involves doing some coding on the back end of Excel, this will streamline the process for finding the number of cycles and the maximum and minimum forces in each cycle. Visual Basics for Application (VBA) can be used to code within Excel and the changes will be populated in the Excel sheet. Macros will have to be activated for this process to work (please reference Microsoft's website if needed).
2. The fastest way to access VBA is by pressing alt+f11. On a new project this will populate a grey window as seen in figure 12.

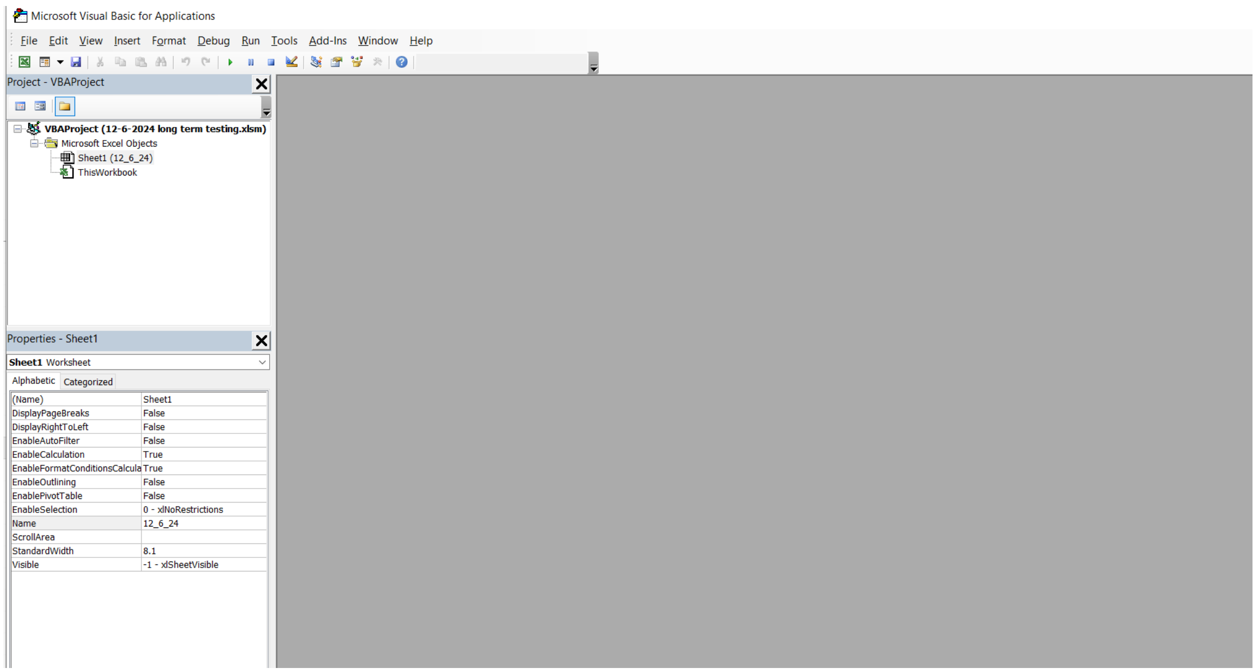

Figure 12: VBA Initial Opening Window

3. To access the coding window double click the current sheet that your data is on, as see in figure 13.

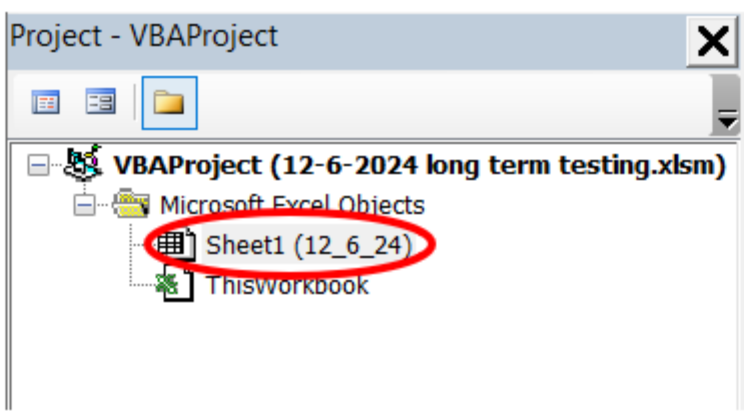

Figure 13: Opening VBA Coding Window

4. This will open a blank window in which the following code can be placed in:

```
Sub localMaxMin()

   Dim Cell As Range

   For Each Cell In Range("F2:F516728")

      If Cell.Value < Cell.Offset(-1, 0).Value And Cell.Value < Cell.Offset(1, 0).Value Then
'Check if cell is smaller than last cell and smaller than the next cell

         With Cell.Interior

            .ColorIndex = 4 ' Set cell color to light green

         End With

      End If
      If Cell.Value > Cell.Offset(-1, 0).Value And Cell.Value > Cell.Offset(1, 0).Value Then
'max value
      With Cell.Interior

            .ColorIndex = 7 ' Set cell color

         End With

      End If
   Next Cell

End Sub

Sub CylceCount()

   Dim Cell As Range
   Dim i As Long


  For Each Cell In Range("F2:F516728")
   If Cell.Value < Cell.Offset(-1, 0).Value And Cell.Value < Cell.Offset(1, 0).Value Then

   Cell(1, 6).Value = i
   i = i + 1
    End If

   Next Cell
End Sub
```

5. This code will be ran in two parts since it is two different commands. To do so you will select the code you want to run in the top right corner of the coding window, as seen in figure 14. From there click the run button as seen in figure 15. The code will take a moment to process. Make sure to switch to the spreadsheet to check if the action worked. For the local Max Min code you will see purple and green highlighted cells in column F. For the Cycle Count you will see the cycle count number in column K at the beginning of each cycle.

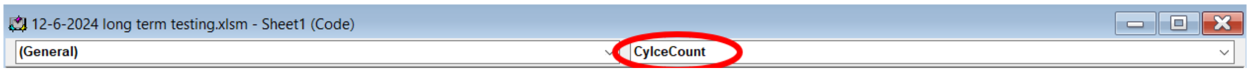

Figure 14: Current Code Running

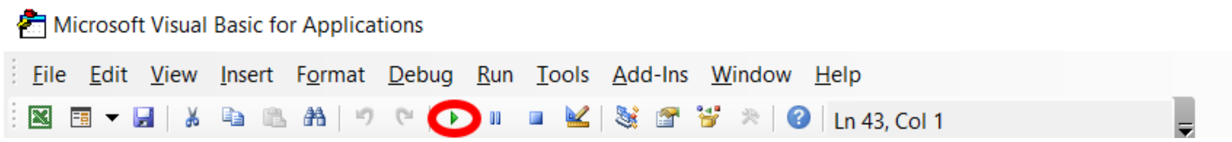

Figure 15: Run Button In VBA

6. Once the first code has run you will need to switch the code that is being run, use figure 14 as a reference again. From there press the run button again. At this point you should see the cycle count and the highlighted cells, as produced by the code.

Calculating Sum Loading and Unloading:

1. As mentioned above the maximum and minimum force values will be highlighted. To calculate the sum loading you will sum up all the values in the "Total" column (column J) from the minimum value of the cycle to the maximum value of the cycle. This value will be then placed in the sum loading column (column L). Use equation 11 as an example

$$\text{Sum loading} = \text{SUM(J2:J20)} \quad (11)$$

2. To calculate the Sum unloading value is only slightly more complicated. The total values in the second half of the cycle will be negative. The best practice is to take the absolute value of the sum for unloading, this will produce an energy return percentage that is positive. To calculate the sum unloading you will start with the total value in the cell after the peak force all the way till the force value before the next minimum. Use equation 12 as an example.

$$\text{Sum Unloading} = \text{ABS(SUM(J21:J40))} \quad (12)$$

Calculating Energy Return Percentage and Energy Loss:

1. To calculate Energy Return Percentage you will be using the sum loading and unloading values that you just calculated. Use equation 13 as an example.

$$\text{Energy Return Percent } = \frac{Sum\ Unloading}{Sum\ Loading} * 100 = \text{(M2/L2)*100} \quad (13)$$

2. To calculate Energy Loss you will also use the sum loading and unloading values, but in a slightly different way. Use equation 14 as an example.

$$\text{Energy Loss} = Sum\ Loading\ - Sum\ Unloading = \text{L2-M2} \quad (13)$$

3. From here you can plot the Energy Return Percent and Energy Loss values vs Cycle Count to see how they change through the cycling process.
4. At this point you have completed your first round of data processing!

Resources:

[1] "ISO 10328:2016," ISO. https://www.iso.org/standard/70205.html
[2] "Static Testing vs Dynamic Testing Explained - Industrial Physics," Industrial Physics, Nov. 14, 2023. https://industrialphysics.com/knowledgebase/articles/static-vs-dynamic-testing/#:~:text=Static%20testing%20can%20also%20sometimes,a%20long%20period%20of%20time.
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[4] Applied Technical Services ATS, "Cyclic Fatigue Testing - Applied Technical Services," Applied Technical Services, Sep. 09, 2024. https://atslab.com/mechanical-testing/cyclic-fatigue-testing/
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eyId=ASIAVRDO7IERPUUWYHGJ&Expires=1728339381&x-amz-security-token=IQoJb3JpZ2luX2VjEN3//////////wEaCXVzLWVhc3QtMSJGMEQCIAJBhH4yR9co3p9ZNX6FbUf5pmJ6f5WyXGaflzhLGFVOAiBKrp66cECTtameZgvM%2Bc/QkyIUkhIdXa/8a1gVjxcmgCqvBQg2EAAaDDM4MDMzNzM0MDcwNiIMpHWL7sTSvX2ZUR1AKowFFQGNFtrtFP28/7WmTXrCX9eOYGGVXdCLeN8SktJGAJtRiPdBG2OeBZ/8RILkot1hqpWsgFfjRUIP2LMUUpic7wKeWFeSz0ETs2SCY6wW6bIUO8uCpRb9xjqu4BIxeI1SCL2CJ7nLEeEJlCLF5upzgFE2BVnrrLhDOUW0dhmHV/jzkZdDkZZEeoglJa8B%2B4trBOXane1nlQTCWdihVCJcwzQWd88dvdMNqZuRXWuuJOMI5x5Oj/R7VMG9SLbZJuGG1SB80Hj81oJ7g27IUgjvxwdonqIYWv0nzJxbMApeD4nc5AMh4zeWXYbTKEhee0PSlQQna8kukk8NUPZAaL/3B%2B8FW3t1eZoKELxw70njPGsOfUPbY/kpwM633XG5Il8P2C5rSmNouAbGhuDXcs0V1R1LbByOCZ4X3RCit8VOsmeGElRjqibmN2tiLceRkianIGjmEQE3CNtdCjazac9N7yu9cw4GYNWUTc3HHOcEpTiFrfa1dYNoA76ny8R7wp0hMK7qI31PZlr0AY5CYu6d0aGntbkb7GWd9i2QIbFjb2vRPerKpIOl2ZZjgXSLnJ7Eni8QRMg3fe8%2BHMKJh4%2BQHchJF0%2Bo8wOg3XZLfjlo1CnbbhVAGzxigPO5FKDk7x9ZymSHPEwJQhRVPAgs8xBMqRgLzEaHXtBBTAGYiV9G6Vh9pCukUFsobcSDVFILgKTg8QnU6k83Qh1WVHUm%2BBd/PqwxDCPCObppEpOfv25JrLePlHVBT6cZ3G56ej4k9fDe2ObdFw48YWB3FpUpyz7BtUmzUpi6RkONknbb%2BN/fLgcr%2BMWXHxrqudr/wQTwX7nHbwu1JMJRpRgKmvm73hVW8GTPnIUI3UrYirafFzCxk5G4BjqyAW9r2aNUPz8RucFmLFE5ZvfHBU7TyI%2Bg4kki4I66flpxZAJXdR2OsF2K4kgJb4TxrveOioLygYy1yKwi0XGg6xGabycTsVIEDZvvVDibDERPqVSk0szw/Zw873TMsANzKsfQHL0g7uHqEbEM2wIKZDbrvDDZ0r1IOEKPoQLeumPDxFOsnoCtPa8prPwNBPumMROSatiuaVMa%2BOaLCX7wDXSka1nOdOG8ufCJw5hT6uSwlmg%3D&Signature=I4IefVa0nI6Kkki3kUQ1AYs3IA0%3D (accessed Nov. 11, 2024).

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<u>Document Edits:</u>

Date	Description of Changes	Initial
10/17/2024	Added adaptor parts for testing image, deleted cyclic fatigue testing, added failure criteria, added 4 inch block to material list, added image to show how foot connects to landmark system, updated figure numbering, updated date, updated reference list, and minor grammatical edits.	LK
10/22/2024	Updated to show failure criteria and where the data comes from in figure 7	LK
10/24/2024	Updated figures regarding foot set up in Landmark testing system, took out 4 inch block in material list	LK
11/11/2024	Deleted directions for placing 4 inch block under foot, changed rate of static proof testing from 2 mm/s to 1 mm/s, changed holding time of static proof testing from 30 seconds to 60 seconds, changed ultimate strength testing loading rate from 150N/s to load and unload by hand, reduced all walking frequencies to 1 Hz and all running frequencies to 2 Hz, updated referencing to include research for frequency of walking and running.	LK
3/13/2025	Added detailed steps about data processing including energy return calculations, energy loss, formatting of excel, and VBA coding needed for calculations.	LK