ME 517 – INTRODUCTION TO FINITE ELEMENT METHOD
FINAL PROJECT

TREAD TENSION MECHANISM: DESIGN AND ANALYSIS

A FINITE ELEMENT ANALYSIS APPROACH

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To: SB Park, ME 517 Instructor

From: Tyler Wei

Subject: Finite Element Method Final Project – Tread Tensioner Analysis

Problem Statement and Element Type/Model

This project is based off of my senior project with Professor Kirill Zaychik (WCP 52 – Ultimate Beach Cart). Essentially this is a multi-terrain vehicle used primarily to transport beach gear to and from the waterfront in an efficient manner. When comparing all the available models currently on the market, WCP 52 is unique in its ability to easily traverse over sand, grass, cement, and dirt due to it being powered from the rear via treads. Treads have a huge advantage over wheels in that they have a much larger surface contact area with the ground. This allows for much better traction and can also distribute the weight of the cart more evenly, providing better stability.

Treads work through a system of multiple belts and sprockets. Typically, one or more of the sprockets are driven via a drive shaft (drive sprocket) and the remaining ones are used to support the belt (idler sprockets). In order to optimize tread traversal, it is vital that the belt is properly tensioned. A belt that has too much slack will slide off the sprockets, immobilizing the cart and rendering the treads useless.

There are many different tread designs and mechanical configurations. For the WCP 52 design, a three sprocket configuration was utilized. Essentially for this configuration, the drive sprocket is at the top with the two idler sprockets on the bottom as shown in Figure 1. In order to maintain tension on the tread belt, each of the idler sprockets was connected to the drive sprocket by a link. This formed a scissor linkage wherein the loading of the cart would spread the linkages, thus tensioning the belt around the tread frame. In order to support the integrity of the belt and to limit the motion of the scissor linkage, a spring is placed in between the scissor linkage. The objective of this analysis is to determine what the spring constant should be under three different loadings and two different linkage geometries.

Figure 1. WCP 52 Ultimate Beach Cart (Left). Tread System (Right).

Modelling

The two geometries utilized for this study were an even length linkage and an uneven one. Figure 2 shows the first configuration and Figure 3 shows the second configuration. The first configuration has links with the length of 8 inches at an initial angle of 97.181 degrees. The second configuration has links with the lengths of 5 inches and 11 inches at an initial angle of 88.958 degrees. These were selected because the sprockets are 4 inches in diameter and the belt is a loop with a total length of 40.6 inches. Also both of these dimensions allow for a contact surface length of 12 inches. Since both of these configurations satisfy both of these conditions, the next geometrical reference point defined was the spring placement. If the linkages were connected at the base and then drawn to be two right triangles, the endpoints of the springs would be located one third of the base away from the acute vertex. This is strategically placed here because that is where the centroid of the triangle would be, thus be the most effective spot to minimize the spring force.

When modelling this on the ANSYS APDL, several idealizations were made. In order to minimize run time and to optimize calculation accuracy, each link for the scissor linkage was idealized as a line element (Element Type LINK180) and the spring was set to be a spring/damper element (Element Type COMBIN14). Since there were two different elements in each of the tread configurations assemblies, it is vital that each element is defined properly. When modelled on ANSYS APDL, the configurations look as displayed in Figure 2 and in Figure 3.

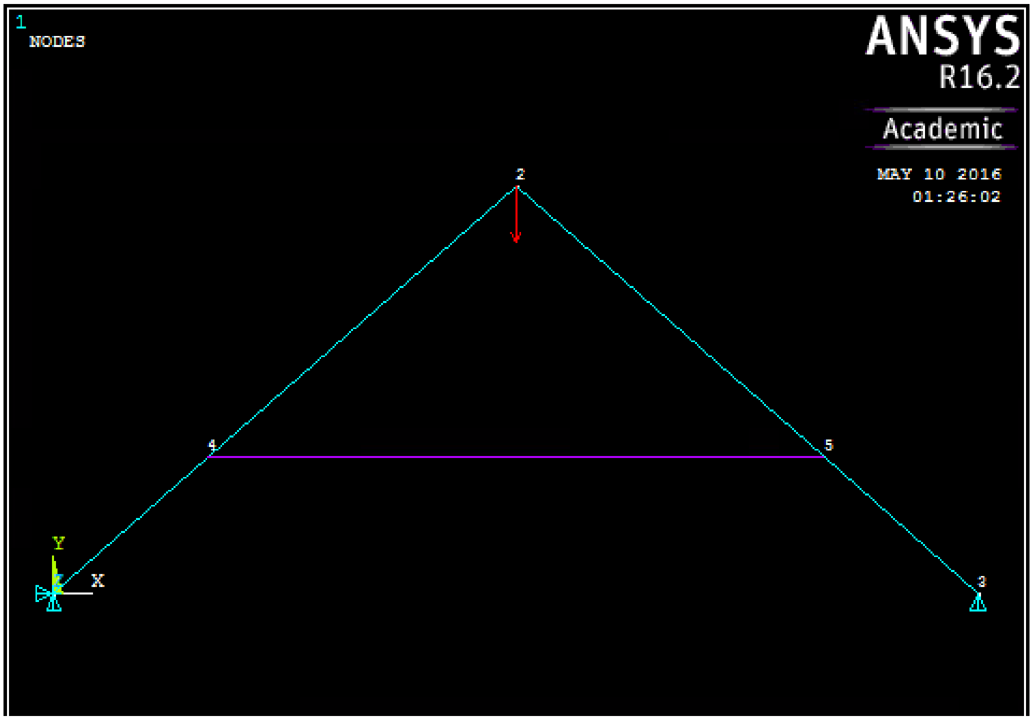


Figure 2. Tread Configuration 1. Links are 8 inches.

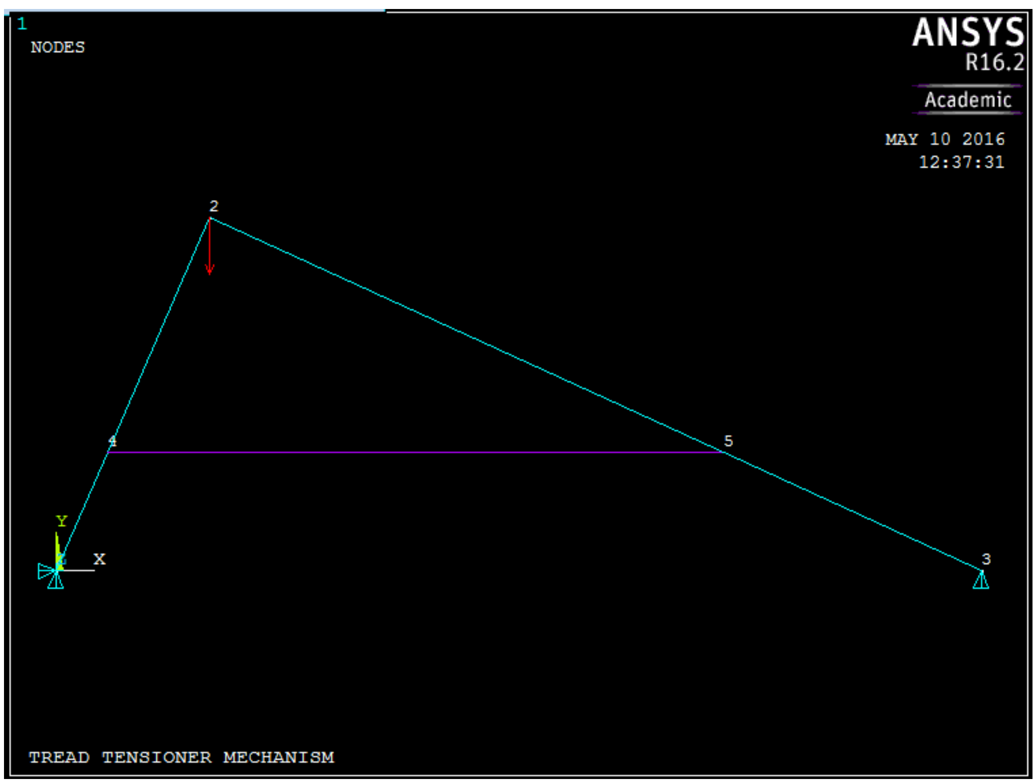


Figure 3. Tread Configuration 2. Links are 5 inches and 11 inches.

Boundary Conditions

As previously mentioned, in order to optimize ANSYS computational time and minimize errors, assumptions regarding design had to be made. Apart from idealizing the geometry, the boundary conditions and loading had to be determined. In both configurations, conditions were applied at the joint displacements, the allowable displacement of the scissor linkage, and the loading applied.

Joint Displacement

The scissor linkage configuration of the tread system is unique in the conditions applied to the nodes. For this simulation, as shown in Figure 2 and Figure 3, Node 1 was constrained in such a way that it was fixed and constrained in the X, Y, and Z displacements and the Y and Z rotations. This is done because ANSYS requires a fixed point in order to run a simulation. Next Node 2 was constrained in such a manner that it was a pin connection. By this, no directional displacements were applied, so the only rotational constraint was the Z rotation. Finally, the last constraint was at Node 3. Since the tensioning mechanism requires that scissor linkage open up, it is essentially a roller support. To properly constrain this, the Y and Z directional displacements were held to zero and the X directional displacement was free. Additionally, the Y and Z rotations were fixed.

Scissor Linkage Displacement

When acquiring the parts for the tread assembly, the belt came in as a standard part along with the associated sprockets. The sprockets were able to fit snuggly within the rubber track due to matching pitches. It was crucial that the track was rubber in that it is elastic in nature. This is vital because it needs to hold the scissor linkage together. As mentioned earlier, a belt that is too slack will not function properly. However, a belt which is tensioned too tight would also render the assembly ineffective because the internal pitches of the rubber track would be overstretched and would not match up and coordinate with the grooves of the drive sprocket, which power the overall system. According to the instruction manual, it was advised that the tracks be stretched to an upper limit of 1.5 inches.

Applied Load

In order to properly tension the belt around the tread assembly, some kind of loading would have to be applied. This loading would be applied at Node 2, the apex. A downwards applied load here would push the linkage apart because the bottom of Node 3 is a roller connection. In this simulation, there were three applied loads. The loads were the weight of the empty beach cart (100 lbf total), the weight of maximum load that the cart can carry (300 lbf total), and (500 lbf total). A quarter symmetry for the loads were applied here because the front and the back of the cart splits the loading halfway and on top of that since the treads are on both the left and right side of the cart, the loading would be split halfway once again. From this, the applied loadings were 25 lbf, 75 lbf, and 125 lbf.

Results

The ANSYS APDL code derived the appropriate spring constants k for all six cases (2 geometries with 3 loadings each) via assigning an arbitrary value for k and seeing what the displacements were by linear interpolation. This essentially narrowed down an answer until the displacement between Node 1 and Node 3 was between 1.495 inches and 1.505 inches. Attached is the tabulated data for the ANSYS Calculated Value, the Theoretical Value, associated Displacement as well as the percent error for the spring constant k.

Trial	**ANSYS APDL Value (lbf/in)**	**Theoretical Value (lbf/in)**	**Displacement (in)**	**Percent Error (%)**
Design 1 Load 1	8.425	8.267	1.4965	1.91
Design 1 Load 2	25.312	24.8	1.5024	2.06
Design 1 Load 3	46.253	41.338	1.5002	11.89
Design 2 Load 1	6.208	6.209	1.4967	0.016
Design 2 Load 2	19.001	18.628	1.4965	2.00
Design 2 Load 3	36.218	31.047	1.5000	16.66

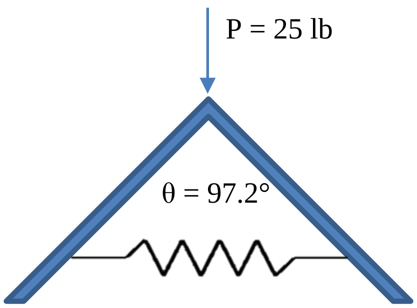
Discussion

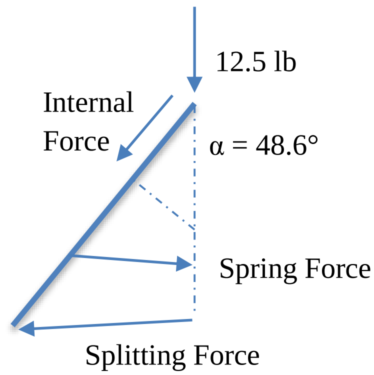
From analysis of the data, it can be determined that the margin of error is relatively small between the ANSYS APDL determined values versus that of the hand verification. It may also be noted that the percent error had a general trend of increasing with the load. A possible cause of the errors may be from the idealizations, but more likely, the constraints. In the real world situation, the idler sprockets are both rollers at the bottom, therefore both nodes should be able to slide freely in the X direction. Unfortunately ANSYS requires that within a model that there be at least one fixed point constraint in order to successfully run its simulation.

Overall, from the tabulated data, it would appear that Design 2, which has the uneven scissor linkage lengths would require a spring of a smaller constant k. By choosing Design 2 over Design 1, the design may be optimized with a more efficient spring, which would be a more financially conscious decision.

Verification

Configuration 1 Load 1

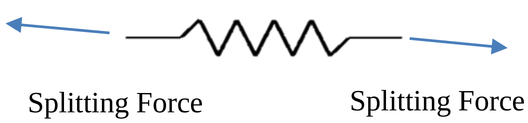


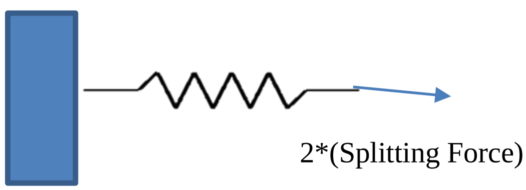


A one half symmetry was utilized to figure out the spring force. The applied load was split in two and the internal axial force was calculated. Next, the horizontal component was calculated and the splitting force was obtained, which relates to the spring force and can be utilized to get the spring constant.

$$InternalForce = 12.5\cos(48.6) = 8.266\ lbf$$

$$SplittingForce = 8.266\sin(48.6) = 6.200\ lbf$$



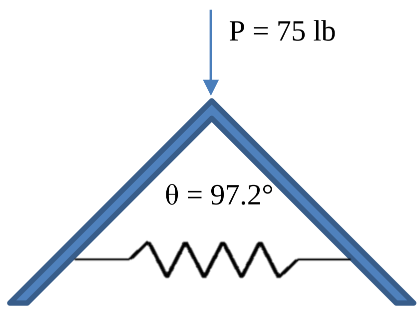


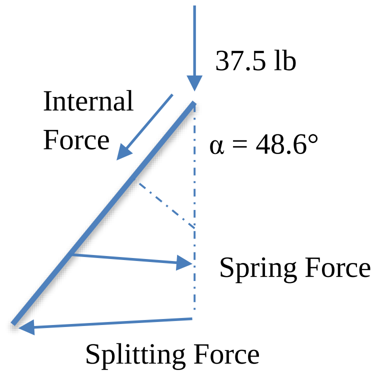
$$F = kx$$

$$2(6.200)lbf = k \times (1.5\ in)$$

$$\boldsymbol{k = 8.267\ lbf/in}$$

Configuration 1 Load 2

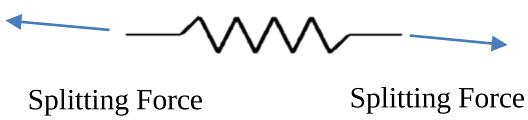


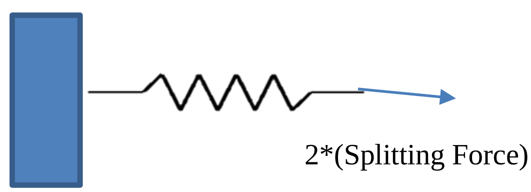


A one half symmetry was utilized to figure out the spring force. The applied load was split in two and the internal axial force was calculated. Next, the horizontal component was calculated and the splitting force was obtained, which relates to the spring force and can be utilized to get the spring constant.

$$InternalForce = 37.5\cos(48.6) = 24.799\ lbf$$

$$SplittingForce = 24.799\sin(48.6) = 18.602\ lbf$$



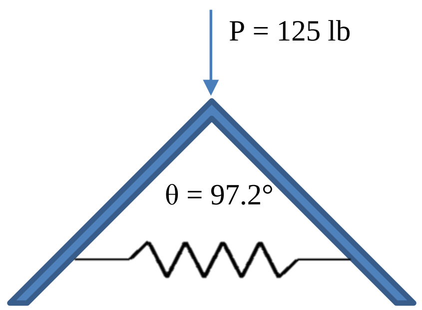


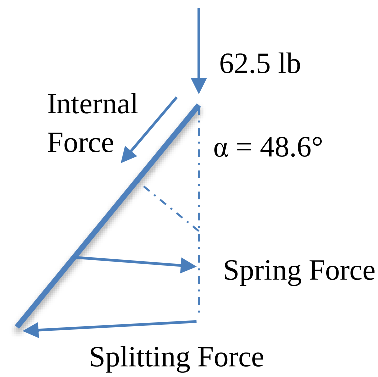
$$F = kx$$

$$2(18.602)lbf = k \times (1.5\ in)$$

$$\boldsymbol{k = 24.8\ lbf/in}$$

Configuration 1 Load 3

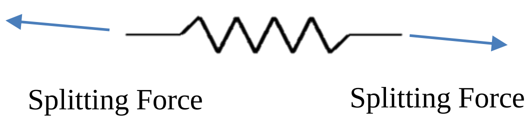


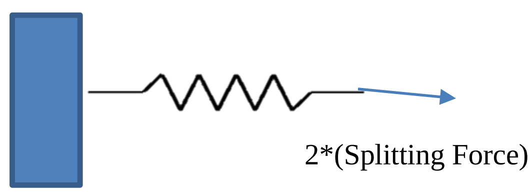


A one half symmetry was utilized to figure out the spring force. The applied load was split in two and the internal axial force was calculated. Next, the horizontal component was calculated and the splitting force was obtained, which relates to the spring force and can be utilized to get the spring constant.

$$InternalForce = 62.5\cos(48.6) = 41.332\ lbf$$

$$SplittingForce = 41.332\sin(48.6) = 31.004\ lbf$$



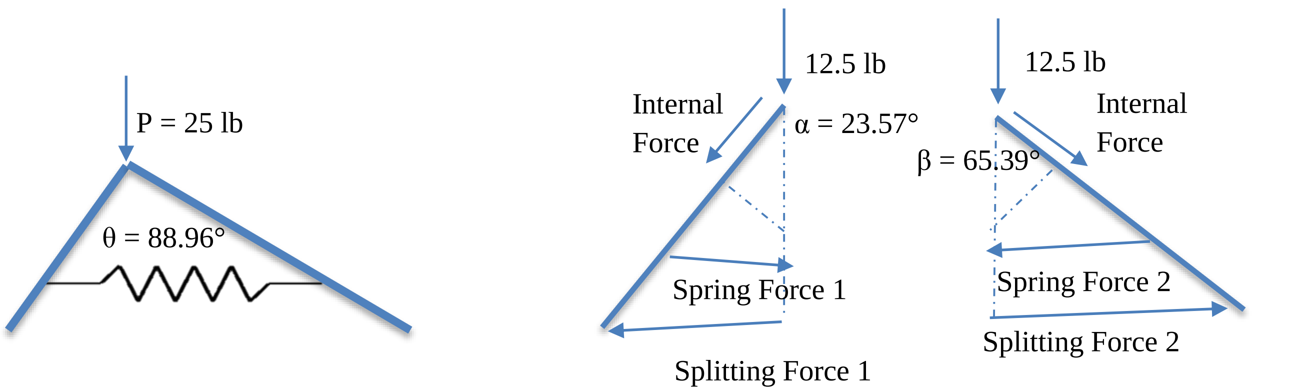


$$F = kx$$

$$2(31.004)lbf = k \times (1.5\ in)$$

$$\boldsymbol{k = 41.338\ lbf/in}$$

Configuration 2 Load 1



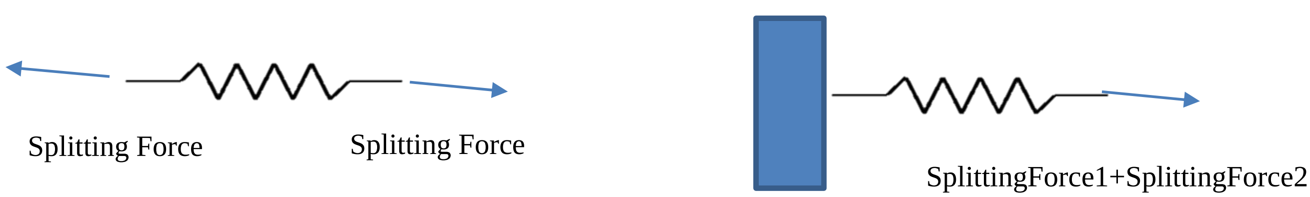
The applied load was split in two and the internal axial force was calculated. Next, the horizontal component was calculated and the splitting force was obtained, which relates to the spring force and can be utilized to get the spring constant.

$$InternalForce1 = 12.5\cos(23.57) = 11.457\ lbf$$

$$SplittingForce1 = 11.457\sin(23.57) = 4.581\ lbf$$

$$InternalForce2 = 12.5\cos(65.39) = 5.206\ lbf$$

$$SplittingForce2 = 5.206\sin(65.39) = 4.733\ lbf$$

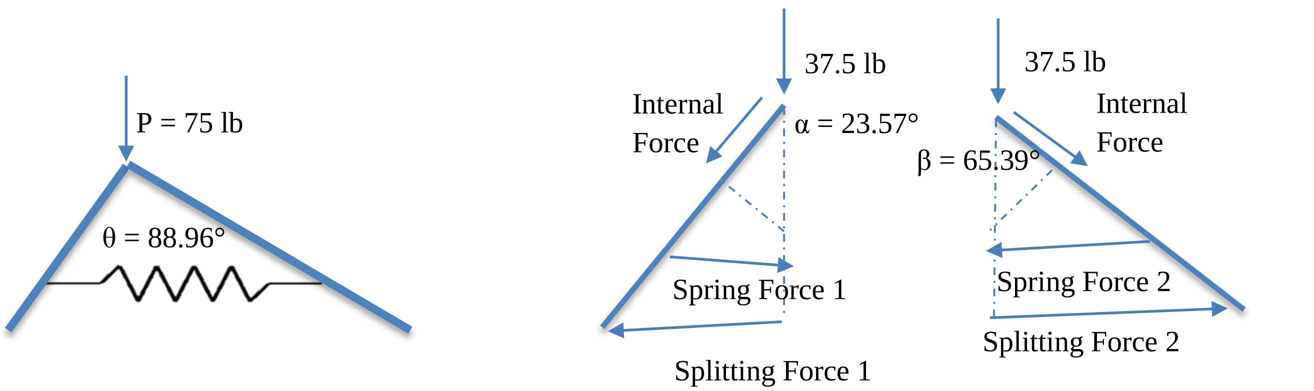


$$F = kx$$

$$4.581 + 4.733\ lbf = k \times (1.5\ in)$$

$$\boldsymbol{k = 6.209\ lbf/in}$$

Configuration 2 Load 2



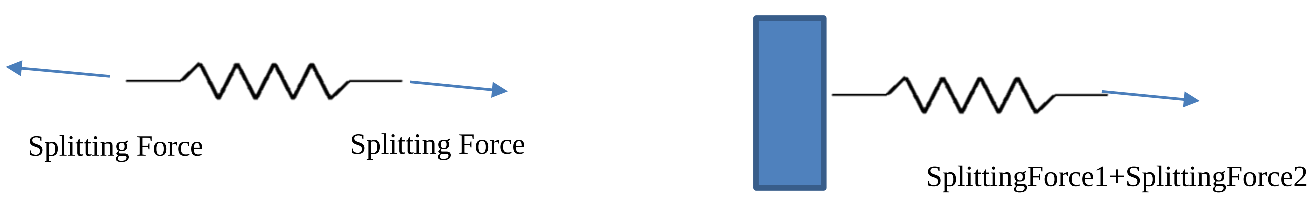
The applied load was split in two and the internal axial force was calculated. Next, the horizontal component was calculated and the splitting force was obtained, which relates to the spring force and can be utilized to get the spring constant.

$$InternalForce1 = 37.5\cos(23.57) = 34.372\ lbf$$

$$SplittingForce1 = 34.372\sin(23.57) = 13.744\ lbf$$

$$InternalForce2 = 37.5\cos(65.39) = 15.617\ lbf$$

$$SplittingForce2 = 15.617\sin(65.39) = 14.198\ lbf$$

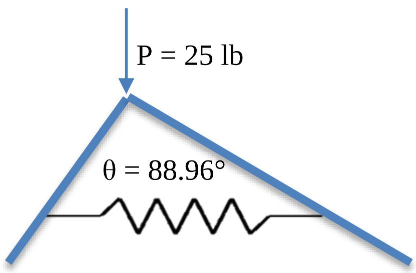


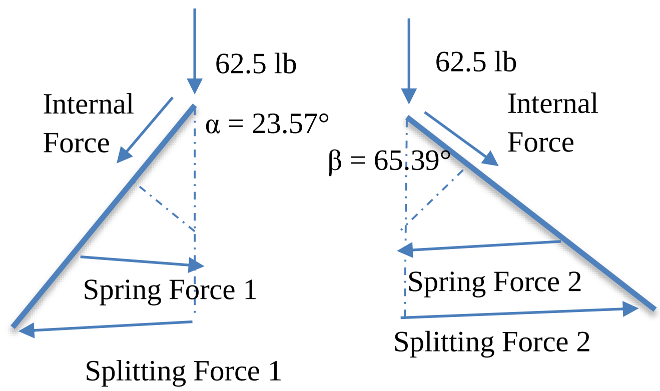
$$F = kx$$

$$14.198 + 13.744\ lbf = k \times (1.5\ in)$$

$$\boldsymbol{k = 18.628\ lbf/in}$$

Configuration 2 Load 3





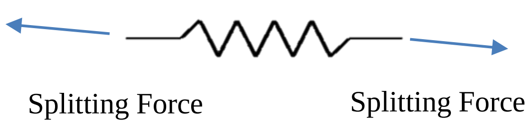
The applied load was split in two and the internal axial force was calculated. Next, the horizontal component was calculated and the splitting force was obtained, which relates to the spring force and can be utilized to get the spring constant.

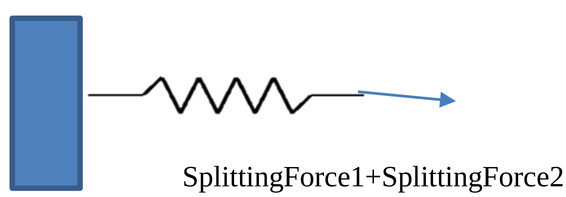
$$InternalForce1 = 62.5\cos(23.57) = 57.286\ lbf$$

$$SplittingForce1 = 57.286\sin(23.57) = 22.907\ lbf$$

$$InternalForce2 = 62.5\cos(65.39) = 26.028\ lbf$$

$$SplittingForce2 = 26.028\sin(65.39) = 23.663\ lbf$$





$$F = kx$$

$$22.907 + 23.663\ lbf = k \times (1.5\ in)$$

$$\boldsymbol{k = 31.047\ lbf/in}$$

ANSYS APDL Scripts

```
finish
/clear
/PREP7
/TITLE, TREAD TENSIONER MECHANISM CONFIGURATION 1
!L=8                         ! LENGTH OF ONE LEG
*AFUN,DEG                    ! TRIG FUNCTIONS IN DEGREES
THETA=41.41                  ! ANGLE TO BE USED TO CALCULATE A & B
A=2*L*COS(THETA)             ! CALCULATED X LOCATION - NODE 3
B=L*SIN(THETA)               ! CALCULATED Y LOCATION - NODE 2

ET,1,LINK180                 ! LINKAGE ELEMENT
ET,2,COMBIN14                ! SPRING ELEMENT
keyopt,2,3,0
R,1,8.425                    ! SPRING CONSTANTS k1 = 8.425, k2 = 25.312, k3 = 46.253
SECTYPE,1,LINK
SECDATA,0.5
MP,EX,1,10E6
N,1
N,2,A/2,B
N,3,A
N,4,A/6,B/3
N,5,5*A/6,B/3

TYPE,1
SECN,2
E,1,4
TYPE,1
SECN,2
E,4,2
TYPE,2
E,4,5
TYPE,1
SECN,2
E,2,5
TYPE,1
SECN,2
E,5,3
D,1,UX,0,,,UY,UZ,ROTY,ROTZ
D,2,UZ,0
D,3,UY,0,,,UZ,ROTX,ROTY
F,2,FY,-12.5                 ! LOAD F1 = -12.5, F2 = -37.5, F3 = -62.5
OUTPR,,1
FINISH
/SOLU
antype,0
SOLVE
FINISH
/POST1
PLNSOL,U,X
```

```
finish
/clear

/PREP7
/TITLE, TREAD TENSIONER MECHANISM CONFIGURATION 2
*AFUN,DEG                       ! TRIG FUNCTIONS IN DEGREES
THETA=41.41                     ! ANGLE TO BE USED TO CALCULATE A AND B
A=12
B=5*SIN(66.422)

ET,1,LINK180                    ! LINKAGE ELEMENT
ET,2,COMBIN14                   ! SPRING ELEMENT
keyopt,2,3,0
R,1,50                          ! SPRING CONSTANT
SECTYPE,1,LINK
SECDATA,0.5
MP,EX,1,10E6
N,1
N,2,5*COS(66.422),B
N,3,A
N,4,5/3*COS(66.422),B/3
N,5,12-1/3*(12-5*COS(66.422)),B/3

TYPE,1
SECN,2
E,1,4
TYPE,1
SECN,2
E,4,2
TYPE,2
E,4,5
TYPE,1
SECN,2
E,2,5
TYPE,1
SECN,2
E,5,3
D,1,UX,0,,,UY,UZ,ROTY,ROTZ
D,2,UZ,0
D,3,UY,0,,,UZ,ROTX,ROTY
F,2,FY,-50                      ! LOAD
OUTPR,,1
FINISH
/SOLU
antype,0
SOLVE
FINISH
/POST1
PLNSOL,U,X
```