MSET Demonstration Package
Springs Experiments
Springs in Tension
Series/Parallel Spring Stiffness

Mentis Sciences Education Toolkit Vision and Development History

Located in the historic Mill District of downtown Manchester, Mentis Sciences is an engineering firm which provides advanced material design and manufacturing capabilities to Department of Defense customers. Mentis specializes in the design, development and testing of advanced composite materials with a goal of providing unique flexibility, rapid development and prototyping for various composite applications.

Mentis Sciences, Inc. was founded in 1996 by John F. Dignam, following more than thirty years of service at the Army Materials Research Lab, where he served as the Director of Missile Materials. John F. Dignam spent most of his lifetime promoting national security and developing the most effective material systems to aid in countering global threats. He founded Mentis Sciences to continue promoting innovation, expertise, and emerging materials and manufacturing technologies, that will enhance U.S. security and promote economic growth.

His legacy continues under the strong and visionary leadership of John J. Dignam, who brings unique and innovative technical expertise to solving some of the nation's most daunting engineering challenges. The core values of ethics, integrity, community service, and commitment to excellence instilled by John F. Dignam live on with John J. Dignam and the Mentis team, and are apparent in every aspect of the company's structure, personality, and operations.

Mentis Sciences Internship Program recruits local high school students in good academic standing who reside in the HUBZone area of Manchester, NH. Successful youth with good attitudes and high motivation to work and learn have come through various avenues including non-traditional avenues like the Manchester Police Athletic League, The Salvation Army, and Manchester's Office of Youth Services.

Mentis makes a serious commitment of its resources to support the internship program by providing short courses in STEM related disciplines, student engineering activities and mentoring activities. In result of these courses, Mentis Sciences started to see a gap in STEM education. Biology and Life Science concepts were often the focus of science in the classroom, technology often included a smartphone app and engineering was nonexistent. Our interns and every student deserve to be introduced to STEM concepts with tools and resources that allow them to experience concepts hands-on and in a collaborative environment.

With this vision for our students, Mentis transferred skills used in their own manufacturing facility every day and descaled the concepts and tests into one integrated unit. Mentis has developed an integrated STEM toolkit that configures to complete 40 STEM tests. With limited lab space and budgets for lab testing equipment being tight, the Mentis Sciences Engineering Toolkit (MSET) departs from the high cost limited functionality of current educational testing systems.

The MSET offers a unique view into the world of material testing and physical science. Data indicates the MSET Program increased student participation in the classroom, interest in STEM careers and opportunities for females in STEM. Students develop a deep understanding in STEM, engineering and physical science concepts.

In many ways, the internship program and new shared vision has provided Mentis employees a new sense of purpose in their work. Mentis is now expanding their vision for the MSET program, beyond their own interns and are offering the MSETs STEM educational opportunities to other schools and educational partners in their community and around the United States.

Mentis believes that every student, no matter their upbringing or education status, should have the opportunity to learn, pursue their dreams and have the high-quality resources to so. This enrichment MSET program has proven to be beneficial, providing life-changing experiences for interns, students, as well as Mentis employees. We are excited to share it with you.

Springs Introduction

In this unit students will explore various spring combinations (parallel and series) and calculate the stiffness of individual springs and combinations of springs. Students will synthesize data to examine spring stiffness as it relates to load, elongation, and deflection. At the end of the unit students will apply concepts in an inquiry-based project where they will design a suspension system for an all-terrain vehicle based on knowledge gained from running the springs experiment on the MSET.

The materials in this section have been created and organized to assist teachers in the design of lessons that use the MSET equipment and applied inquiry-based projects that are aligned with the Next Generation Science Standards, as well as the Massachusetts Science and Technology/Engineering Curriculum Framework.

Teachers
Teachers should review the Understanding by Design unit plan with particular attention given to the Essential Questions students will be expected to answer by the conclusion of the unit. Throughout the lessons and experiences teachers should assess students' progress toward their capacity answering the essential questions. Finally, teachers should use the rubric to assess students' comprehension and application of the foundational principles associate with the lesson, experiment and materials covered in the unit.

Students
It is assumed that students participating in this unit will have experience in the following areas:

- How to interpret data plots
- How to calculate the slope of a line
- How to scale values
- Basic algebra skills including rearranging of variables to solve for specific unknowns
- How to interpret equations describing physical events
- How to use data from an experiment to make decisions that satisfy design criteria

Table of Contents

UbD Chart -Springs in Tension and Series/Parallel Spring Stiffness

<table>
<tr><th colspan="3">Desired Results</th></tr>
<tr>
<td rowspan="6">STANDARDS/ESTABLISHED GOALS

<u>Next Generation Science Standards</u>

Engineering Design:
HS-ETS1-4 Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints in interactions within and between systems relevant to the problem.

Forces and Interactions:
HS-PS2-1 Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration

<u>Massachusetts State Standards</u>

Technology and Engineering:
HS-ETS1-4. Use a computer simulation to model the impact of a proposed solution to a complex real-world problem that has numerous criteria and constraints on the interactions

HS-ETS3-4(MA). Use a model to illustrate how the forces of tension, compression, torsion, and shear affect the performance of a structure. Analyze situations that involve these
forces and justify the selection of materials for the given situation based on their properties.

Introductory Physics:
HS-PS2-1. Analyze data to support the claim that</td>
<td colspan="2">Transfer</td>
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<tr><td colspan="2">Students will be able to independently use their learning to make determinations about the appropriate spring configurations and level of spring stiffness to use when designing a structure.</td></tr>
<tr><td colspan="2">Meaning</td></tr>
<tr>
<td>UNDERSTANDINGS
Students will understand that…
1. Spring stiffness is related to the load applied and the elongation of the spring.
2. Newton's 2nd Law of Motion is the conceptual foundation of spring stiffness
3. Spring stiffness can be determined using mathematical models.
4. The stiffness of a group of springs is affected by the configuration of the springs.
5. Determining stiffness of sets of springs can help with selection of materials when designing structures.
6. Computer simulations and software can help model and compute spring stiffness.</td>
<td>ESSENTIAL QUESTIONS

1. How can determining spring stiffness help with the selection of materials for manufacturing?
2. What is the difference in stiffness between springs in a parallel and series configuration?
3. Why is there is a difference in stiffness between springs in parallel and series configurations?
4. How is Newton's second law of motion related to spring stiffness?</td>
</tr>
<tr><td colspan="2">Acquisition</td></tr>
<tr>
<td>Students will know…
• Definitions of a spring series and a set of parallel springs
• Definitions of load, elongation, and deflection</td>
<td>Students will be skilled at…
• Apply mathematical computations to mathematical model(s) to determine stiffness
• Interpret graphs to draw conclusions</td>
</tr>
</table>

Newton's second law of motion is a mathematical model describing change in motion (the acceleration) of objects when acted on by a net force.	• Newton's 2nd Law of Motion • Definition of "spring stiffness" • The equations for determining stiffness of a series of springs and parallel springs	• Use computer software to collect data and model spring stiffness of both a spring series and parallel springs • Apply the scientific method in an experiment

Evidence

Assessment Evidence

PERFORMANCE TASK(S):
There are two performance tasks/experiments related to spring stiffness, which will be conducted during different class periods. Assessment evidence will be collected from both experiments to help evaluated student understanding:

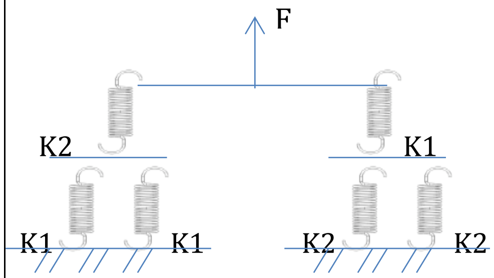
1. In the first spring stiffness lesson, students will learn to measure and calculate the stiffness of individual springs and apply their results to help solve a real-world manufacturing problem. Assessment evidence will be in the form of calculations and results depicted in tables and graphs included in students' final reports. Students will also apply their results by determining the percent error between their results and a manufacturer's specifications. They will then discuss the possible reasons for the error and how to meet the specifications required by the fictional manufacturer. (See Data Analysis #4 in Experiment 2).

2. Students will use the MSET device to conduct an experiment to measure the stiffness of the springs in both a series configuration and a parallel configuration. They will use the MSET software to graph the stiffness of each spring and each configuration. Students will all so use equations (given) to determine the stiffness of each configuration and proceed to compare the stiffness of the springs in each configuration. Students will then need to explain the reason for the difference in stiffness and how these two configurations could be used to design various structures. Designing of structures will be done in future lessons.

3. As a final performance assessment, students will complete the Inquiry-Based Mini-Project (see page 34), where they will design a suspension system for an all-terrain vehicle. Students will need to determine the appropriate spring resistance taking into consideration load and deflection and then provide a rationale for their decisions. The students will use the MSET and mathematical calculations to make decisions and to provide an explanation of their solution. Student understanding will be evaluated using the mini-project rubric (see page 43).

OTHER EVIDENCE:
The essential questions will be used as an entrance/exit slip to determine growth in understanding. The following computational problem will also be used as an entrance and exit slip.

Consider the configuration below.



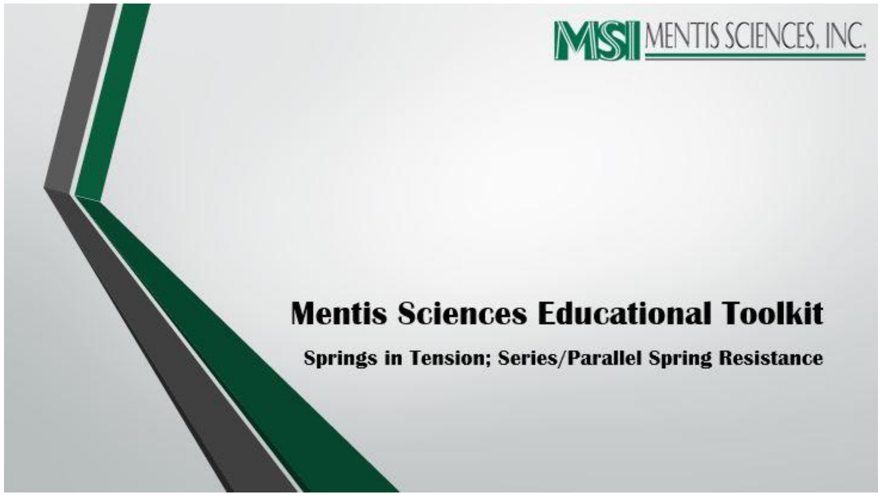
Determine the total stiffness for the spring system.

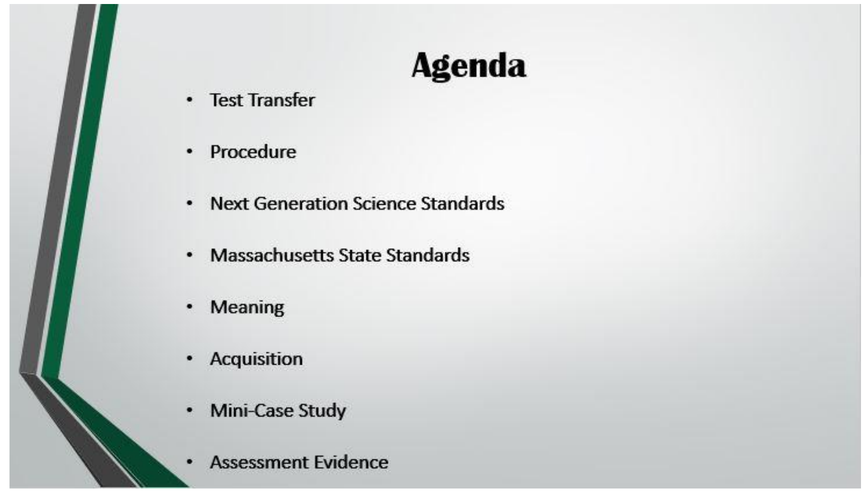
Stage 3 – Learning Plan

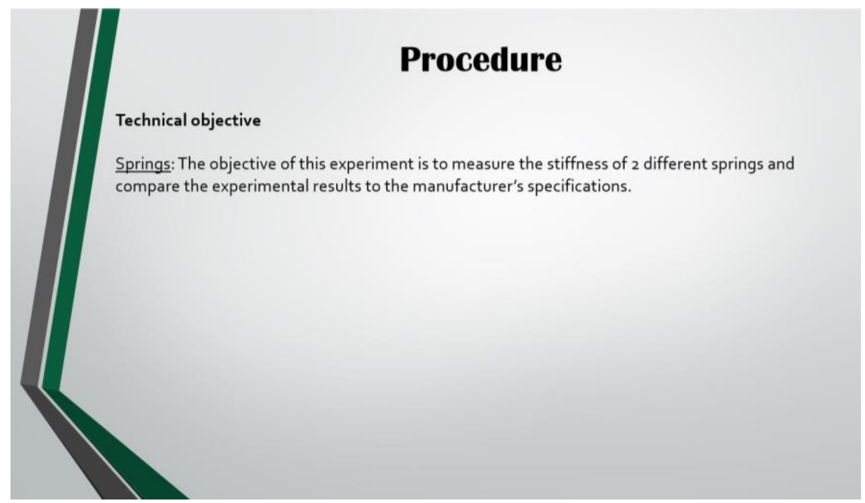
Summary of Key Learning Events and Instruction

See outline of Spring experiment summary included.

PowerPoint Template for Instruction







Procedure

Approach

Springs: In this experiment a set of springs will be individually stretched 20mm. The data will be plotted on an applied load vs elongation graph. Using 2 points on the graph the stiffness of each spring will be calculated. A best fit trend line will be applied to the data and the slope will be used to determine the average stiffness of the springs. Percent error will be calculated for comparison to the manufacturer's specification.

Standards/Established Goals

Next Generation Science Standards

Engineering Design:

- HS-ETS1-4 Use a computer simulation to model the impact of proposed solutions to a complex real-world problem.

Forces and Interactions:

- HHS-PS2-1 Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

Standards/Established Goals

Massachusetts State Standards

Technology and Engineering:

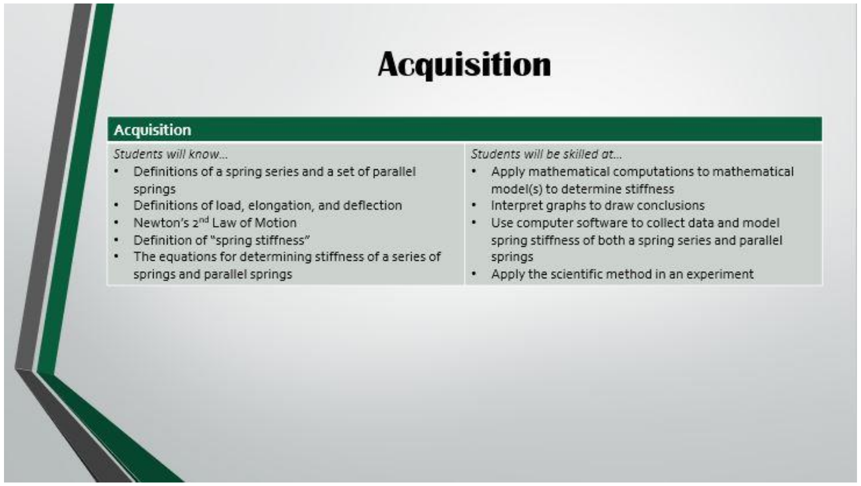
- HSHS-ETS1-4. Use a computer simulation to model the impact of a proposed solution to a complex real-world problem.
- HS-ETS3-4(MA). Use a model to illustrate how the forces of tension, compression, torsion, and shear affect the performance of a structure. Analyze situations that involve these forces and justify the selection of materials for the given situation based on their properties.

Introductory Physics:

- HS-PS2-1. Analyze data to support the claim that Newton's second law of motion is a mathematical model describing change in motion (the acceleration) of objects when acted on by a net force.

Meaning

Meaning	
UNDERSTANDINGS: *Students will understand that…* 1. Spring stiffness is related to the load applied and the elongation of the spring. 2. Newton's 2nd Law of Motion is the conceptual foundation of spring stiffness 3. Spring stiffness can be determined using mathematical models. 4. The stiffness of a group of springs is affected by the configuration of the springs. 5. Determining stiffness of sets of springs can help with selection of materials when designing structures. 6. Computer simulations and software can help model and compute spring stiffness.	ESSENTIAL QUESTIONS: 1. How can determining spring stiffness help with the selection of materials for manufacturing? 2. What is the difference in stiffness between springs in a parallel and series configuration? 3. Why is there is a difference in stiffness between springs in parallel and series configurations? 4. How is Newton's second law of motion related to spring stiffness?


Acquisition
Acquisition
Students will know...
• Definitions of a spring series and a set of parallel springs
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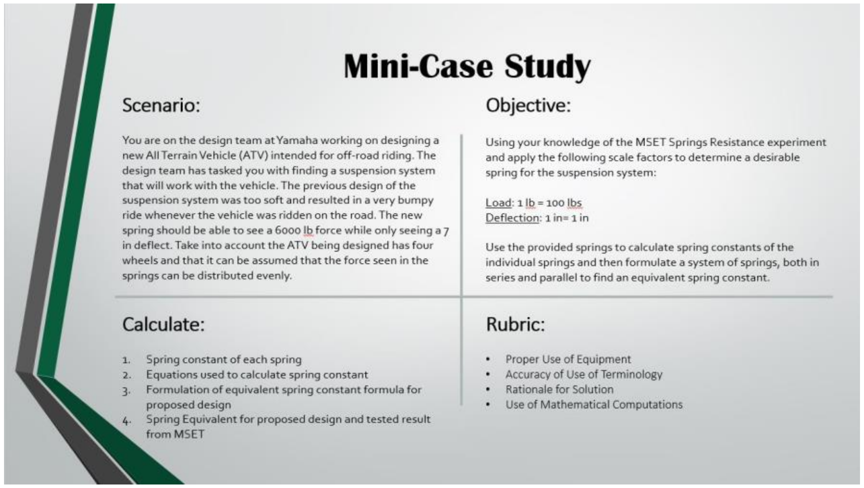
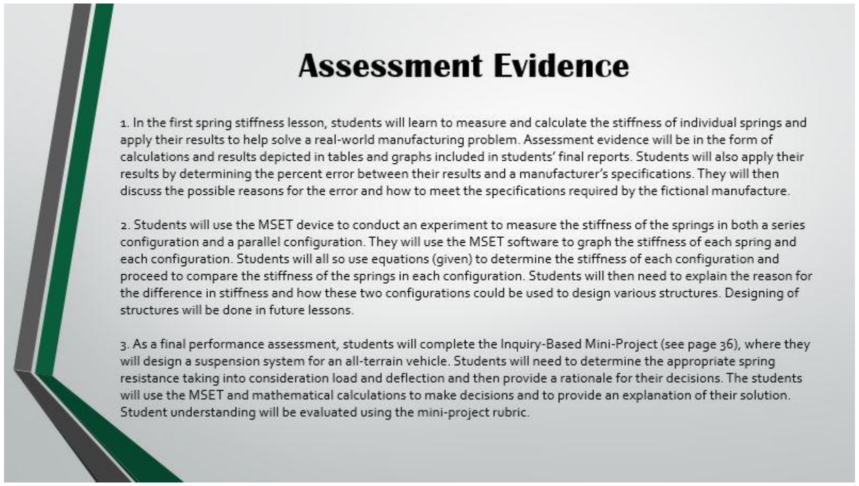
• Apply the scientific method in an experiment


Mini-Case Study
Scenario:
You are on the design team at Yamaha working on designing a new All Terrain Vehicle (ATV) intended for off-road riding. The design team has tasked you with finding a suspension system that will work with the vehicle. The previous design of the suspension system was too soft and resulted in a very bumpy ride whenever the vehicle was ridden on the road. The new spring should be able to see a 6000 lb force while only seeing a 7 in deflect. Take into account the ATV being designed has four wheels and that it can be assumed that the force seen in the springs can be distributed evenly.
Objective:
Using your knowledge of the MSET Springs Resistance experiment and apply the following scale factors to determine a desirable spring for the suspension system:
Load: 1 lb = 100 lbs
Deflection: 1 in= 1 in
Use the provided springs to calculate spring constants of the individual springs and then formulate a system of springs, both in series and parallel to find an equivalent spring constant.
Calculate:
1. Spring constant of each spring
2. Equations used to calculate spring constant
3. Formulation of equivalent spring constant formula for proposed design
4. Spring Equivalent for proposed design and tested result from MSET
Rubric:
• Proper Use of Equipment
• Accuracy of Use of Terminology
• Rationale for Solution
• Use of Mathematical Computations


Assessment Evidence
1. In the first spring stiffness lesson, students will learn to measure and calculate the stiffness of individual springs and apply their results to help solve a real-world manufacturing problem. Assessment evidence will be in the form of calculations and results depicted in tables and graphs included in students' final reports. Students will also apply their results by determining the percent error between their results and a manufacturer's specifications. They will then discuss the possible reasons for the error and how to meet the specifications required by the fictional manufacture.
2. Students will use the MSET device to conduct an experiment to measure the stiffness of the springs in both a series configuration and a parallel configuration. They will use the MSET software to graph the stiffness of each spring and each configuration. Students will all so use equations (given) to determine the stiffness of each configuration and proceed to compare the stiffness of the springs in each configuration. Students will then need to explain the reason for the difference in stiffness and how these two configurations could be used to design various structures. Designing of structures will be done in future lessons.
3. As a final performance assessment, students will complete the Inquiry-Based Mini-Project (see page 36), where they will design a suspension system for an all-terrain vehicle. Students will need to determine the appropriate spring resistance taking into consideration load and deflection and then provide a rationale for their decisions. The students will use the MSET and mathematical calculations to make decisions and to provide an explanation of their solution. Student understanding will be evaluated using the mini-project rubric.

MSET Experiment Procedure – Springs in Tension

Technical objective

The objective of this experiment is to measure the stiffness of 2 different springs and compare the experimental results to the manufacturer's specifications.

Background

The stiffness of a spring (K) is defined as the ratio of the load applied to the spring and the resulting elongation of the spring as is written in Equation #1. A spring with an applied load "F" is elongated a distance "L" as shown in Figure 1. This is usually expressed as a rate such as pounds per inch (lbs/in) or Newtons per millimeter (N/mm).

$$K = \frac{Applied\ Force\ "F"}{Elongation\ "L"} \qquad \text{eq. (1)}$$

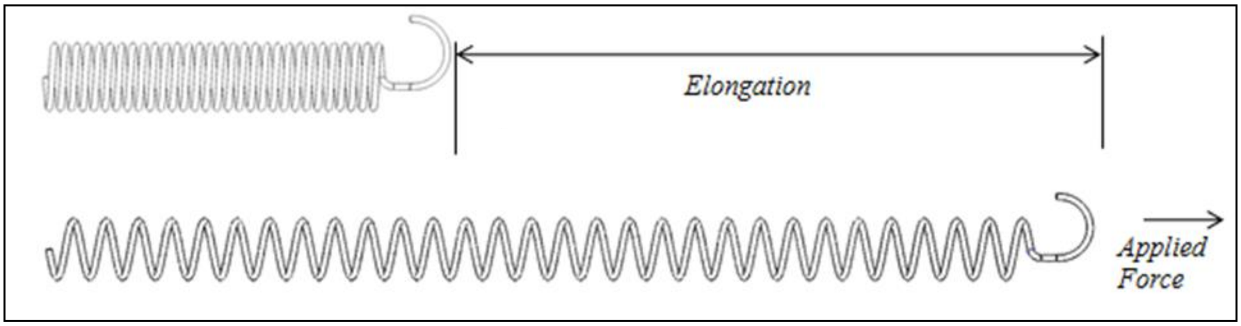


Figure 1- Spring Stretched with Applied Load

A spring's stiffness is typically linear as shown in the Load vs. Elongation plot in Figure 2. The stiffness is the slope of this line and can be calculated by knowing two points along the line as shown by Equation 2. The average stiffness can be determined by plotting several load and elongation values and fitting a linear trend line to the data and finding the equation for this line. This is also shown in Figure 2 by plotting the results in Microsoft Excel and adding a linear trend line and displaying the line equation. The spring stiffness plotted in Figure 2 has a value of 15.08 N/mm.

$$K = Slope = \frac{Change\ in\ Load\ (\Delta F)}{Change\ in\ Elongation\ (\Delta L)} \qquad \text{eq. (2)}$$

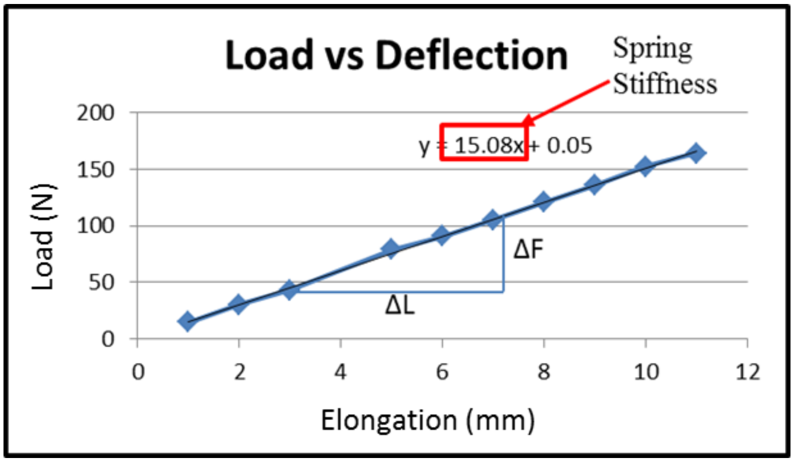


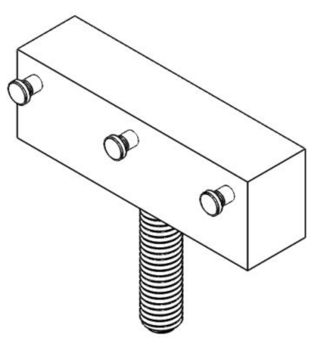
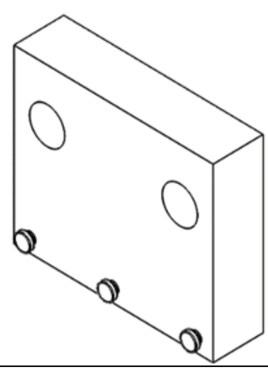
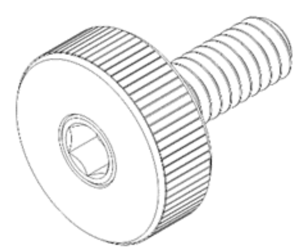
Figure 2- Plot of Applied Load vs. Elongation

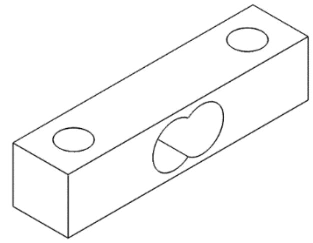
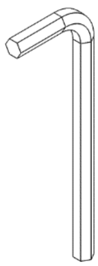
Approach

In this experiment a set of springs will be individually stretched 20mm. The data will be plotted on an applied load vs elongation graph. Using 2 points on the graph the stiffness of each spring will be calculated. A best fit trend line will be applied to the data and the slope will be used to determine the average stiffness of the springs. Percent error will be calculated for comparison to the manufacturer's specification.

Experiment Setup

1. Gather the following components:

Carriage Spring Plate	Top Spring Plate	¾" Thumbscrew x2
		

Spring 1	Spring 2	5kg Load Cell
		
4mm Hex Wrench 		

2. Attach the tower to the base plate as shown in the Quick Setup Guide. **Safety shield must be used for this experiment; it has been omitted from the following illustrations for clarity purposes.**
3. Use the 4mm hex wrench to attach the 5kg load cell to the carriage with the arrow pointing up.

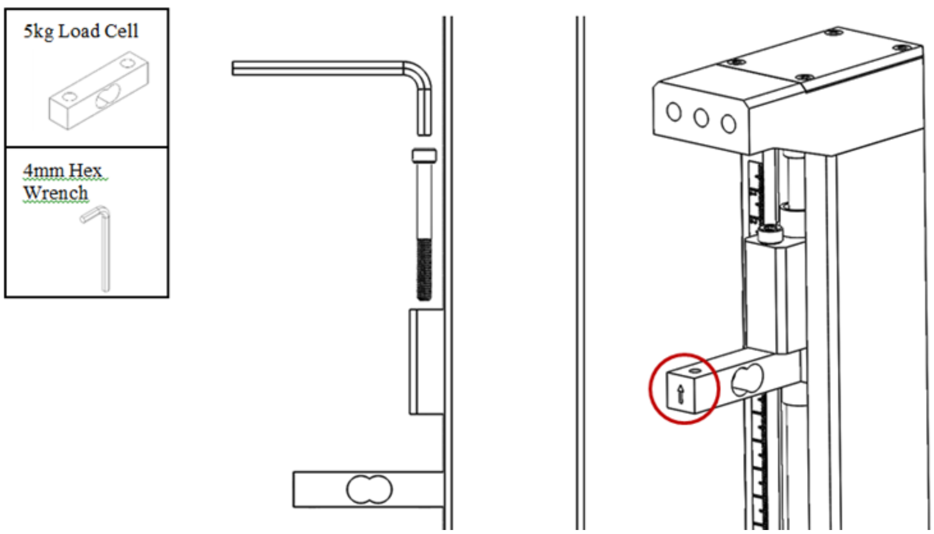


Figure 3: Load Cell Orientation

4. Plug the load cell into port 1 at the back of the SIM.

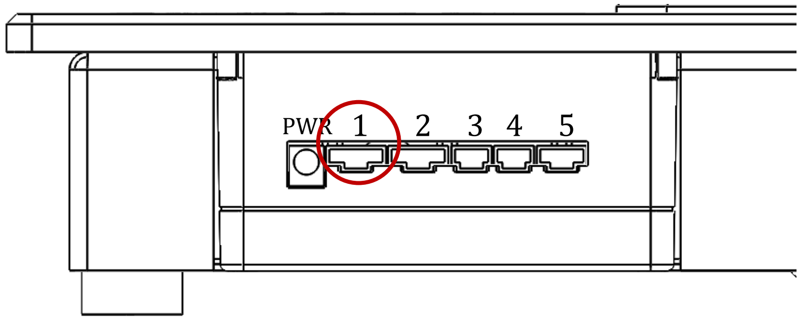


Figure 4: Port 1 on SIM

5. Thread the carriage spring plate as shown in Figure 5 approximately four full turns. Turn the spring plate as needed to orient it with the pins facing away from the carriage. Connect the top spring plate to the top mount using the two 3/4" thumbscrews.

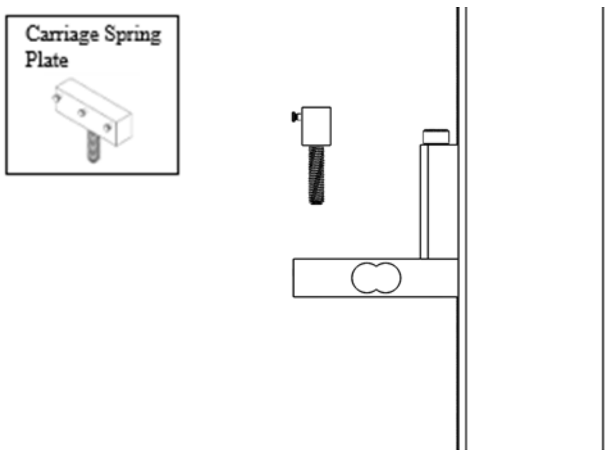


Figure 5: Attachment of Carriage Spring Plate

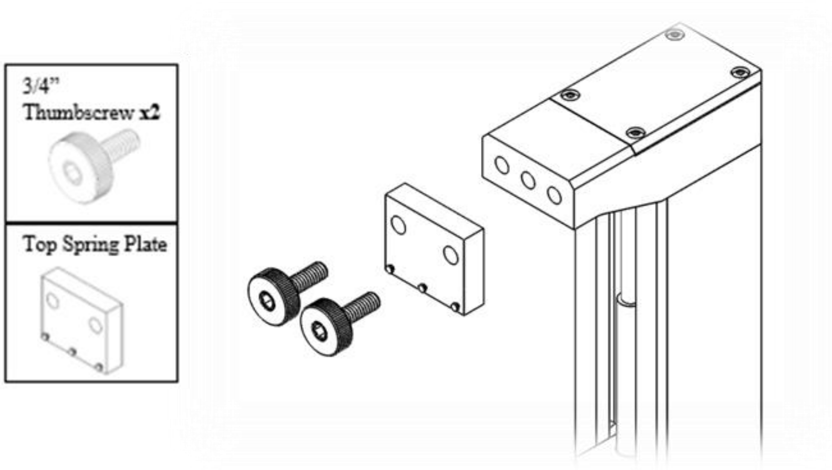
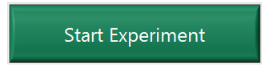


Figure 6: attachment of Spring Plate to the Load Cell and Top Mount

Experimental Procedure

1. Put on safety glasses.
2. In the MSET software, click "Spring Stiffness" then 

to launch the springs in tension experiment.

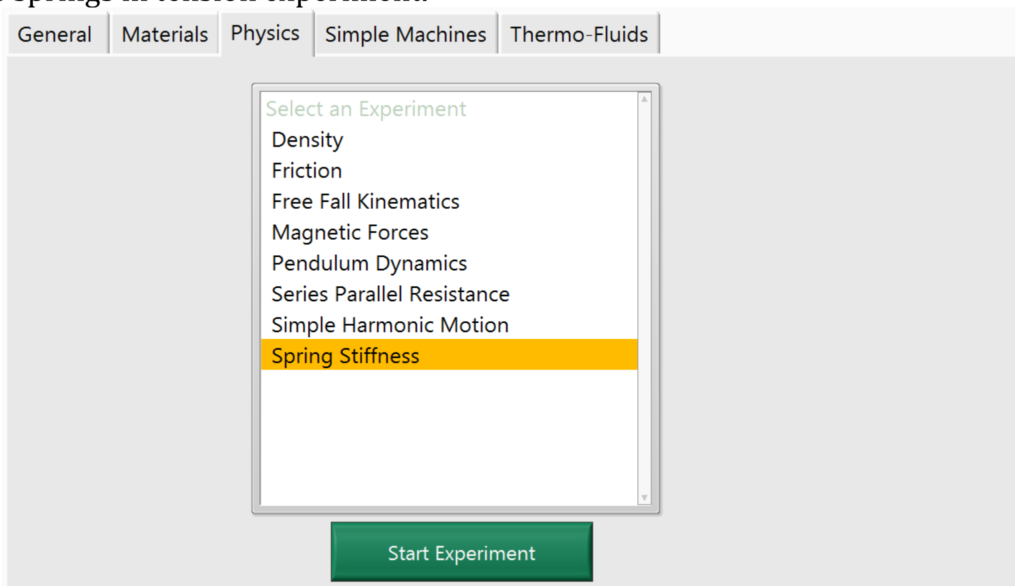


Figure 7: Location of Springs in Tension Experiment

3. Select the 5 kg loadcell from the menu options.

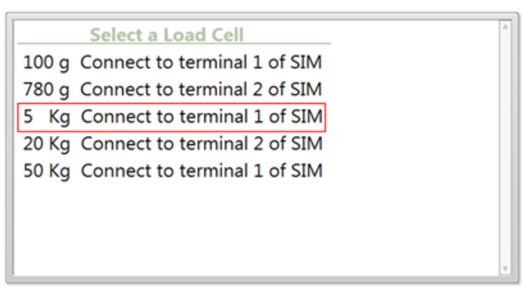


Figure 8. Load Cell Options

4. Raise the carriage until the top is level with the 1.5 cm mark on the tower ruler as shown in Figure 9.

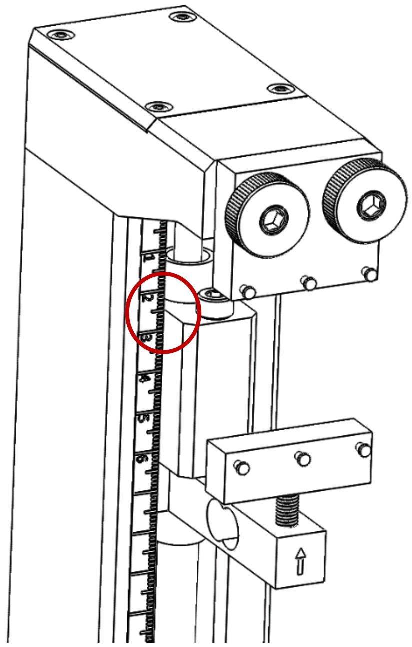


Figure 9: Alignment of Carriage

5. Attach spring #1 to the center pegs of the plates as shown in Figure 10. There should be a slight pre-load on the spring at this time.

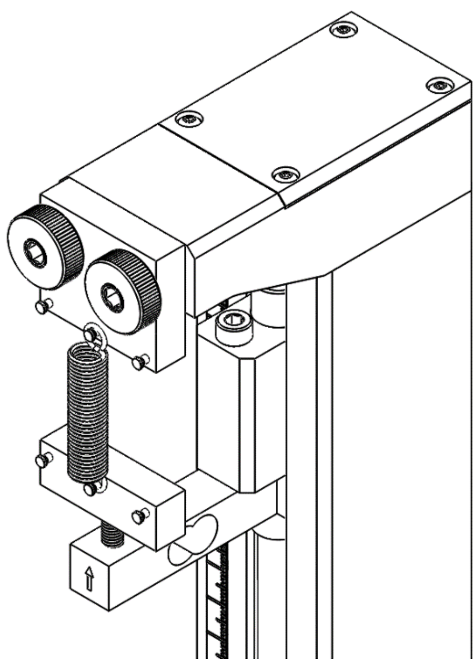


Figure 10: Spring 1 Attached to Spring pegs

6. Click Start Measuring to begin reading the sensors.
7. Press and hold Zero Readings on the MSET program to zero the load and displacement readouts.

8. Click Log Data to begin collecting data.

9. Lower the carriage until it has displaced 20mm as displayed on the MSET program.

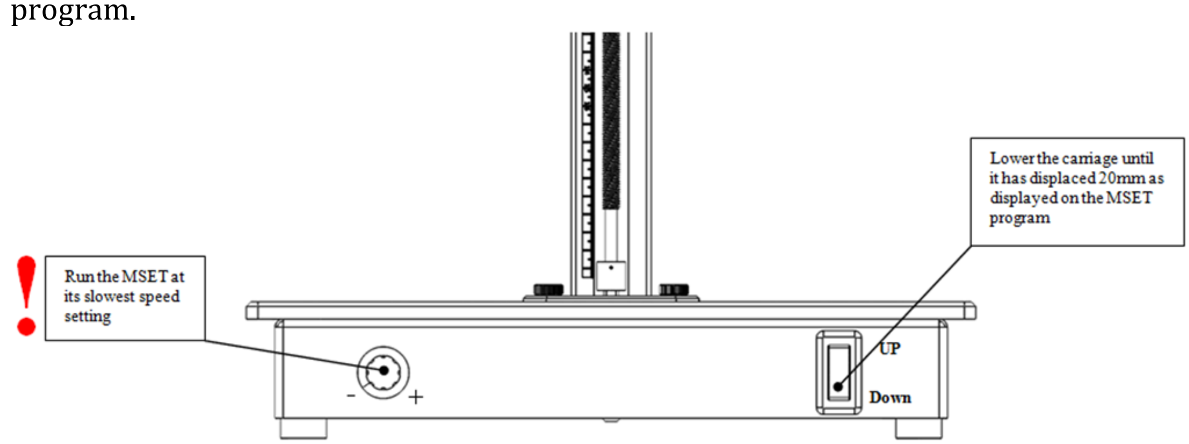


Figure 11: Experiment Operation

10. When the final displacement is achieved, release the direction control switch and click Stop Data Logging then Stop Measuring.
11. Record the ending load and displacement values in Table 1 in the data analysis section of this tutorial.
12. Press Save Results. A window will pop up notifying the user that data will be saved once Return to Main is pressed at the end of the experiment.

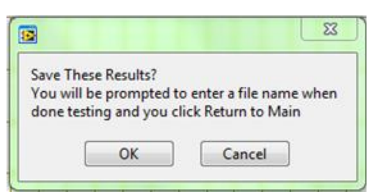


Figure 12: Save Results Prompt

13. Return the carriage to the 1.5cm position and remove spring 1 from the pegs. Now attach spring 2 in the same configuration.
14. Repeat steps 4-12 using spring 2.
15. Upon completing step 12 using spring 2, return the carriage to the 1.5cm position and remove spring 2.
16. Now press Return to Main to save both data sets. Enter an appropriate filename and press ok.
17. The data collection portion of this experiment is now complete. Continue to the data analysis portion.

Data Analysis

1. For each spring record the beginning and ending load and deflection Table 1. Calculate the spring stiffness using Equation 2 and enter in Table 1.

Table 1 - Spring Stiffness Calculations Based on Two Points

Spring 1	**Load (N)**	**Deflection (mm)**
Start	0	0
End		
Change (Difference)		
Calculated Stiffness		

Spring 2	**Load (N)**	**Deflection (mm)**
Start	0	0
End		
Change (Difference)		
Calculated Stiffness		

2. In the MSET StaticData folder, open the data saved from testing the two springs. Using a data processing program, such as Microsoft Excel, plot the load deflection data for each spring and determine the slope of each plot by adding a linear trend line and its equation. Report the average stiffness in Table 2.

Table 2- Average Spring Stiffness's From Linear Trendline

Spring	**Stiffness (N/mm)**

1	
2	

3. During the test, springs 1 and 2 were stretched 20mm. Determine how much force would be required to stretch each spring 60mm, 70mm, and 80mm.
4. The manufacturer reports the springs to have the stiffness in the table below.

Table 3- Manufacturers Stiffness Specifications

Spring	Stiffness (N/mm)
1	0.455
2	0.212

For comparing experimental results to an expected result, it is often useful to evaluate the percent error. Using Equation#3 below, calculate the percent error between the experimentally determined stiffness' (two-point calculation and average trend line analysis) and the manufacturers specified stiffness. Record results in Table 4. What are some potential causes for error?

$$\%Error = \frac{|K_{Experiment} - K_{Manufacturer}|}{K_{Manufacturer}} \times 100 \qquad \text{eq.(3)}$$

Table 4 - Percent Error between Experimental Stiffness and Manufacturers Specifications

MSET

	Two-Point Stiffness	Average Stiffness
Spring 1		
Spring 2		

Experiment Procedure –

MSET Experiment Procedure – Series/Parallel Spring Stiffness

Technical objective

The objective of this experiment is to evaluate the total stiffness that results from a pair of springs connected in series and parallel configurations.

Background

Springs are in series when they are connected end to end as is shown in Figure 13. K1 and K2 represent the individual spring stiffness values and are provided in units of N/mm as shown in Table 7.

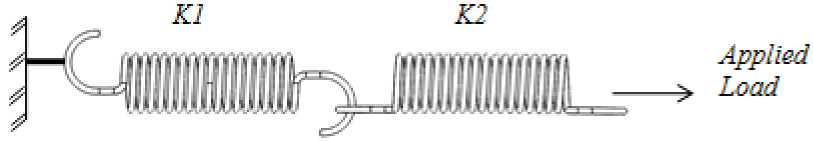


Figure 13- Pair of Springs in Series

The combined stiffness for two springs in series can be determined using Equation (1).

$$K_{Series} = \frac{K_1 \cdot K_2}{K_1 + K_2} \qquad \text{eq. (1)}$$

Two springs held side-by-side are in parallel as shown in Figure 14.

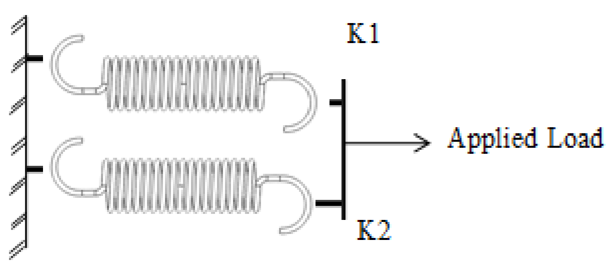


Figure 14 - Pair of Springs in Parallel

The combined stiffness for the springs in parallel is determined using Equation (2).

$$K_{parallel} = K_1 + K_2 \qquad \text{eq. (2)}$$

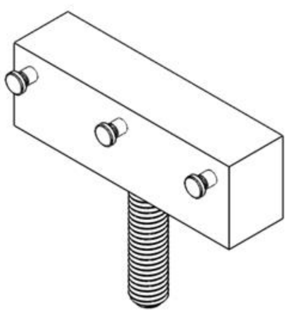
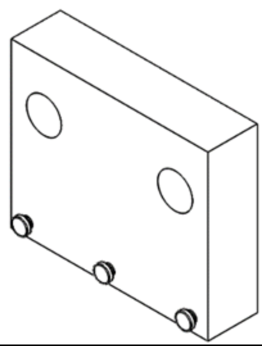
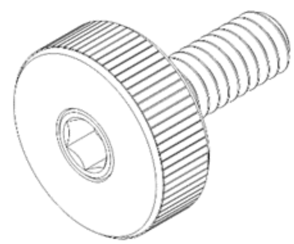
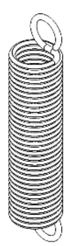
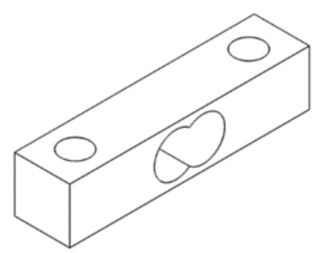
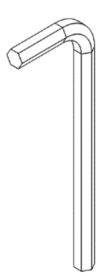
Where: K1 = stiffness of spring 1
K2 = stiffness of spring 2

Approach

A total of four springs with two different stiffnesses are provided for use in this experiment. Similar springs will be tested in the series and parallel configuration. Additionally, pairs of springs with different stiffnesses will be tested in the series and parallel configurations.

Experiment Setup

1. Gather the following components:

Carriage Spring Plate 	Top Spring Plate 	3/4" Thumbscrew x2 
Spring 1 	Spring 2 	5kg Load Cell 
4mm Hex Wrench 		

2. Attach the tower to the base plate as shown in the Quick Setup Guide. **Safety shield must be used for this experiment; it has been omitted from the following illustrations for clarity purposes.**
3. Use the 4mm Hex wrench to attach the 5kg load cell to the carriage with the arrow pointing up.

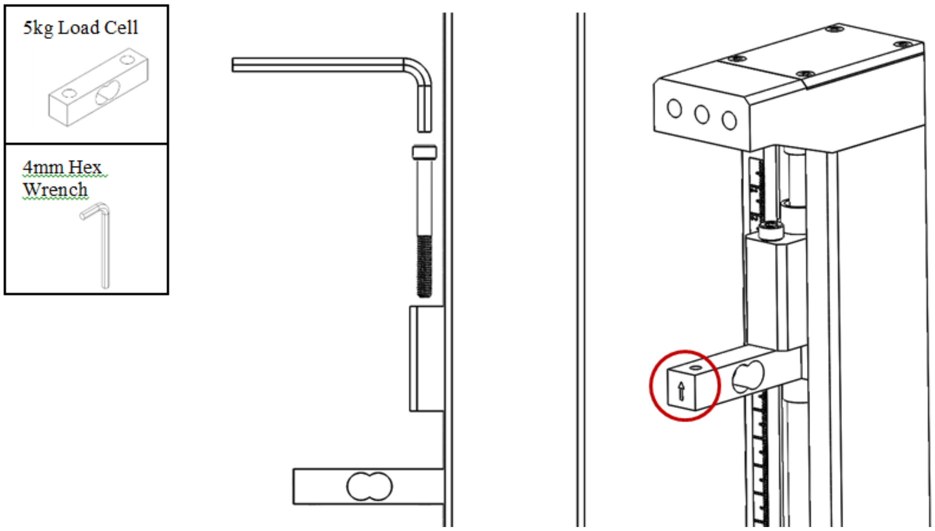


Figure 15: Load Cell Orientation

4. Plug the load cell into port 1 at the back of the SIM.

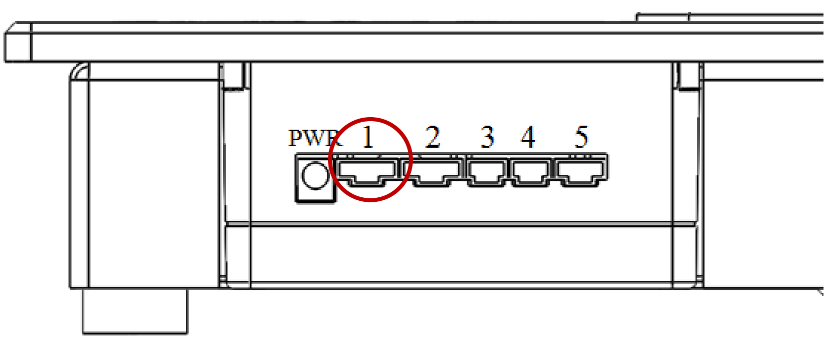


Figure 16: Port 1 on SIM

5. Thread the carriage spring plate as shown in Figure 5 approximately four full turns. Turn the spring plate as needed to orient it with the pins facing away from the carriage. Connect the top spring plate to the top mount using the two 3/4” thumbscrews.

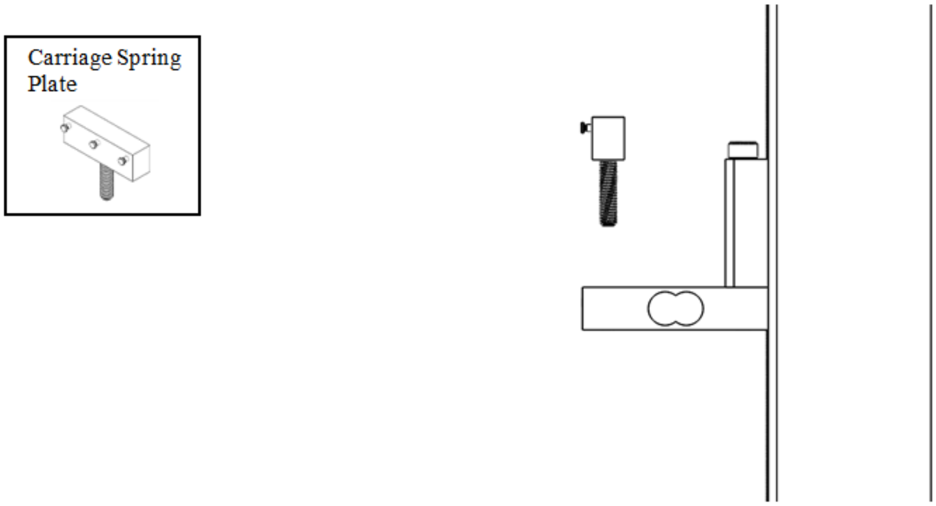


Figure 17: Attachment of Carriage Spring Plate

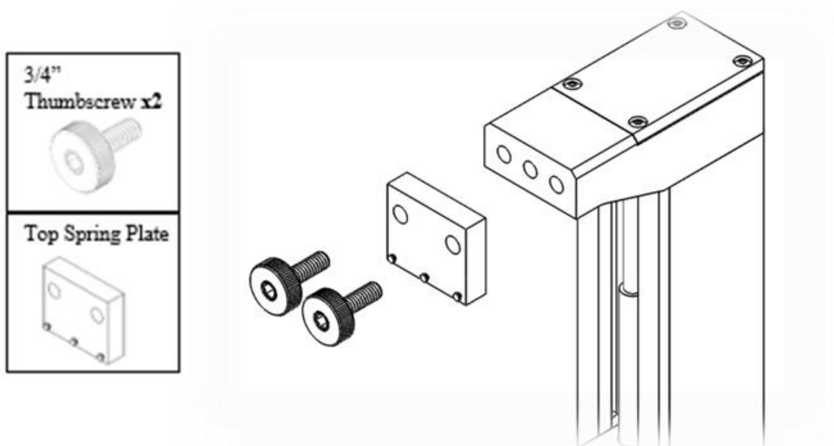


Figure 18: Attachment of Spring Plate to the Load Cell and Top Mount

Experimental Procedure / Parallel

1. Put on safety glasses.
2. Double click "Series/Parallel Resistance" to launch the series and parallel resistance experiment.

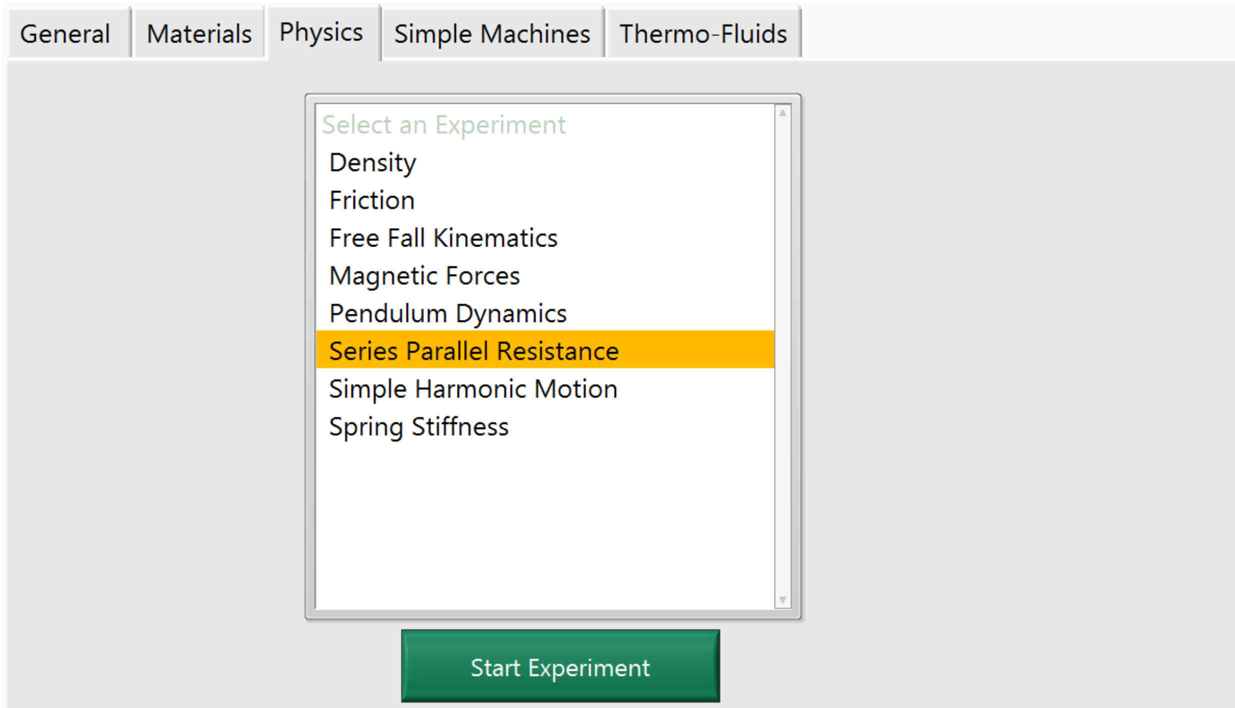


Figure 19: Location of Series and Parallel Resistance Experiment

3. Raise the carriage until the top is level with the 1.5cm mark on the tower ruler shown in Figure 20.

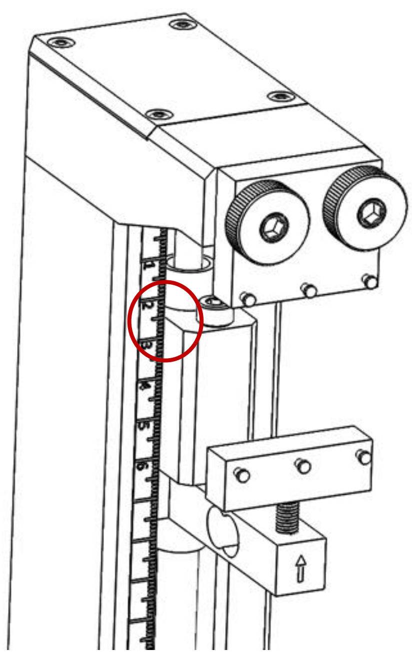


Figure 20: Alignment of Carriage

4. Attach the pair of spring #1's to the outside pegs on the as a shown in Figure 21.

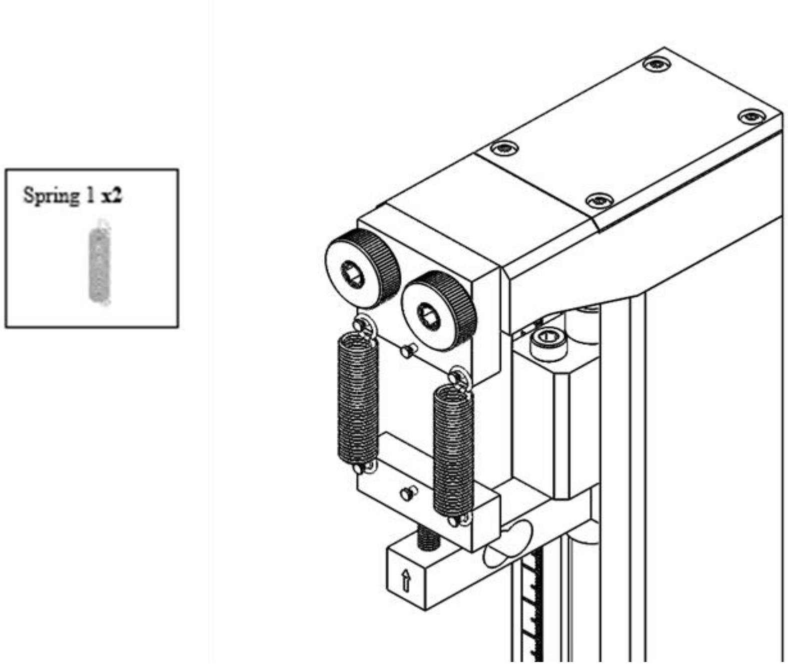
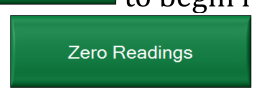
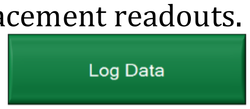


Figure 21: Spring 1 Configured in Parallel

5. Click  to begin reading the sensors.
6. Press and hold  on the MSET program to zero the load and displacement readouts.
7. Press  to begin collecting data.
8. Lower the carriage until it has displaced 20mm as displayed in the MSET program.

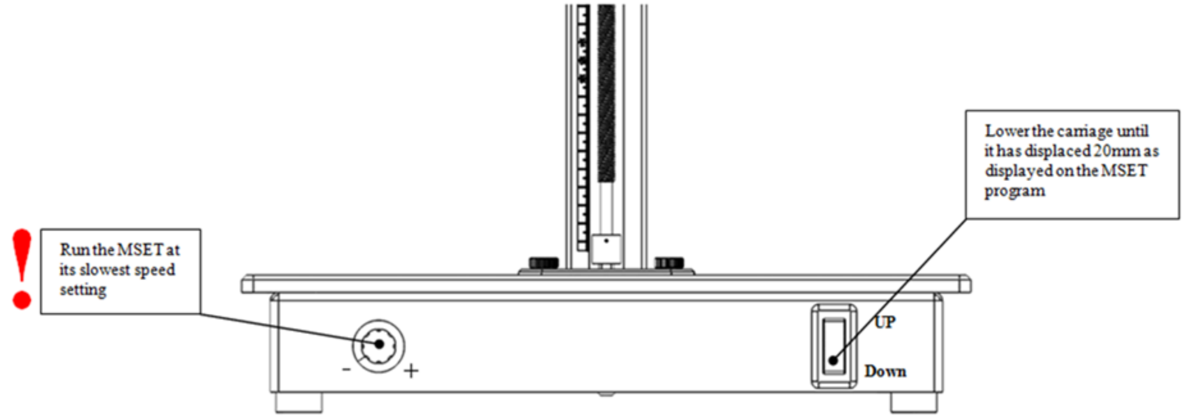


Figure 22: Experiment Operation

9. When the final displacement is achieved, release the direction control switch and click Stop Data Logging then Stop Measuring.
10. Record the ending load and displacement values in Table 5 in the data analysis section of this tutorial.
11. Press Save Results. A window will pop up notifying the user that data will be saved once Return to Main is pressed at the end of the experiment.

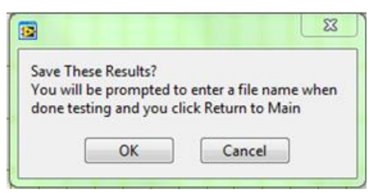


Figure 23. save Results Prompt

12. Return the carriage to the 1.5cm position and remove the pair of spring 1's from the pegs.
13. Repeat steps 4-12 using a pair of spring 2's and again with combination of one spring 1 and one spring 2.
14. Now press Return to Main to save all three data sets for the parallel configuration.
15. Enter a file name and press "ok".

Experimental Procedure / Series

1. Position the carriage until the top is level with the 5.5cm mark on the tower ruler.

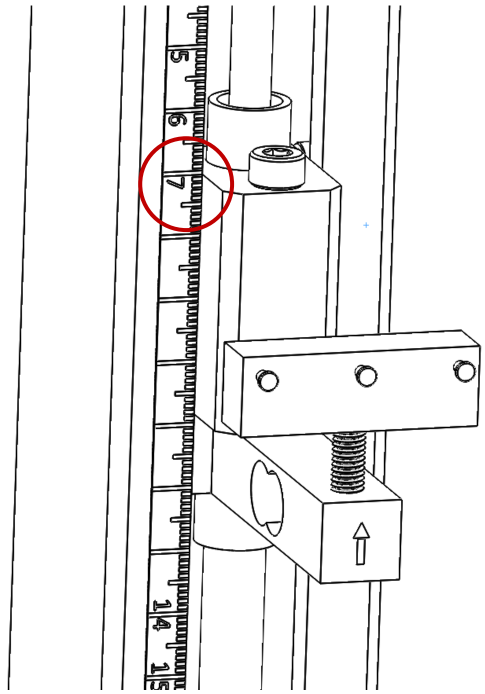


Figure 24: Carriage Alignment for Springs in Series

2. Take the pair of Spring 1's and hook them end to end. And attach them to the center pegs.

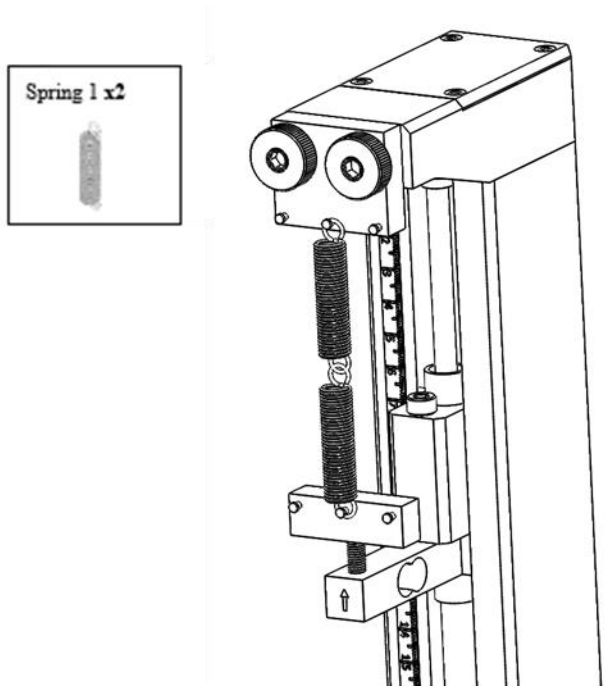


Figure 25: Spring 1 Configured in Series

3. There should be slight tension on the springs. If there isn't any, adjust the carriage downward slightly until a slight pretension is put on the springs.
4. Click Start Measuring to begin reading the sensors.
5. Press and hold Zero Readings on the MSET program to zero the load and displacement readouts.
6. Press Log Data to begin collecting data.
7. On the MSET base, press and hold the direction control switch down to lower the carriage until it has displaced 30mm as displayed on the MSET program.

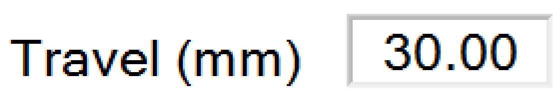
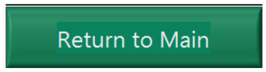


Figure 26: Travel Readout

8. When the final displacement is achieved, release the direction control switch and click Stop Data Logging then Stop Measuring .

9. Record the ending load and displacement values in Table 5 in the data analysis section of this tutorial.
10. Press 

. A window will pop up notifying the user that data will be saved once 

is pressed at the end of the experiment.

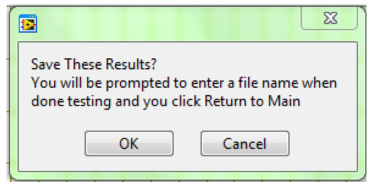


Figure 27. Save Results Prompt

11. Press “ok”.
12. Return the carriage to the 5.5cm position and remove the pair of spring 1’s from the pegs. Now attach spring 2’s in the same configuration.
13. Repeat steps 2-10 using spring 2’s and again with a combination of one spring 1 and one spring 2.
14. Now press 

to save all three data sets.
15. Enter a file name and press “ok”.
16. The data collection portion of this experiment is now complete. Continue to the data analysis portion.

Data Analysis

1. For each spring configuration record the beginning and ending load and deflection in the tables below. Calculate the spring system stiffness using Equation #3 (below) and record in Table 5.

$$K = Slope = \frac{Change\ in\ Load\ (\Delta F)}{Change\ in\ Elongation\ (\Delta L)} \qquad \text{eq. (3)}$$

Table 5 - Spring System Stiffness Calculations Based on Two Points

Spring 1 in Parallel	**Load (N)**	**Deflection (mm)**
Start	0	0
End		
Change (Difference)		
Calculated Stiffness		

Spring 2 in Parallel	Load (N)	Deflection (mm)
Start	0	0
End		
Change (Difference)		
Calculated Stiffness		

Spring 1& 2 in Parallel	Load (N)	Deflection (mm)
Start	0	0
End		
Change (Difference)		
Calculated Stiffness		

Table 5 (cont.) - Spring System Stiffness Calculations Based on Two Points

Spring 1 in Series	Load (N)	Deflection (mm)
Start	0	0
End		
Change (Difference)		
Calculated Stiffness		

Spring 2 in Series	Load (N)	Deflection (mm)
Start	0	0
End		
Change (Difference)		
Calculated Stiffness		

Spring 1& 2 in Series	Load (N)	Deflection (mm)
Start	0	0
End		
Change (Difference)		

Calculated Stiffness	

2. Access the data saved from testing the two springs. Using a data processing program, such as Microsoft Excel, plot the load deflection data for each spring and determine the slope of each plot. Report the average stiffness in Table 6.

Table 6 - Average Spring System Stiffnesses from Linear Trendline

Spring Combination	**Series Stiffness (N/mm)**	**Parallel Stiffness (N/mm)**
1+1		
2+2		
1+2		

3. The manufacturer reports each spring to have the stiffness shown in Table 7.

Table 7- Manufacturers Stiffness Specifications

Spring	**Stiffness (N/mm)**
1	0.455
2	0.212

Using the Equations 1 and 2 described in the background section, calculate the combined stiffness for all spring configurations. Complete the table below with the calculated stiffnesses.

Table 8- Spring System Stiffness based on Manufacturers Specifications

Spring Combination	**Series Stiffness (g/mm)**	**Parallel Stiffness (g/mm)**
1+1		
2+2		
1+2		

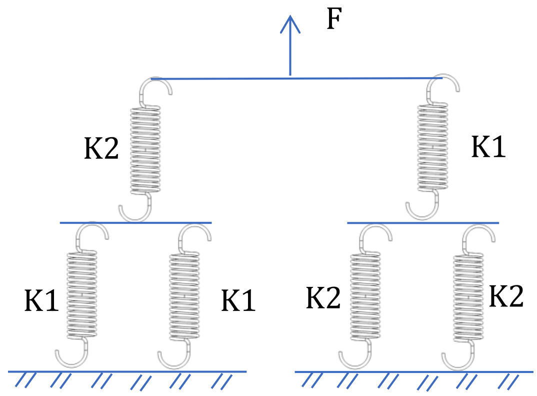
Determine the percent error between the calculated stiffnesses and the experimentally determined stiffnesses using Equation (4). What are some potential causes of error?

$$\%Error = \frac{|K_{Experiment} - K_{Calculated}|}{K_{Calculated}} \times 100 \qquad \text{eq. (4)}$$

Table 9- Percent Error between Experimental Stiffness and Expected (calculated) stiffness for each System of Springs

Spring Configuration	**Two-Point Stiffness**	**Average Stiffness**
1+1 Parallel		
2+2 Parallel		
1+2 Parallel		
1+1 Series		
2+2 Series		
1+2 Series		

4. Consider the configuration below.



Calculate the total stiffness for the spring system.

MSET – SPRING STIFFNESS

Purpose

Develop an understanding of spring stiffness and how an applied force results in a measurable stretching or elongation of the spring.

Springs

Springs are basic components used in engineering designs. A trampoline for example is fabricated with springs to support the weight and bouncing forces generated by a user.

Theory

The stiffness, or resistance to stretching of a spring depends on material composition, and spring geometry. Spring stiffness "K" can be determined by measuring the amount of deformation (stretch) "X" as a force "F" is applied.

$$F = K(X)$$

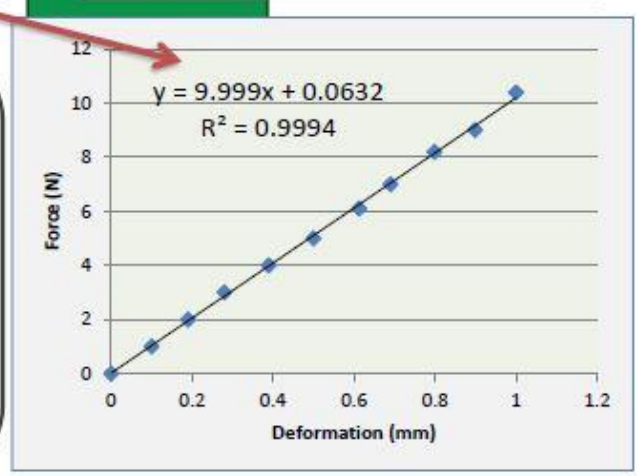
This relationship is also valid for springs loaded in compression

Setup

Results

A number of springs of various stiffness will be measured and compared published manufacturer values. The results will then be used to select a spring for a defined application problem

K



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MSET - SERIES / PARALLEL RESISTANCE

Purpose

Evaluate the effects of configuring springs in series and parallel. Predict and measure both arrangements to show their effects on applied forces.

Springs

Springs are used in many physics & engineering applications. As an example; automobiles, bicycles, clocks, and a large number of other mechanical devices use springs.

This bicycle seat uses a number of springs configured in series and parallel to resist forces

Theory

The force, "F" of a single stretched spring is related to its elongation (Δx) and its stiffness (k) as follows:

$$F = k\Delta x$$

When two springs are connected in series the equivalent resistance K is equated as:

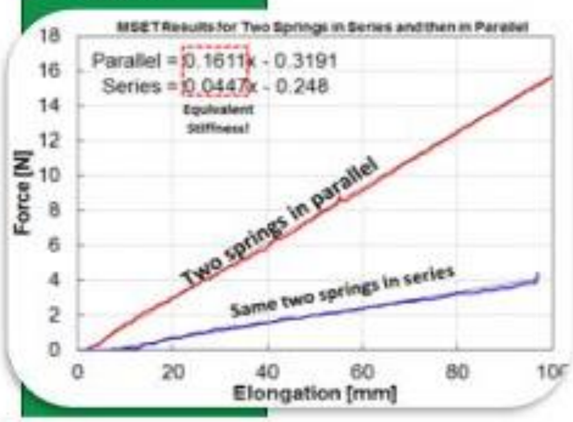
$$K = \frac{K_1 K_2}{(K_1 + K_2)}$$

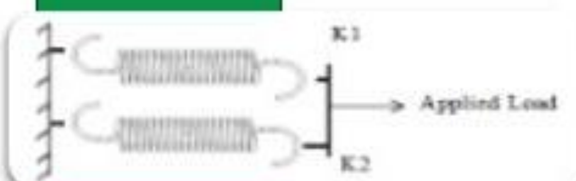
When two springs are connected in parallel the equivalent resistance K is equated as

$$K = K_1 + K_2$$

Setup

Results





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Inquiry-Based Mini Project - Springs in Tension and Series/Parallel Spring Stiffness

You are on the design team at Yamaha designing a new All-Terrain Vehicle (ATV) intended for off-road riding. The design team has tasked you with finding a suspension system that will work with the vehicle. The previous design of the suspension system was too soft and resulted in in a bumpy ride whenever the vehicle was ridden on the road. The new spring should be able to see a 6000 lb force while only seeing a 7 in deflection. Take into account the ATV being designed has four wheels and that it can be assumed that the force seen in the springs is distributed evenly.

Using your knowledge of the MSET Springs Resistance experiment and apply the following scale factors to determine a desirable spring for the suspension system:

Load: 1 lb = 100 lbs
Deflection: 1 in= 1 in

Use the provided springs to calculate spring constants of the individual springs and then formulate a system of springs, both in series and parallel to find an equivalent spring constant.

Calculate the following:

1. Spring constant of each spring
2. Equations used to calculate spring constant
3. Formulation of equivalent spring constant formula for proposed design
4. Spring Equivalent for proposed design and tested result from MSET

Your proposal/explanation will be evaluated using the mini-project rubric.

Teacher Solution Key – Springs in Tension and Series/Parallel Spring Stiffness

Yamaha Motor Company has assigned its design team the task of creating a suspension system for a new ATV. The goal is to find a suspension system that is firm enough to avoid a bumpy ride when used on the road. This new system should only see a deflection of 7 inches when exposed to a maximum load of 6000 pounds. Because the ATV is four wheels and the force seen in the springs will be evenly distributed, 1500 pounds each spring. Due to the fact that the four spring systems will be in parallel, each stiffness (denoted by k) can be directly added, as shown in equation 1:

(Eq. 1) $k_{parallel} = k_1 + k_2$

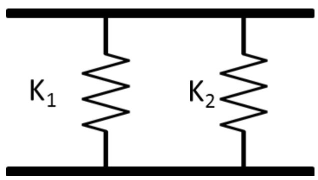

Figure 28: Springs in Parallel

When two springs are in series, the resultant stiffness is as follows:

(Eq. 2) $k_{series} = \frac{(k_1 * k_2)}{(k_1 + k_2)}$

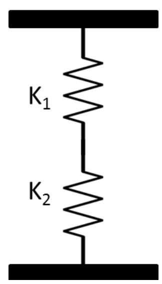

Figure 29: Springs in Series

Relating the applied load to the spring constant and deflection is shown in the following equation:

(Eq. 3)

a. $F = k * x,$

Where F is the load applied and x is the deflection seen in the spring. This formula can be written in terms of a derivative showing how the slope of the force versus deflection will be the resulting spring constant, k.

(Eq. 3)

b. $k = \frac{F}{x}$ or $k = \frac{dF}{dx} = \frac{F_2 - F_1}{x_2 - x_1}$

Using equation 3b the minimum k value was determined to be 857.14 lb/in for the entire ATV and 214.28 lb/in per wheel. The design team was limited to two separate springs, each with its own spring stiffness. The MSET was used to determine the stiffness of each spring type by performing the “Springs in Tension” experiment on each spring. Pictured in Figure 30, force was plotted with respect to deflection.

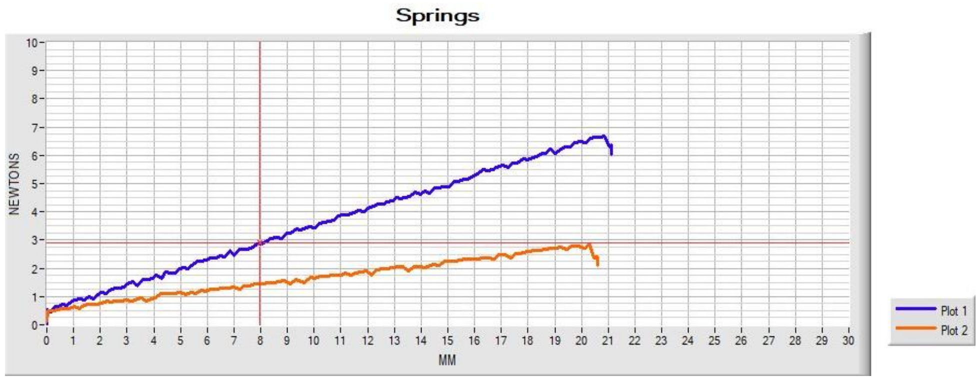

Figure 30: Spring 1 and Spring 2 Load/Deflection Plots

Each of these plots can be represented by a best fit line of their fairly linear portions, shown in Figure 31 and Figure 32. The slope of each of these lines represents individual spring stiffness, as shown by equation 3b. The measured stiffness of spring 1 was 3.0 N/cm (1.713 lb/in). Using the same process for spring 2, the slope displayed a stiffness of 1.117 N/cm (0.6378 lb/in). Using the conversion factor given in the instructions the spring stiffness calculated for each spring are as follows:

Spring ID	Tested Stiffness (N/cm)	Tested Stiffness (lb/in)	Scaled Stiffness (lb/in)
Spring 1	3.000	1.7130	171.3
Spring 2	1.117	0.6378	63.78

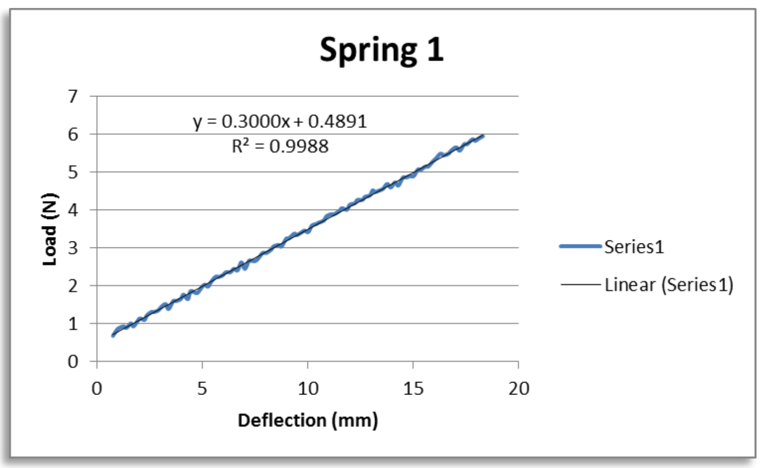

Figure 31: Spring 1 Load/Deflection Plot Best Fit Line

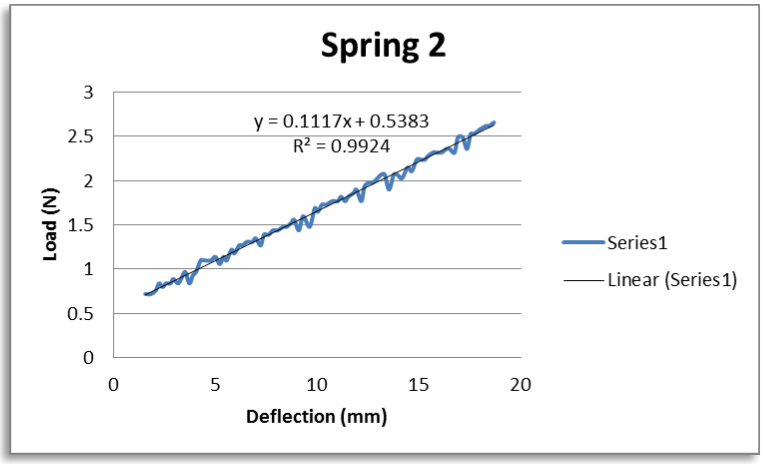

Figure 32: Spring 2 Load/Deflection Plot Best Fit Line

Because neither spring's stiffness is equal to or greater than the target stiffness of 214.28 lb/in, a combined spring system must be created using multiple springs. The deflection should be no greater than 7 inches, so the target stiffness of 214.28 lb/in will be used as a lower boundary. The optimum spring stiffness should be within 5% of that value, so 224.99 lb/in will be considered the upper boundary. The proposed system should fall into that range using as few springs as possible.
Considering every spring and combination of two springs in series, using equation 2, the resulting k values are as follows:

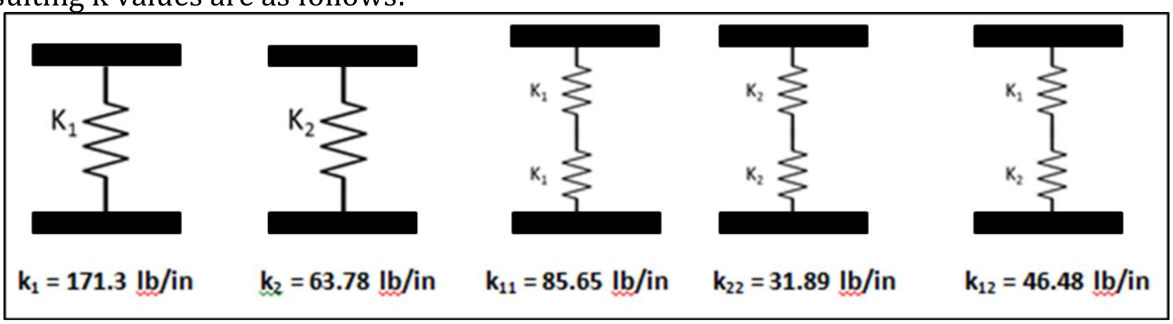

Figure 33: Stiffness of Individual Springs and Two-Spring Series

It was chosen that using k_{12} and k_1 in parallel would result in an optimal spring design.
$k_{12} + k_1 = 217.78\ lb/in$
The spring system that was designed for the Yamaha ATV was stiffer than the lower bound and softer than the upper bound. Figure 34 shows that the k value is within the desired range.

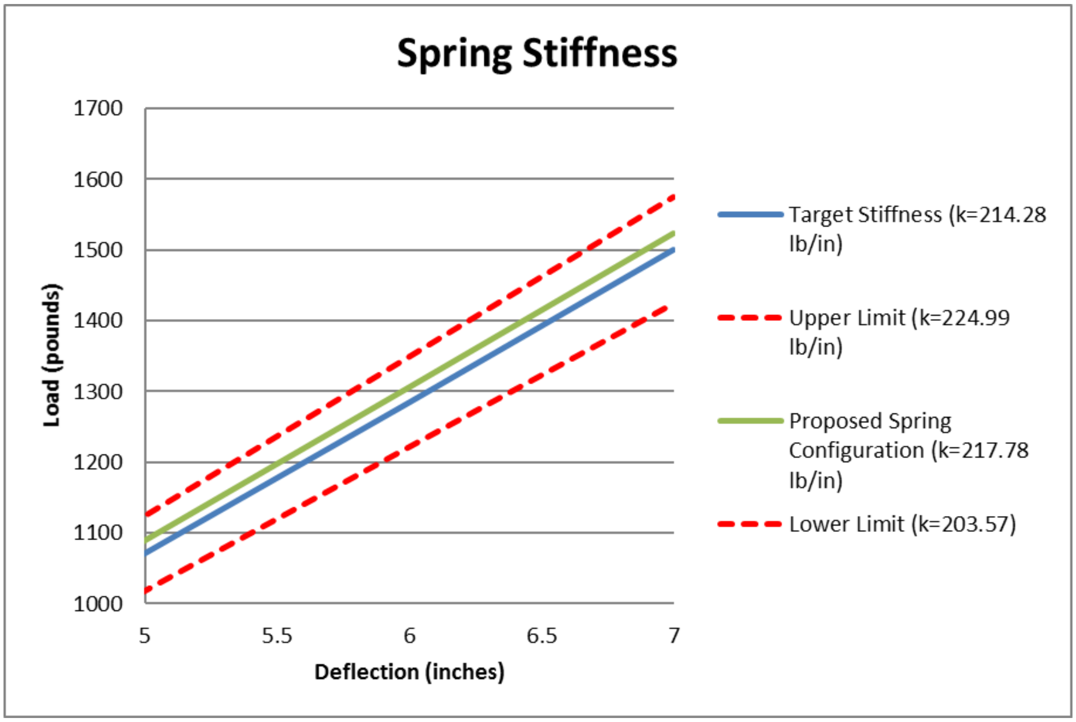

Figure 34: Spring Stiffness within Target Range

This stiffness meets the intended outcome of $214.28 < k < 224.99$, and does so using a system of only 3 springs. The total k value of the four systems in parallel is 871.12 lb/in, and at a load of 6000 pounds, a deflection of 6.89 inches would be seen in the springs of the ATV. This adequately solves the problem of the previous design being too soft. The k value, with a deviation from the desired value of only 1.63%, was well within the target range using only 3 springs. Because of this, the proposed best solution is a system at each wheel composed of a single type 1 spring in parallel with a series consisting of a type 1 and a type 2 spring, as depicted in Figure 35.

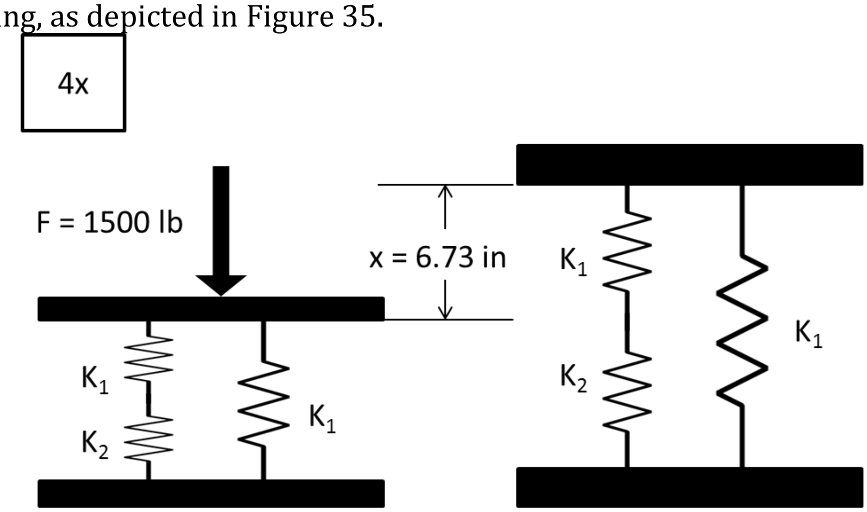

Figure 35: Proposed Solution

Inquiry-Based Mini Project Rubric - Springs in Tension and Series/Parallel Spring Stiffness

	3	2	1	0	Score
Proper Use of Equipment	Used the MSET to collect data accurately	Struggled with using the MSET and getting accurate data. Was able to use it with some assistance.	Even at the end of the experiment, struggled with the used of the MSET and could not accurately collect data using the equipment.	Didn't use the MSET	
Accuracy of Use of Terminology	Used all terms accurately including, parallel springs, spring series, spring stiffness, load, elongation, and deflection	May have used all of the terms but one or two were not used accurately.	Used some of the terms but not all of them or the terms were used but not used accurately.	Didn't use any of the terms in the explanation of the design	
Rationale for Solution	Provided a detailed rationale for the choices made in their solution. Explanation included a connection to Newton's Laws of Motion and how series and parallel spring combinations led to determination of spring constant for the proposed design.	Provided a rationale for their solution, but could only briefly connect their solution to Newton's Laws of Motion or only partially explained how series and parallel spring combinations led to determination of spring constant for the proposed design.	Provided a rationale, but their explanation was lacking connections to Newton's Laws of Motion and/or how series and parallel spring combinations led to determination of spring constant for the proposed design.	Didn't provide a rationale for their solution	
Use of Mathematical Computations	Used the given formulas to calculate spring stiffness (*K*) accurately. Calculations were used to explain how series and parallel spring combinations led to determination of spring constant for the proposed design.	May have used the given formulas to calculate spring stiffness accurately, however could not use it to explain how series/parallel spring combinations led to determination of spring constant.	Attempted to use the given formula to calculate spring stiffness, but included some miscalculations.	Did not use the given formula for calculations.	