PHYS 1P91 Experiment 08

Elastic forces: Springs

Notes

- Words in blue are links to additional reading or videos.
- Text in gray boxes are hints and things to take note of.
- Text in red boxes are important instructions or prompts that guide you to DISCUSS some of the key RESULTS and CONCEPTS learned in the lab. These prompts may not be the only items that need to be included in your report.

> **IMPORTANT: This lab requires error propagation - do not forget you MUST include your scanned error propagation pdf.**

1 Objectives

- Use the iOLab to study the concept of elastic deformation.
- Calculate the spring constant from Hooke's Law.
- Test combined physical property of springs combined in parallel or series.

2 Introduction

Elasticity is a property of materials that when an object is deformed in size or shape by an external force, it will return to it's original size or shape when that force is removed.

Springs are an interesting example of this; when when you combine elasticity with Newton's third law of balanced forces, then a spring in tension can be seen as an effective source of a pulling force for any engineering mechanism. The force required to stretch the spring is equal to the force the spring pulls back.

Hooke's Law is an empirical observation: most materials exhibit *linear* amounts of elasticity, when subjected to a reasonable amount of stress or strain. Hooke's Law is stated as

$$F = kx \tag{1}$$

where x is the *extension* of the spring beyond its normal physical length. F is the force to extend the spring that distance, and k is a parameter that makes the units work out, but in the end describes the stiffness of the spring: the larger k is, the more force it takes to stretch or compress the springs.

There are many engineering applications where the right value of k is important for the correct operation of a device, such as mechanical clocks, or the clutch in the transmission of your car.

In this lab, you'll learn some basics of engineering and determine the value of k from the materials at hand.

3 Procedure

For this experiment you will need the following items from the 1P91 accessory kit:

- paperclips
- two matched springs (do not use the singular spring from the iOLab original kit)

3.1 Prepare the iOLab.

First we need to calibrate the `Force gauge` sensor in the +y direction as we have done before (*i.e.* only the mass hanging portion). Calibrate using the **eyebolt** and change the number in the `Calibrate to the weight of` box to -100g instead of the usual 100g.

After calibrating with the +y-axis pointed up, place the iOLab at rest on its wheels on a flat surface, and have nothing touching the eyebolt on the `Force gauge` sensor. If you take 3 seconds of data with the device like this you will notice the force is non-zero. This means we need to calibrate the `Force gauge` sensor for this setup. Take another 3 seconds of data with the wheels on the flat surface and then hit `set zero`.

We will use the iOLab's force sensor to measure the spring's tension force, so attach the eye bolt to the sensor as a place to attach the spring. However, the extension of the spring would be hard to measure with a tape measure when you are probably using one or both hands to extend the spring. Luckily the iOLab has another way to measure distance – its wheel sensor.

Take one paperclip and bend open it enough to create two places to attach the springs through their hook. Then, loop the paperclip through the eye bolt such as in Figure 1. Continue to bend the paperclip a bit so that the two ends where the springs will attach are about even and the same distance from the iOLab – it doesn't need to be exact.

Attach one spring and pull on it. Make sure the paperclip doesn't slip or move about with just one spring. Attach the other spring to the other connection point.

One option for the other ends of the springs is to slip their free ends onto your screwdriver. Hold them there with your finger. In Figure 1, the set-up is being tested by hanging the iOLab from the springs. Another option is to make a matching paperclip-spring harness, as shown in Figure 2. This paperclip could be held by your hand.

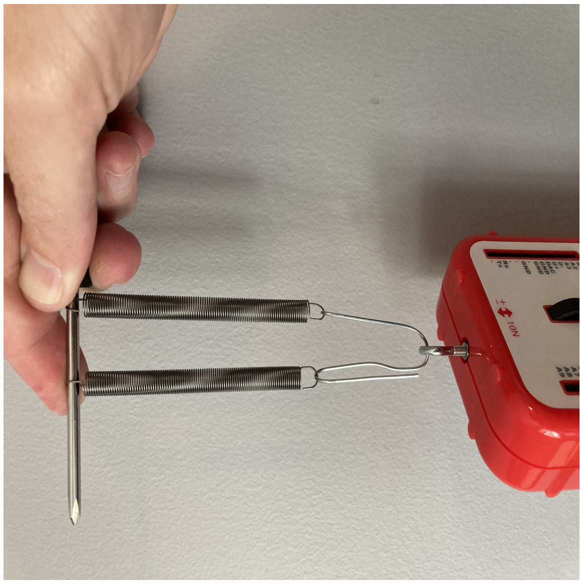

Figure 1: Example of how to connect the iOLab to two springs using a paperclip. The other end is attached to the screwdriver held in your hand.

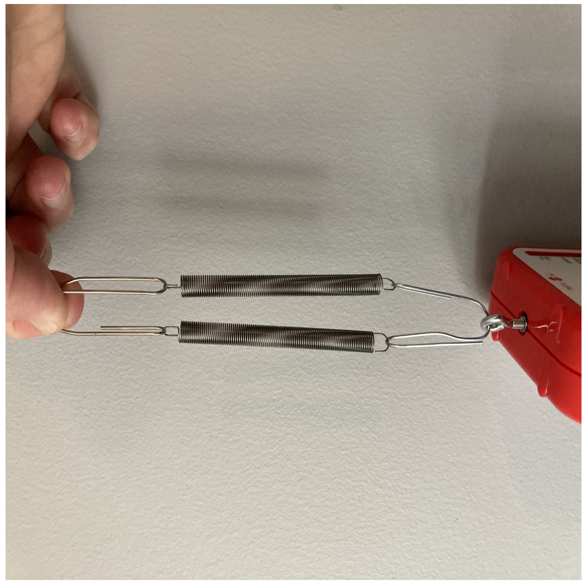

Figure 2: Example of how to connect the iOLab to two springs using a paperclip. The other end uses another bent paperclip that can be held with the fingers.

Place the iOLab on a flat surface, wheels side down. The paperclip/springs/screwdriver system may be a bit hard to hold, but if you keep the screwdriver parallel to the surface it should work. Pull on the iOLab with your free hand to extend the springs, and make sure they seem to extend equally.

Once you are happy with your set-up, take a picture for your lab report.

4 Take data

4.1 A single spring

In this part, we will find the spring constant of just one spring. **Remove one of the springs from the paperclip/ screwdriver harness, and set it aside**.

With one hand firmly holding the spring harness, set the iOLab on its wheels upon a horizontal, flat surface. Pull back on the iOLab with your other hand until it barely lifts the spring up off the surface – not so much that the springs would pull it rolling back to your hand. This is zero spring force and zero extension of the spring. It may seem inexact, and we will test whether it is in our analysis.

Include a free-body diagram of the system and forces acting on it.

Set the software to record both the `Force` and `Wheel` sensors. You may wish to collect anywhere between 20 seconds to several minutes of data, depending on how long you feel is needed.

During the data collection, roll the iOLab away from your hand holding the spring harness, stretching the spring by a few centimeters. Pause for $\sim$1 second, then repeat. Hold the spring harness very firmly – don't let that hand move!

When you reach between 20$\sim$30 centimeters, in the time remaining, randomly shorten the spring, pause, then shorten again. Each *pause* allows us to collect data on the force at several positions. You should collect about 10-12 positions in all.

> I found that as the force got higher, I tended to accidentally lift the iOLab to pull harder. Of course the wheel was not rolling then, and it was no longer measuring the distance.

Save both the force sensor and wheel sensor data to separate files.

Save pictures of both the force-time and wheel position-time graphs for your report.

Your data may look something like the red curve in Figure 3. As you extend the spring, the force increases (in tension, so increasing negative value). Each time you paused, a short plateau appears where the force at that spring extension is constant. You want to record the absolute value of the average value of the data from that region, $|\bar{F}|$. Each pause - each plateau - is a data point in the equation $F = kx$.

Zoom into each plateau, including at the very beginning when you were not stretching the spring, as shown in highlighted region A of Figure 3. Record the average force and the standard deviation.

> The blue highlighted regions in Figure 3 show just some of the things that might find in your data. Remember, rather than perfection, go with what you have!
>
> - A typical plateau is shown in highlight **A**.

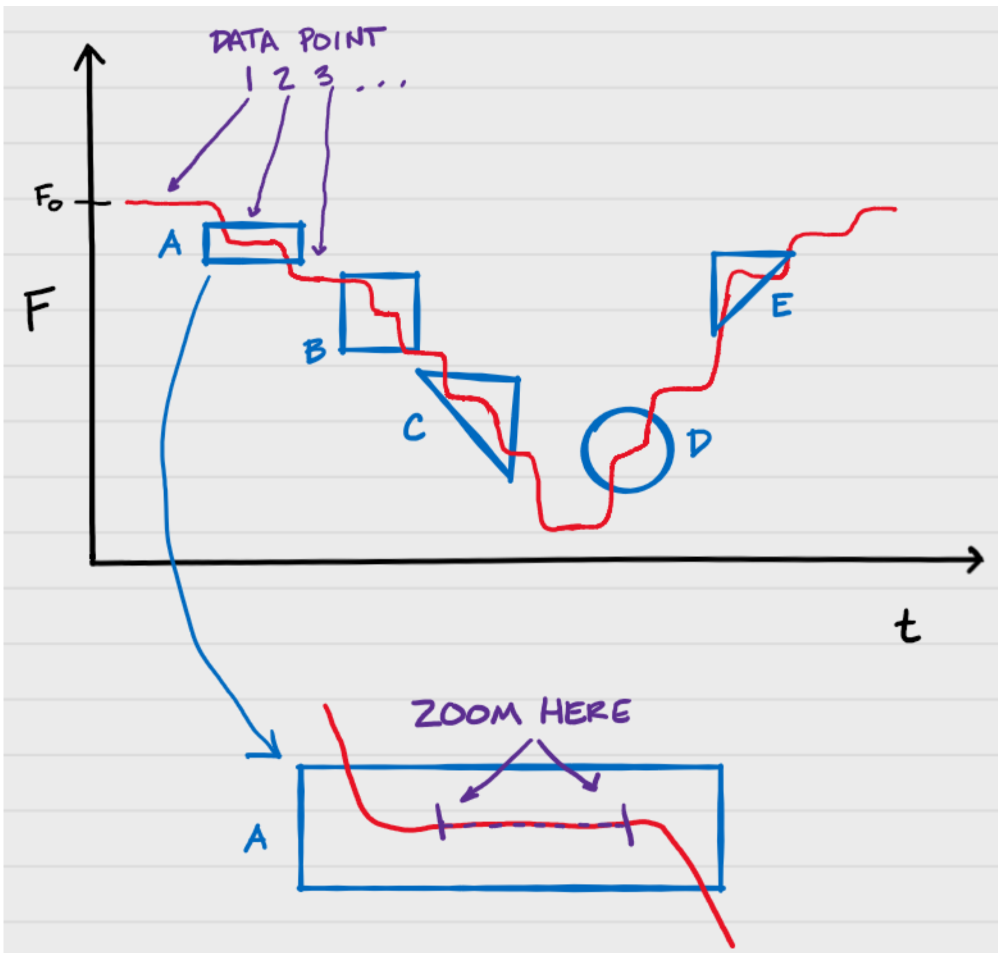

Figure 3: Example force-time graph in red. The average of the data in each plateau is a data point. The areas highlighted in blue are described in the text.

> - Sometimes your pause will be rather short, like in highlight **B**. That is okay, there are still many data points in that short region, so zoom into what you have.
> - Even if the transition from one pause to the next was a little slow, like highlight **C**, zoom into the short region where the force is fairly constant and go ahead and use the reported value.
> - If the pause was unsteady, and no constant plateau really formed like in highlight **D**, you can consider skipping that point.
> - If your motion overshot, like in highlight **E**, use only as much of the constant plateau as you can.

Switch to graph the wheel position data. It should look like Figure 3 flipped upside down. You were pulling in the $+y$-direction, and so recorded positive values of the displacement. At each plateau, you find the distance traveled, and thus the spring's extension x.

> The position data should start very close to 0 m.

> For each force data point recorded above, also record the spring extension in the same way.
>
> **REMINDER** we always assume the largest experimental error. Even though iOLab online might give very small error for the position sensor the position sensor only has a *precision* of 1mm. Use this hint to determine what the correct rounding and error should be for these values.

Once you have recorded 10∼12 data points this way, find the actual force at each extension. The first plateau is the calibration point F_0, so subtract that number from each average force.

> For your error derivation sheet you only need to show one of the equations for the calibrated forces! However you must calculate the uncertainty for all of them using the same method.

Clear the data window of any recorded data. Type into the data window the force F as the `y`-axis data, and the extension x as the `x`-axis data, and fit to the equation `y=Ax`.

> If your line of best fit does not look like it has the correct slope feel free to add a constant B to it to help your fit. Make sure to include the units of B, its uncertainty, what it represents physically, and what the value should be.

Report the value of the spring constant k and it's uncertainty, and provide a properly-labelled graph of your fit.

4.2 Two springs together

You can manipulate the effective spring constant of a mechanical device by changing the material of the spring, by changing its physical dimensions, or by adding a second spring. When adding second spring, even if it were identical to the first, some surprising things happen to the overall mechanical properties of the combination.

There are two ways of adding a second spring; in series or in parallel. In series, both springs experience the same stress (force/area) but share the deformation. Since the effective length is doubled, the effective spring constant is cut in half (equation 5.37).

In parallel, the springs may deform the same, but share the stress between them. Since the area the force is spread over doubles, the effective spring constant is doubled too (equation 5.37).

The new spring constant of the two systems are

$$\frac{1}{k_{\text{eff}}} = \frac{1}{k_1} + \frac{1}{k_2} \text{ for series} \tag{2}$$

$$k_{\text{eff}} = k_1 + k_2 \text{ for parallel} \tag{3}$$

Because you are using two matched springs, $k_1 = k_2$, which you have just measured. Think about how that changes k_{eff}.

Since the springs are the same, $k_1 = k_2$, we can calculate the effective spring constants k_{eff} from equations 2 and 3 in terms of k_1 and a constant only. State these two equations in your report in the form $k_{eff} = n * k_1$ where n is a constant

Using the experimental value and uncertainty of k_1 from Section 4.1 determine what the experimental k_{eff}'s should be. Make sure to include uncertainty and include these values in your lab report.

Re-attach the second spring to your harness in parallel as described in Figures 1 and 2.

Repeat the experiment from previous section, and find the effective spring constant of the two springs in parallel.

What is the percent difference between the expected and measured spring constant, assuming both springs had the same spring constant, $k_1 = k_2$? Are the values within experimental error?

Attach the second spring in series to the first spring, instead of in parallel.

Repeat the experiment from the previous section, and find the effective spring constant of two springs in parallel.

What is the percent difference between the expected and measured spring constant, assuming both springs had the same spring constant, $k_1 = k_2$. Are the values within experimental error?

Could you *feel* the difference in the spring stiffness between the two combinations?

BONUS: use your knowledge of springs

There were only two springs of the same spring constant k in your iOLab kit. However, there are many other multi-spring systems that can be made using combinations of series and parallel setups. Create a diagram of a system with multiple springs (all with the SAME spring constant k) connected in series and/or parallel which results in an effective spring constant equal to k, the spring constant for any one of the springs alone.

Include this diagram in your report. NOTE: there are MANY ways to create this circuit. To keep things simple, let's say you cannot use more than 10 springs to create your theoretical setup.

Finishing Up

Now that you have completed the lab, be sure you filled out all portions of the data tables (templates found on Sakai), include figures, and develop a robust discussion using prompts found throughout the manual.
Ensure to give yourself enough time to complete the report and to hand it in by the due date as late lab reports will not be accepted! If you have any questions please attend a live lab session to get help from one of the course lab demonstrators, or email Phys1P91@brocku.ca.