Lab Report 3
– Hooke's Law –

XUAN MAI TRAN

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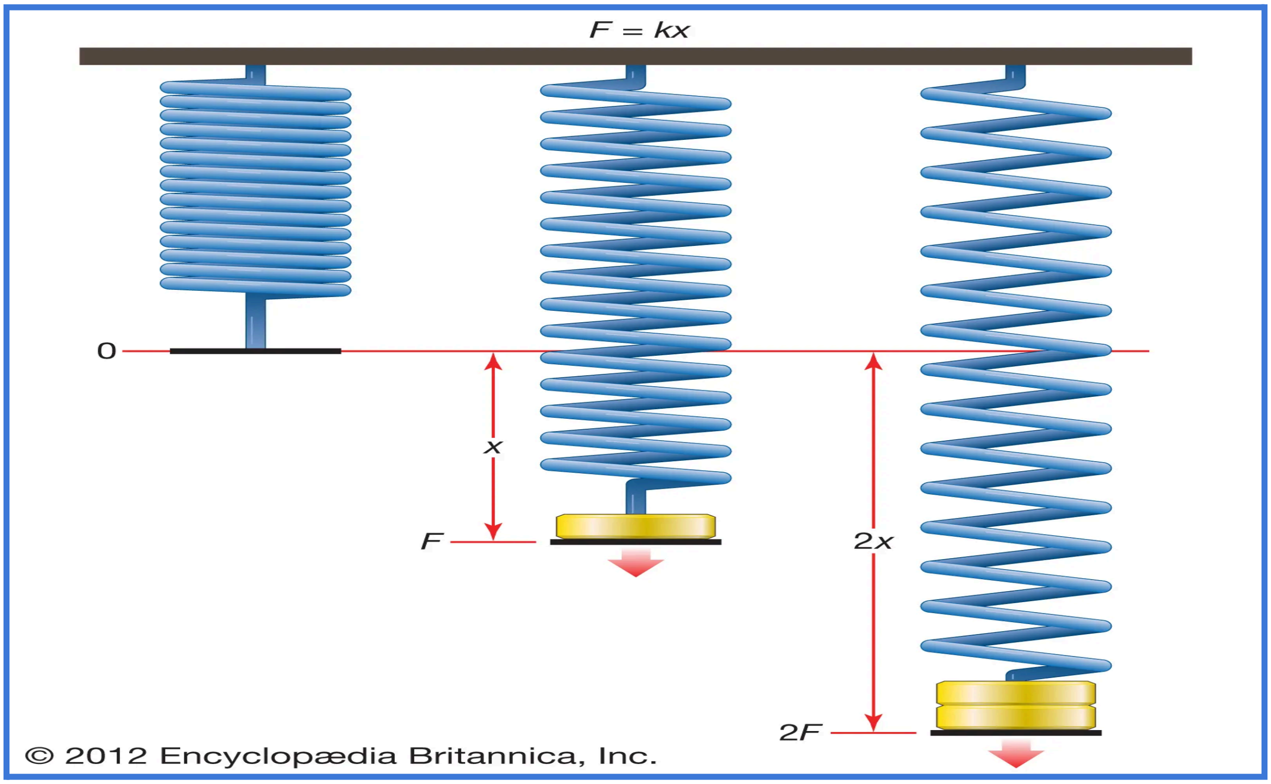
DR. JOSEPH BARCHAS



Objectives

To confirm Hooke's Law and measure spring constants experimentally.

Equipments

The list of equipments used in this experiment is:

- Hanging Masses
- Lab Stand and Pendulum Clamp
- Springs
- Meter Stick

Theory and Equations

1. Hooke's Law

Hooke's Law indicates that the force produced by a spring is proportional to the spring's displacement from equilibrium, x:

$$\boxed{F_{spring} = -kx\hat{i} \qquad \text{units: N}}$$

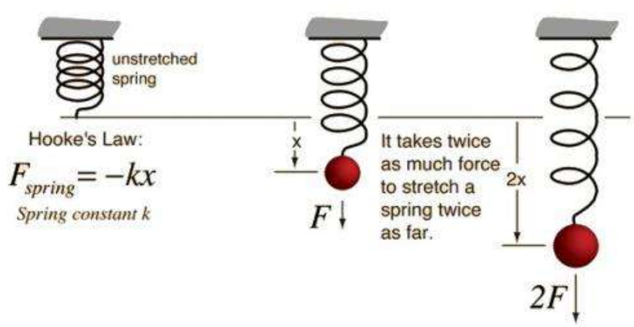


Illustration of Hooke's Law (source: Williams, 2015)

The k is the constant of proportionality, called the spring constant. It varies from spring to spring, but is constant for a given spring.

When an object with a mass (m) is attached to a spring with the spring constant k, it will oscillate with a period T. Described by:

$$T = 2\pi\sqrt{\frac{m}{k}} \qquad \text{units: s}$$

One oscillation period T is the time it takes for the mass to return to the same position and velocity.

2. Percentage Difference

As we will have 2 values for the spring constant obtained in 2 different ways.

$$\text{Percentage Difference} = \left| \frac{(Value\ 1) - (Value\ 2)}{\frac{1}{2}[\ (Value\ 1) + (Value\ 2)\ ]} \right| * 100\% \qquad \text{units: \%}$$

Summary of Procedures

First, we set up a stable surface with a laboratory stand and a spring attached to a pendulum clamp. We gently attached a suspended mass to the spring that could be stretched but not damaged. Holding the mass at rest, we measured the length of the spring with a ruler. We then moved the mass up or down to create oscillations. To measure the time, we recorded the time for 10 periods by starting a stopwatch at the same time the mass passed through the center and starting the count from 0. We counted each oscillation and stopped the stopwatch at the time the count reached 10. We repeated the process with 15 different values of the suspended masses to collect 15 data entries with different properties of spring length, period, and the corresponding hanging masses.

Data and Observations

Hanging Mass (kg)	Spring Length (m)	Time Intervals for 10 periods (s)
0.1050	0.465	12.06
0.1250	0.495	12.51
0.1450	0.542	13.15
0.1650	0.600	13.96
0.1750	0.625	14.79
0.1850	0.645	14.78
0.2050	0.725	15.58
0.1550	0.572	8.910
0.1150	0.468	12.40
0.1350	0.520	13.10
0.1950	0.675	15.17
0.1300	0.505	12.65
0.1400	0.532	13.06
0.1500	0.556	13.65
0.1600	0.580	14.11

Data Analysis

Spring Force: $F = W = mg$ with m = hanging mass and g = 9.800 m/s^2.

Period T: $T = \frac{Time\ Interval}{10}$

We also have: $T = 2\pi\sqrt{\frac{m}{k}}$ => $T^2 = \frac{4\pi^2}{k}m$

(with T is period, m is hanging mass, k is spring constant)

Sample Calculation:

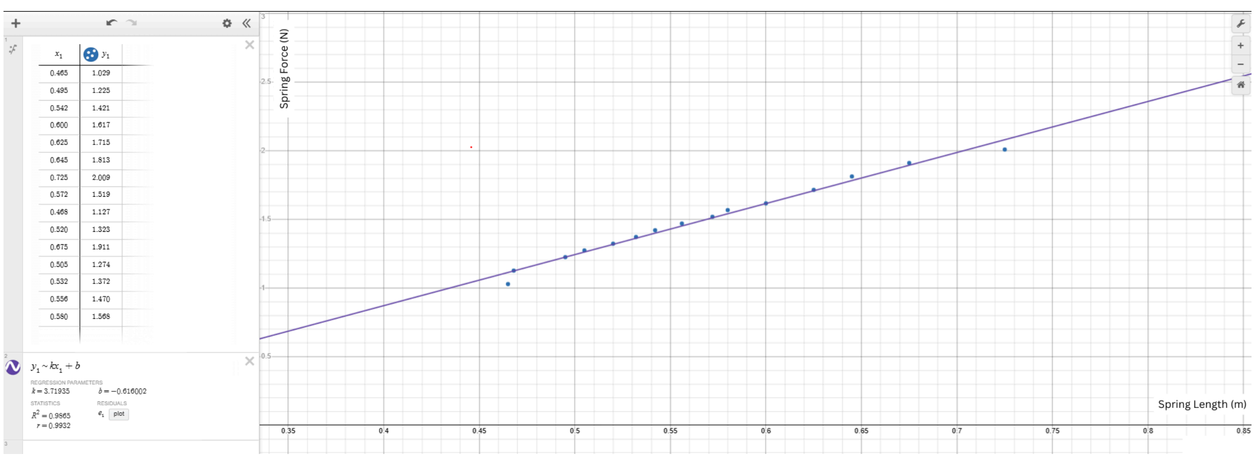
Hanging Mass = 0.1050 kg

- Spring Force: $F = mg = 0.1050\text{kg} * 9.800\text{m}/s^2 = 1.029\text{ N}$
- Period T: $T = \frac{Time\ Interval}{10} = \frac{12.06s}{10} = 1.206\text{ s}$
- Period Squared: $T^2 = (1.206s)^2 = 1.454\ s^2$

Hanging Mass (kg)	Time Intervals for 10 periods (s)	Force (N)	Period T (=Time Interval / 10 periods) (units: s)	Period Squared (T^2) (units: s^2)
0.1050	12.06	1.029	1.206	1.454
0.1250	12.51	1.225	1.251	1.565
0.1450	13.15	1.421	1.315	1.729
0.1650	13.96	1.617	1.396	1.949
0.1750	14.79	1.715	1.479	2.187
0.1850	14.78	1.813	1.478	2.184
0.2050	15.58	2.009	1.558	2.427
0.1550	8.910	1.519	0.891	0.794
0.1150	12.40	1.127	1.240	1.538
0.1350	13.10	1.323	1.310	1.716
0.1950	15.17	1.911	1.517	2.301
0.1300	12.65	1.274	1.265	1.600
0.1400	13.06	1.372	1.306	1.706
0.1500	13.65	1.470	1.365	1.863
0.1600	14.11	1.568	1.411	1.991

To find the relationship between the Spring Force and the Spring Length, we scatter plots on a graph, then find a linear function fit to the data below. The slope produced by this linear function will be equal to the spring constant. As follows Hooke's Law, the force exerted by a spring is proportional to its displacement (change in spring length) and the slope of the graph representing this proportionality is the Spring Constant.

Spring Length (m)	Spring Force (N)
0.465	1.029
0.495	1.225
0.542	1.421
0.600	1.617
0.625	1.715
0.645	1.813
0.725	2.009
0.572	1.519
0.468	1.127
0.520	1.323
0.675	1.911
0.505	1.274
0.532	1.372
0.556	1.470
0.580	1.568



From the graph above, we have the function of y (Spring Force) and x (Spring Length) as below:

$$\mathbf{y = 3.71935x - 0.6160022}$$

With **k = 3.71935**

There is another way to measure the Spring Constant that is based on the relationship between hanging mass and period time square.

As we have,

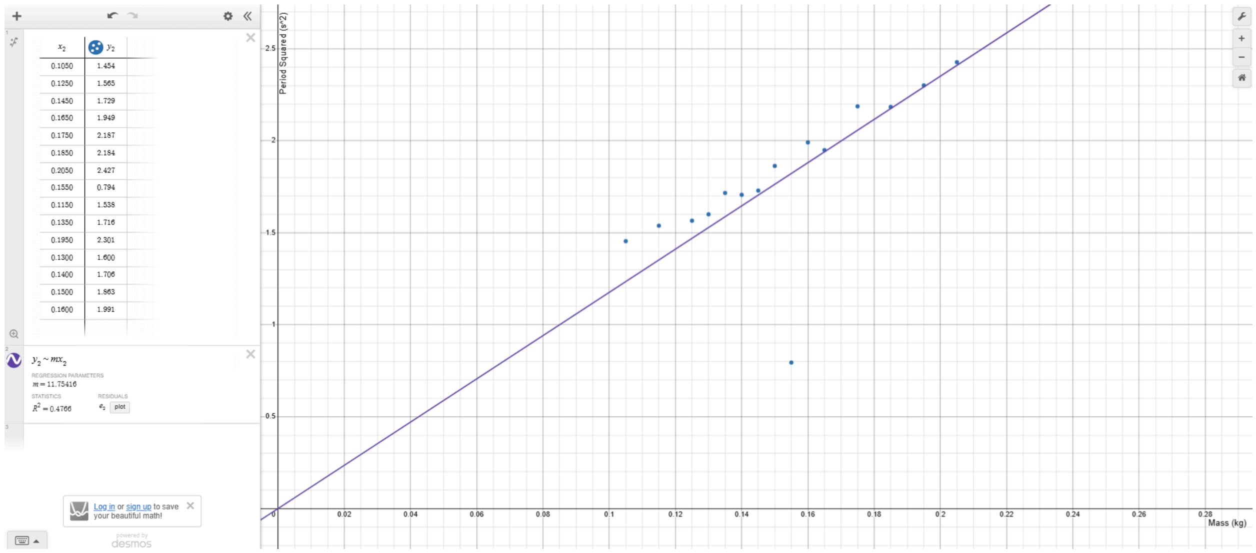
$$T^2 = \frac{4\pi^2}{k} m \quad \sim \quad y = mx \quad \text{and} \quad m = \frac{4\pi^2}{k}$$

(with y is Period Squared (units: s^2), x is hanging mass (units: kg), m is coefficient)

Hanging Mass (kg)	Period Squared (units: s^2)
0.1050	1.454
0.1250	1.565
0.1450	1.729
0.1650	1.949
0.1750	2.187
0.1850	2.184
0.2050	2.427
0.1550	0.794
0.1150	1.538
0.1350	1.716
0.1950	2.301
0.1300	1.600
0.1400	1.706
0.1500	1.863
0.1600	1.991

From the graph below, we have the coefficient m = 11.75416 of the function y = mx above (y is Period Squared, x is Hanging Mass).

As, $m = \frac{4\pi^2}{k} = 11.75416$ => $\mathbf{k} = \frac{4\pi^2}{m} = \frac{4\pi^2}{11.75416} = \mathbf{3.35868}$



Results

Based on the 2 different graphs above, we collected 2 values of Spring Constant (k).

Now we calculate their percentage difference to compare the difference between those k values.

$$\text{Percentage Difference} = \left| \frac{(Value\ 1) - (Value\ 2)}{\frac{1}{2}[\ (Value\ 1) + (Value\ 2)\ ]} \right| * 100\%$$

$$= \left| \frac{3.71935 - 3.35868}{\frac{1}{2}[\ 3.71935 + 3.35868]} \right| * 100\%$$

$$= 10.19125\ \%$$

Discussion / Conclusion

Based on the first graph above, we can see that there is a proportional relationship between Spring Length and Spring Force which is in perfect agreement with the statement of Hooke's Law. As the displacement length of the spring increases, the spring force will also increase and vice versa. That ratio is considered as the Spring Constant.

When we further check the Spring Constant using another formula in the second graph above, we can collect the Spring Constant value (k) which is only about 10% different from the k value we measured using Hooke's Law. That means that for every spring, there exists a Spring Constant that is constant and proportional to the Spring Force.

The 10% difference could be due to human error between measuring time manually with a stopwatch and measuring the 10 periods by eyes. If we can automate this process, the result will definitely become more accurate and the percentage difference may reduce.

References

Williams, M. (2015, February 16). What is Hooke's Law? Phys.org. https://phys.org/news/2015-02-law.html.