An alternative tool to explain Hooke's Law and the principle of Dynamometer: The rubber band

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(Received 23 November 2010; accepted 11 February 2011)

Abstract

In this experiment, behaviors of the elastic materials when exerted a force were interpreted through the graphs where the elasticity coefficient of the rubber band was calculated. At the same time, the reason for using an elastic material inside the dynamometer and the limits of elasticity were discussed by two different demonstrations conducted with rubber band.

Key Words: Hooke' s law, dynamometer, rubber band.

Resumen

En este experimento, los comportamientos de los materiales elásticos cuando se ejerce una fuerza fueron interpretados a través de los gráficos, donde se calculó el coeficiente de elasticidad de la goma elástica. Al mismo tiempo, la razón para el uso de un material elástico en el interior del banco y los límites de elasticidad fueron examinados por dos manifestaciones diferentes realizados con la banda de goma.

Palabras clave: Ley de Hooke, dinamómetro, banda de goma.

PACS: 01. 40. Fk, 01.40.gb, 01.50.Pa **ISSN 1870-9095**

I. INTRODUCTION

Gravity is one of the fundamental forces in the universe. We know that when an object is subjected to external forces,– such as gravity- its size or shape, or both change depending on its atomic bonding structure or elasticity. For example, a spring undergoes change in size and shape through compression or extension. You may experience such kind of change when you jump into bed as the bedsprings are compressed by your weight exerted on it [1]. The thing to be highlihted in this example is that the compression of the bedsprings is directly proportional to the the weight applied showing the Hook's Law. In most of the basic physics laboratories, generally the springs are used for the purpose of showing especially the Hook's Law and modeling the elastic materials [2, 3]. In this experiment, we would like to propose "the rubber band" that can be used for the Hook's Law and some spring based experiments [4, 5] we used rubber band because it is extremely flexible as it can be stretched up to a few hundred per cent without breaking and also it completely recovers and contracts to its original length after releasing the deforming force as stated by Euler [6, p. 58]. Morever it is simple, cheap and can easily be obtained. This experiment will discuss the discovery of Hook's Law, the basic principle of dynamometer, the properties of elastic materials and the limits of elasticity at the primary and secondary education level.

II. BASIC PRINCIPLE

The elastic materials can be outstretched in dimension by exerting force on and they can return back to their original positions when that force is removed.

There is a linear relationship between the tensile force exerted on the material and the amount of stretching according to the Hook's Law. This relation in one dimension can be shown by the following equation:

$$F = k\Delta x\,. \qquad (1)$$

In the above equation, k and Δx stand for the elasticity coefficient and the amount of extension in length of the elastic material when the force is exerted on compared to the length when no force is exerted on respectively.

III. APPARATUS AND EXPERIMENT

The tools required for the experiment are a wooden ruler of 30cm, 3 identical rubber bands which are standard in type and length, a paper clip, 5 different mass up to 150gr (the measurements done with the rubber band used in this experiment gave fine results up to the mass of 150gr), a pan (20gr), a fixed base, two iron rods and an affixing.

The system shown in Figure 1 was set up by passing a rubber band on the paper clip. The pan can be hanged on the rubber band in order to put the masses easily. After passing the rubber band on the paper clip, record the initial lentgh of the rubber band (x_0). Afterwards, switch the mass of 30gr (with total mass of 50gr including the mass of the pan to the rubber band. This time, the rubber band starts to extend until the restoring force gets equal to the gravitational force exerting on the mass. Record the amount of extension in length (x). In this situation, the first equation can be written as the following:

$$Mg = k\Delta x\,, \tag{2}$$

"g" ($g = 9,8m/s^2$) is the free-fall acceleration.

FIGURE 1. Experimental setup.

When the other masses (50g, 70g, 90g and 110g respectively including the mass of the pan) were switched respectively, total mass and the gravitational force increase leading an increase in the amount of extension in length. This situation is shown in Table I clearly.

The experiment is repeated orderly with the same masses but this time putting over the two rubber bands respectively on the initial rubber band (so as to increase the thickness of the rubber band gradually) for switching the masses. By this way, as the number or the thickness of the rubber increase the amount of extension in length decrease for the same mass. This situation can be seen when the Tables I, II and III were compared to each other.

TABLE I. The switched masses when there is only one rubber band (*M*), the corresponding gravitational forces to these masses *G=mg*, the length of the rubber band (*x*) and the amount of extension in length $\Delta x = x - x_0$.

M (kg)	*G (N)*	$x_0(m)$	*x (m)*	Δx *(m)*
0,05	0,05.g	0,07	0,084	0,014
0,07	0,07.g	0,07	0,088	0,018
0,09	0,09.g	0,07	0,092	0,022
0,11	0,11.g	0,07	0,096	0,026
0,13	0,13.g	0,07	0,100	0,030

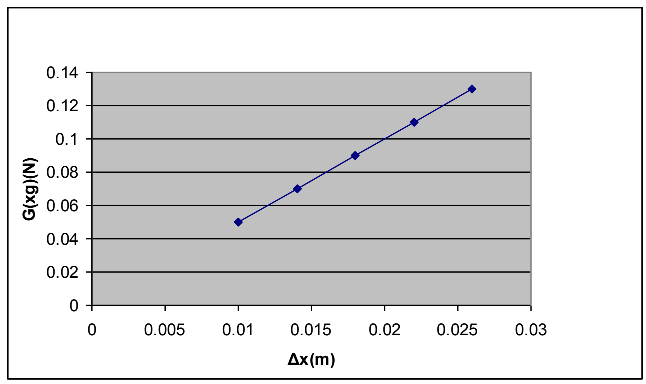

FIGURE 2. The amount of extension of rubber band corresponding to the gravitational force exerted on only one rubber band.

$$k = \frac{0,13g - 0,05g}{0,030 - 0,014} = \frac{0,8.9,8}{0,016} = 490 \text{ N/m.} \tag{3}$$

TABLE II. The switched masses when there are two rubber bands (*M*), the corresponding gravitational forces to these masses *G=mg*, the length of the rubber band (*x*) and the amount of extension in length $\Delta x = x - x_0$.

M (kg)	*G (N)*	$x_0(m)$	*x (m)*	Δx *(m)*
0,05	0,05.g	0,07	0,077	0,007
0,07	0,07.g	0,07	0,079	0,009
0,09	0,09.g	0,07	0,081	0,011
0,11	0,11.g	0,07	0,083	0,013
0,13	0,13.g	0,07	0,085	0,015

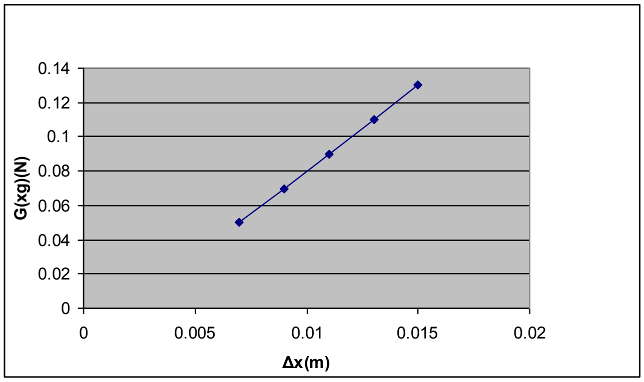

FIGURE 3. The amount of extension of rubber band corresponding to the gravitational force exerted on two rubber bands connected in parallel.

$$k=\frac{0,13g-0,05g}{0,015-0,007}=\frac{0,8.9,8}{0,008}=980 \text{ N/m.} \qquad (4)$$

TABLE III. The switched masses when there are three rubber bands (*M*), the corresponding gravitational forces to these masses *G=mg*, the length of the rubber band (*x*) and the amount of extension in length $\Delta x = x - x_0$.

M (kg)	*G (N)*	$x_0(m)$	*x (m)*	Δx *(m)*
0,05	*0,05.g*	*0,07*	*0,075*	*0,005*
0,07	*0,07.g*	*0,07*	*0,076*	*0,006*
0,09	*0,09.g*	*0,07*	*0,077*	*0,007*
0,11	*0,11.g*	*0,07*	*0,079*	*0,009*
0,13	*0,13.g*	*0,07*	*0,080*	*0,010*

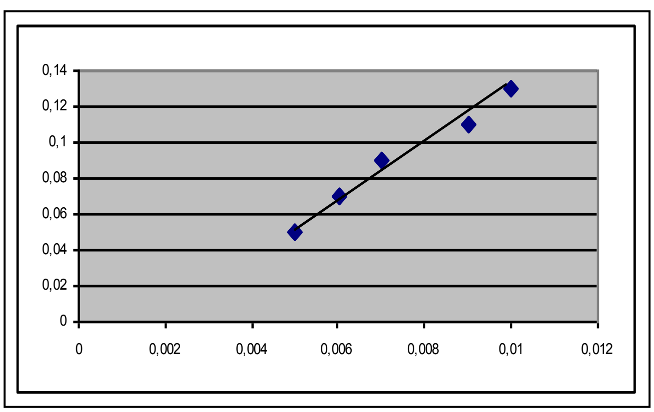

FIGURE 4. The amount of extension of rubber band corresponding to the gravitational force exerted on three rubber bands connected in parallel.

As seen in the last graph, the data taken from 3 rubber bands together are in the linear line. This graph is approximately linear. However, as the number of rubber bands increases their extension length decreases by using the same masses is the reason for this situation that reduces the precision of the measurement.

In this case, the measurements should be more sensitive by using more precise measurement tools such as Verrnier caliper and micrometer.

IV.SUGGESTED ANALYSIS AND DEMONSTRATIONS

The students can draw different graphs by using the above data and discuss the results. The students are asked to calculate the gravitational force and the extension amount of the rubber band in each system; and also draw the graph of the extension amount of the rubber band depending on the gravitational force. The graphs drawn depending on the data in Tables I, II and III were shown in Figures 1, 2 and 3 respectively. These graphs are almost linear and in consistent with the equation 1. The students are also asked to calculate the coefficient of elasticity for each system by using these graphs. These coefficients which can easily be calculated from the inclination of the graphs were given under the graphs.

The students are asked to show by drawing graphs that what kind of relation exists between the number of parallel connected rubber bands (the thickness) and the extension amount. This graph can easily be drawn by considering the extension length in the tables for any mass.

At the end of this experiment, the students are asked to compare the weights of various masses switched on 10cm long sewing yarn and 2 identical rubber bands (Figure 5). In this way, depending on their daily experiences, the students are able to compare the weights of two different masses by means of comparing the extension amount in elastic materials. However, they are not able to interpret about the mass switched on the sewing yarn, since the sewing yarn can not extend in observable manner. At the end of this demonstration, why an elastic material is used inside the dynamometers is discussed.

FIGURE 5. Experimental setup.

Another demonstration may take place by switching a 1000gr mass on a single rubber band that will break off it (Warning: avoid from the rubber band that probably will dash out). By the end of this demonstration, the limits of the elasticity of the elastic matter may be discussed. At that moment, the students are asked about how the system should be changed in order to measure the weight of this mass. In here, the students probably think by using the results of the previous experiment that more rubber bands should be added to that single one or the thickness of the rubber band and therefore the coefficient of elasticity should be increased.

V. CONCLUSION

As a result, the extension amount of the elastic materials increases as the force exerted on them increases, the extension amount decreases as the thickness (coefficient of elasticity) of the material increases.

Parallel connection of the elastic materials would increase the coefficient of elasticity. Elastic materials have an elasticity limit and exceeding this limit will affect the elastic properties of matter.

This experiment is designed to help students improve various skills. These are measuring, tabulating, drawing graphs, discovering through thinking on Hook's Law, establishing cause-effect relationship by considering the elastic properties of the materials used in dynamometers, discussing on the limit cases of elasticity and deformation and etc. This experiment can easily be set up by using the materials which can easily be obtained. Therefore, this experiment can be used in science and physics laboratories in primary and secondary levels.

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