Design and Fabrication of a Spring Constant Testing Machine and Determination of Spring Constant of a Compression Spring

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Abstract: The main objective of this project is to determine the stiffness which is commonly known as spring constant of a compression spring under various load. The kit which has been built into a machine to stretch or compress test springs, while measuring load and displacement is called spring testing kit. It tests springs and finds their properties – good for mechanical workshops use. It includes a set of different springs to compare spring rates and effect of different spring sizes. It has wide range and variety of experiments. Easy-to-use, compact instrument that fits on a small bench or desktop and as a spring force constant determination as a learning tool for graphing and modeling. Compression of a spring in a spring constant testing machine is an example of a loading that can be treated as a combination of a direct shear load and a torsional load. This project is just a prototype which can be improved for implementation in industrial work.

Keywords: **Spring testing kit, hook's law, stiffness, shear stress, Wahl factor.**

I.   INTRODUCTION

Spring testing kit is an instrument that builds into a machine to stretch or compress test springs, while measuring load and displacement. The kit includes a spring for tensile tests and a different spring for compression tests. A spring is an elastic object used to store mechanical energy. Springs are usually made out of spring steel. Small springs can be wound from pre-hardened stock, while larger ones are made from annealed steel and hardened after fabrication. Some non-ferrous metals are also used including phosphor bronze and titanium for parts requiring corrosion resistance and beryllium copper for springs carrying electrical current (because of its low electrical resistance).

When a spring is compressed or stretched, the force it exerts is proportional to its change in length. The rate or spring constant of a spring is the change in the force it exerts, divided by the change in deflection of the spring. That is, it is the gradient of the force versus deflection curve. An extension or compression spring has units of force divided by distance, for example lbf/in or N/m. Torsion springs have units of force multiplied by distance divided by angle, such as $N \cdot m/rad$ or $ft \cdot lbf/degree$. The inverse of spring rate is compliance that is: if a spring has a rate of $10 \, N/mm$, it has pliance of $0.1 \, mm/N$. The stiffness (or rate) of springs in parallel is additive, as is the compliance of springs in series.

Depending on the design and required operating environment, any material can be used to construct a spring, so long as the material has the required combination of rigidity and elasticity: technically, a wooden bow is a form of spring.

Compression of a helical spring is an example of a loading that can be treated as a combination of a direct shear load and a torsion load. The relationship between the load and deflection of the spring is referred to as the spring constant, with units of load per deflection. With load plotted along the Y-axis and deformation plotted along the X-axis, the spring constant is determined as the slope of the straight line.

Various research works were done and also many experiments were conducted for the determination of spring constant. A method for determining the spring constant of cantilevers for atomic force microscopy was conducted by [1]. Experiment regarding effect of spring stiffness to check the suspension capability as shock absorber in a bus was carried out by [2]. There are springs with controllable stiffness and test was done on controllable stiffness by [3]. Design and manufacturing of hydraulic spring stiffness testing machine was done by [4]. Variable stiffness coil spring for vehicle was optimized, designed and calculated by [5]. Further researches were also conducted on the determination of spring constant. Determination of spring constant as a learning tool for graphing and modeling was done by [6]. A simplified dynamic model for constant force compression spring was developed by [7]. The spring constant testing kit which we developed in this experiment will be able to determine the value of stiffness for spring. Calibration of torsional spring constants was compared by different methods by using torsional photo detector. [8]. Research were performed for design, analysis and optimization of leaf spring where spring stiffness was also calculated [9]. Spring constant for helical spring was found by finite element method and abacus script [10].

II.   MATERIAL AND METHODOLOGY

At first assemble the spring tester on a task frame (MF, separately). The kit includes a spring for tensile tests and a different spring for compression tests. Then apply a compressive or tensile force to the spring by turning an adjustment screw. A load cell (available separately) shows the force applied to the spring. By moving freely with the load cell, scales behind the spring directly measure the spring extension or compression. From the value of load, displacement we can easily measure the spring constant using Hooke`s Law.

A complete list of essential equipment is given below:

A.   Spring

The test includes a compression spring.

B.   Frame

High quality, specially made frames that provides a sturdy base to set up experiments. There are two frames. The larger upright frame

comes with feet and clamps. The feet allow the frame to stand on a workbench or table.

The mini frame shown in Fig.1 is for smaller and more compact experiments.

Fig.1 Mini frame

C. Load Cell (LC)

Load cell Fig.2 is the method of choice for weighing applications. An easy-to read scale that measure force (load).

Fig.2 Load cell

D. Scale

By moving freely with the load cell, scale behind the spring directly measures the spring extension or compression.

III. COMPLETE MODEL OF SPRING TESTING KIT

After assembling the load cell, spring, scale and mini frame we will get the complete model of spring testing kit. The complete model of spring testing kit is shown in Fig.3.
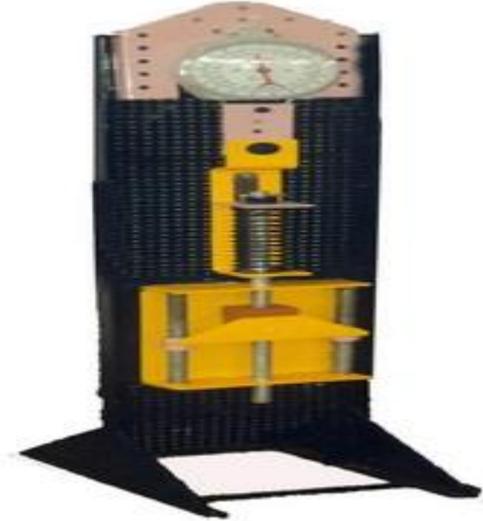

Fig.3 Spring Testing Kit

IV. EXPERIMENT AND ANALYSIS

If a weight, $W = mg$, is applied on an ordinary spring, causing it to stretch a distance x, then an equal and opposite force, F, is created in the spring which opposes the pull of the weight. If W is not so large as to permanently distort the spring, then this force, F, will restore the spring to its original length after the load is removed. The magnitude of this restoring force is directly proportional to the stretch; this relationship for elastic behavior is known as Hooke's law and is described by

$$F = kx \qquad (eq.1)$$

Where k is the constant of proportionality called the spring constant. The spring's restoring force acts in the opposite direction to its elongation, denoted by the negative sign. For a system such as the spring's compression, $(x - x_0)$, is dependent upon the spring constant, k, and the weight of a mass, mg, which compress the spring. If the system of forces is in equilibrium (i.e., it has no relative acceleration), then the sum of the forces down (the weight) is equal and opposite to the sum of the forces acting upward (the restoring force of the spring), or

$$mg = k(x - x_0) \qquad (eq.2)$$

Comparing equation 2 with the form for the equation of a straight line $(y = mx + b)$, we can see that if we plot the force produced by different masses (mg) as a function of the displacement from equilibrium $(x - x_0)$, the data should be linear and the slope of the line will be equal to the spring constant, k, whose standard metric units are N/m.

The maximum stress in the wire may be computed by superposition of the shear stress is given by the equation 3.

$$T = {}^{8WD}\!/_{(\pi d^3 \times F)} \qquad (eq.3)$$

Here, $W = (4C - 1)/(4C - 4) + 0.615/C$ is the Wahl factor of a compression spring.

V.   PROCEDURE

1. Firstly, place a spring on the angled plate bar.
2. Attach a mass hanger directly to the bottom of the spring and record the position of the bottom of the mass relative to a meter stick.
3. Add masses to the spring and record the position of the bottom of the mass hanger.
4. A load cell shows the force applied to the spring. By moving freely with the load cell, scale behind spring directly measures the spring compression. And thus by getting the load and displacement we can measure spring constant of the compression spring.
5. Repeat for other masses.

VI.   DATA COLLECTION

In this experiment we determine the spring constant of compression spring by using three springs. Here we use Hook's law to determine the spring constant. We make three experiments and there is some error in every step.

Sample 1:
$L_{free} = 8\ in; D = 2.1\ in; d = 5.4\ mm;$
$L_{wire} = 78.9\ in; \rho = 7500\ kg/m^3; M = 0.344\ kg;$
$C = D/d = 9.9$

Table 1: Experimental Data for sample 1

No of obs.	Mass (kg)	Force (N)	Initial dis, X (m)	Final dis, X_0(m)
1.	25	245	0.2032	0.1473
2.	30	294	0.2032	0.1372
3.	35	343	0.2032	0.127
4.	40	392	0.2032	0.1168
5.	45	441	0.2032	0.1067

Table 1 (continued)

No of obs.	Change of dis, $(X-X_0)$ (m)	Wahl Factor, W	Shear Stress, $\tau(MPa)$	Spring constant, k (KN/m)
1.	0.05588	1.15	243.04	4.384
2.	0.06604	1.15	291.65	4.451
3.	0.07620	1.15	340.25	4.501
4.	0.08636	1.15	388.86	4.539
5.	0.09652	1.15	437.47	4.569

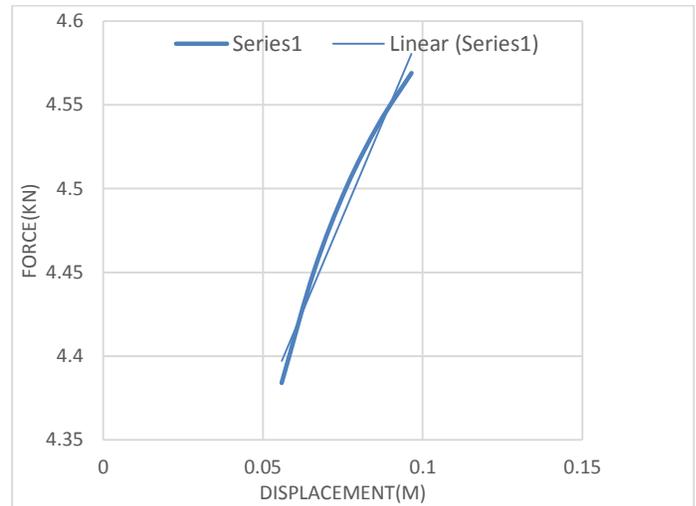**Fig. 4. Force vs. displacement for sample 1**

Sample 2:
$L_{free} = 6\ in; D = 1.7\ in; d = 6.35\ mm;$
$L_{wire} = 48.9\ in; \rho = 7500\ kg/m^3; M = 0.295\ kg;$
$C = D/d = 6.8$

Table 2. Experimental data for sample 2

No of obs.	Mass (kg)	Force(N)	Initial dis, X (m)	Final dis, X_0(m)
1.	30	294	0.1524	0.1423
2.	40	392	0.1524	0.1397
3.	50	490	0.1524	0.1372
4.	60	588	0.1524	0.1346
5.	70	686	0.1524	0.1321

Table 2 (continued)

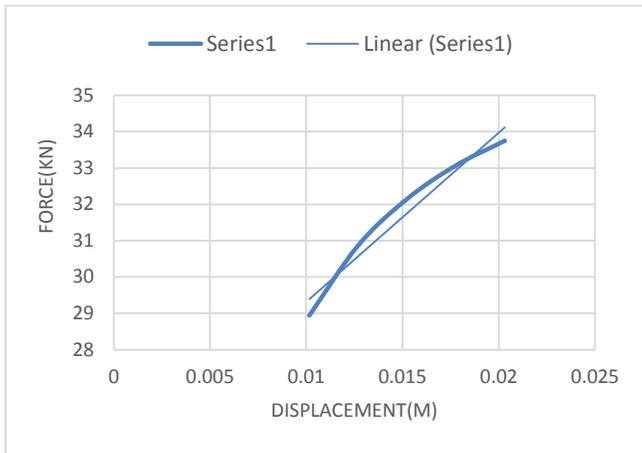| No of obs.	Change Of dis, $(X-X_0)$ (m)	Wahl Factor, W	Shear Stress, $\tau(MPa)$	Spring constant, k (KN/m)
1.	0.01016	1.22	154.03	28.94
2.	0.01270	1.22	205.37	30.87
3.	0.01524	1.22	256.72	32.15
4.	0.01778	1.22	308.06	33.07
5.	0.02032	1.22	359.41	33.75

Fig.5 Force vs. displacement for sample 2

Sample 3:

$L_{free} = 5.85\ in$; $D = 1.7\ in$; $d = 6.1\ mm$;
$L_{wire} = 66\ in$; $\rho = 7500\ \frac{kg}{m^3}$; $M = 0.367\ kg$;
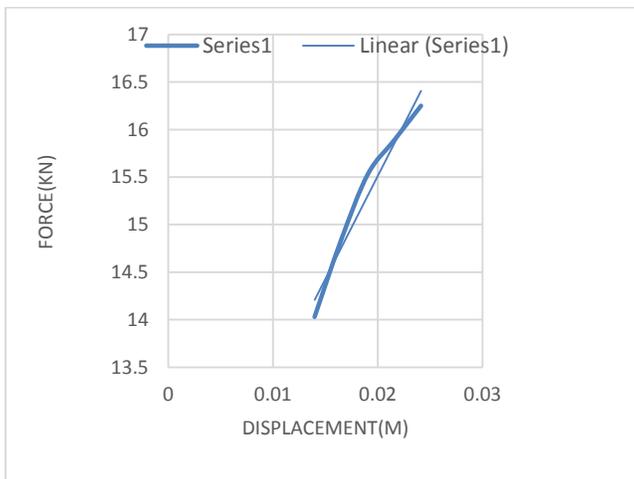$C = D/d = 7.08$

Fig.6 Force vs. displacement for sample 3

VII.   CALCULATION

The calculation of the experiment is given below:
From, Sample-1 and Table-1
Ideal condition, spring at rest

Spring constant, $k = \dfrac{d^4 G}{8D^3 n}$

Where, D = 0.5334 m; $k = \dfrac{(0.0054)^4(79.3 \times 10^9)}{8(0.05334)^3(12)}$

= 4.628 KN/m, n = 12
Actual condition,
1. Spring constant, k = 2450.05588 = 4.384 KN/m
2. Spring constant, k = 2940.06604 = 4.451 KN/m
3. Spring constant, k = 3430.07620 = 4.501 KN/m
4. Spring constant, k = 3920.08636 = 4.539 KN/m
5. Spring constant, k = 4410.09652 = 4.569 KN/m

Average Spring Constant, k = 22.4445 = 4.489 KN/m

$Error = \dfrac{4.628 - 4.489}{4.628} \times 100 = 3\%$

From, Sample-2 and Table-2
Ideal condition, spring at rest

Spring constant, $k = \dfrac{d^4 G}{8D^3 n}$

Where, D = 0.04318 m; $k = \dfrac{(0.0065)^4(79.3 \times 10^9)}{8(0.04318)^3 \times 6}$

= 33.364 KN/m, n = 6

Actual condition,
1. Spring constant, k = 2940.01016 = 28.94 KN/m
2. Spring constant, k = 3920.01270 = 30.87 KN/m
3. Spring constant, k = 4900.01524 = 32.15 KN/m
4. Spring constant, k = 5880.01778 = 33.07 KN/m

Average Spring Constant, k = 158.785 = 31.76 KN/m

$Error = \dfrac{33.36 - 31.76}{33.36} \times 100 = 4.7\%$

From, Sample-3,
Ideal condition, spring at rest

Spring constant, $k = \dfrac{d^4 G}{8D^3 n}$

Where, D = 0.04318 m, $k = \dfrac{(0.0065)^4(79.3 \times 10^9)}{8(0.04318)^3 \times 6}$

= 15.49 KN/m, n = 11

Average Spring Constant, k = 76.445 = 15.29 KN/m

$Error = \dfrac{15.49 - 15.29}{15.49} \times 100 = 1.3\%$

VIII.   RESULTS AND DISCUSSIONS

At the beginning, assemble the spring tester on a task frame (MF, separately). The kit includes a spring for compression tests. Then apply a compressive force to the spring by turning an adjustment screw. A load cell (available separately) shows the force applied to the spring. By moving freely with the load cell, scales behind the spring directly measure the spring extension or compression. From the value of load, displacement we can easily measure the spring constant using Hook`s Law. We know Hook's Law states that "as the extension so is the force".

IX.   SUMMARY RESULTS

The summary result of this experiment is given below.
1. Average Spring Constant, k = 4.489 KN/m
Error = 3.0%

2. Average Spring Constant, k = 31.76 KN/m
Error = 4.7%

3. Average Spring Constant, k = 15.29 KN/m
Error = 1.3%

X. DISCUSSIONS ON RESULTS

In this experiment, we determine the spring constant of a compression spring using Hook's Law. We took three springs of different sizes. But every steps some error occurred. For first spring error is 3%, for second spring error 4.7% and for third spring error 1.3%. The sources of error in this part of the experiment are due to the precision of the location measurement using the meter stick and the accuracy of the slotted masses. The meter stick was mounted vertically and behind the spring. By plotting the value of force and displacement on the graph a straight line is found.

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