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Design and Development of Helical Compression Spring Stiffness Testing Machine for I.C. Engine Valves with Stepper Motor by Using Computer Control

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Abstract - **Helical compression springs play a vital role in IC Engine because of its stable function ability during the cyclic loading. This paper focuses on information on design and development of helical compression spring stiffness testing machine. Our aim is to design a spring stiffness testing machine with stepper motor by using computer control, which emphasizes to measure a stiffness of helical compression springs for I.C. Engines valves for the various fluctuating load. A tested spring installed in a machine which improves the performance of the machine and produces the more efficient and reliable results. Only considering the single parameter (Deflection due to vibration) stiffness of the spring is calculated. This paper focuses on a new methodology for Testing Spring stiffness using helical compression spring stiffness testing machine with computerized control.**
***Keywords*: Helical Compression Springs, Stiffness, Load, Deflection, Computer Control**

I. INTRODUCTION

A spring is a mechanical elastic body whose purpose is to store energy and release it slowly or rapidly detect or distort under loading conditions. Helical compression spring and tension springs are widely all over the world and they are primary machine elements of the suspension system of vehicles, measurement of a system such as in weighing machine, I.C. Engine valves, different hydraulic valves etc. The energy stored and released is fully dependent upon the stiffness of the spring which emphasis to make attention to measure deflection corresponding to the load which finally resulting in the accurate spring stiffness [5]. For all types of springs, the most important factor is its stiffness value which differs according to the application. A life of spring may be affected with the load to load and spring to spring, which finally resulting requirement of the accurate and proper value of spring stiffness. Also by knowing the main readings i.e. deflections and applied load, it is possible to measure spring stiffness [4, 6].

II. THEORY

In today's growing market there are many companies which use the springs and spring are the main components in their product/machines components in which they installed the springs but one major problem arises reference to the checking the stiffness of the spring because spring uses for installation have different diameters ,different height and shapes and also for checking the stiffness of spring more time is required and also initial investment hence ultimately the cost of testing more and also testing machine has high maintenance and operational cost and also time is very important factor which affects the productivity of industries and it is important to achieve precision and accuracy hence we manufactured this machine to optimize everything with new method [8,9,10]

A. Spring Terminologies

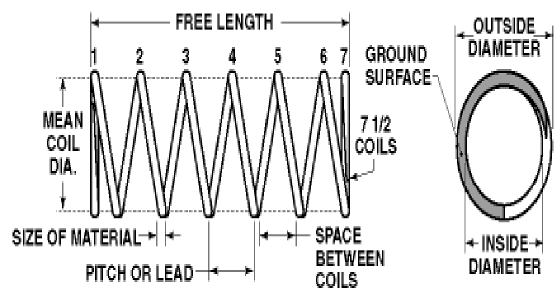

Fig.1 Spring Terminology

1. *Deflection (F):* Motion imparted to a spring by application or removal of an external load.
2. *Free Length (Fl):* Overall length of a spring which is not under load**.**
3. *Mean Diameter (Dm):* The average diameter of the mass of spring material, equal to one-half the sum of the outside and inside diameters. In a helical spring, this is the equivalent to the outside diameter minus one wire diameter.
4. *Pitch (p):* Distance from center to center of wire in adjacent coils in an open-wound spring.
5. *Solid Length (Sl):* Length of a compression spring when deflected under sufficient load to bring all adjacent coils into contact - no additional deflection is possible.
6. *Spring Index(C):* Ratio of mean diameter to wire diameter.
7. *Torque (T):* A twisting action in torsion springs which produces rotation. Equal to the load multiplied by the distance (or moment arm) from the load to the axis of

the spring. Generally expressed as in-lbs. or N.mm.

8. *Total Number of Coils (Nt):* The sum of the number of active and inactive coils in a spring body.
9. *Wahl Factor (k):* A factor to correct stress in helical springs effects of curvatures and direct shear.

III. DESIGN, MECHANISM AND FABRICATION

Complex arithmetic calculations are involved in spring design process with material science. Springs are used in everyday consumer devices including cellular phones and computers they are used widely in industrial applications including automotive and aerospace they are used in precision medical devices [2]. But spring used in IC engine applications have different configuration such as different diameters of coil, solid length, free length, stiffness values, etc. So it must be necessary that to manufacture a testing rig. This can have wide range of testing of spring and material for the testing variety of spring we can avail the facility for adjusting the height of spring for different spring for different height.

Design of Spring Stiffness Machine:

$$Stiffness = \frac{\text{load}}{\text{deflection}}$$

A. Design of Lead Screw:

- Material for Lead Screw- Carbon steel C-45
- Yield Stress- S_{yt}=360N/mm²
- Factor of Safety=1.51

1. Tensile and crushing strength:

$$\sigma_t = \frac{Syt}{F.S}$$

$$\sigma_t = \frac{360}{1.51}$$

$$\sigma_t = 238.41\ N/mm^2$$

So,

$\sigma_t = \sigma_c = 238.41\ N/mm^2$

2. Shear Stress:

$$\tau = 0.5*238.41 = 119.205\ N/mm^2$$

3. Calculation for d_c:

$$\sigma_c = \frac{w}{\frac{\pi}{4}*dc^2}$$

w=1000N

$$238.41 = \frac{1000}{\frac{\pi}{4}*dc^2}1$$

d_c^2=5.34mm

d_c =2.31mm

4. *Let's*

Consider pitch=5mm

Diameter of Shaft=22mm

d_m= {[22-(0.5*p)]

d_m =[22-(0.5*5)]

d_m =20mm

d_m =2cm

Step I: Torque is required to raise the load

$$M_t = \frac{w\ dm}{2}\tan(\emptyset - \alpha)$$

$$\tan\alpha = \frac{l}{\pi\ dm}$$

$$\tan\alpha = \frac{5}{\pi*20} \quad \alpha = \tan^{-1}\left(\frac{5}{\pi*20}\right)$$

$$(\alpha = 5.45deg) \qquad \text{………….. (1)}$$

Then,

$$(\tan\emptyset = \mu)$$

$$\tan\emptyset = 0.15$$

$$\emptyset = \tan^{-1}(0.15)$$

$$(\emptyset = 8.53deg.) \qquad \text{……………. (2)}$$

Step II: Torque is required to lower the load

$$M_t = \frac{w\ dm}{2}\tan(\emptyset - \alpha)$$

$$M_t = \left(\frac{1000\ \ 20}{2}\right)\tan(8.53 - 5.45)$$

$$M_t = 538.07N.mm$$

Velocity,

$$V = \frac{\pi dmN}{1000}$$

Assume V=9 m/min

$$9 = \frac{\pi*20*N}{1000}$$

$$N = 143.31rpm \approx \mathbf{150rpm}.$$

Power required,

$$W = \frac{2\pi NMt}{60}$$

$$W = \frac{2\pi*150*5.38}{60}$$

$$W = 84.50\ w$$

B. Radial Ball Bearing Design

Press Fit ∅20 51104 (FAG)

Fr= 0, Fa=1000N rpm=12

Then,

Thrust Factor:

X and Y respectively

$$\frac{Fa}{Fr} = \frac{1000}{0} = 0\ N$$

TABLE I FINAL SPRING DIMENSIONS

Spring No	Outer Diameter(OD)	Inner Diameter(ID)	Free Length	Applied Load	Deflection
01	$29.5^{\pm0.6}$	$23.1^{\pm0.6}$	70.35	35.16	40.00
02	23.75	19.00	66.00	10.8	29.00
03	$34^{\pm0.5}$	$26.8^{\pm0.5}$	$59^{\pm1.5}$	$54^{\pm5.5}$	28.00
04	$30^{\pm0.5}$	$22^{\pm0.5}$	$52.4^{\pm1.5}$	$66.2^{\pm5.5}$	23.00
05	$27.2^{\pm0.5}$	$20.8^{\pm0.5}$	$50.0^{\pm0.5}$	$36.8^{\pm3.5}$	23.00

C. Proposed Set-Up

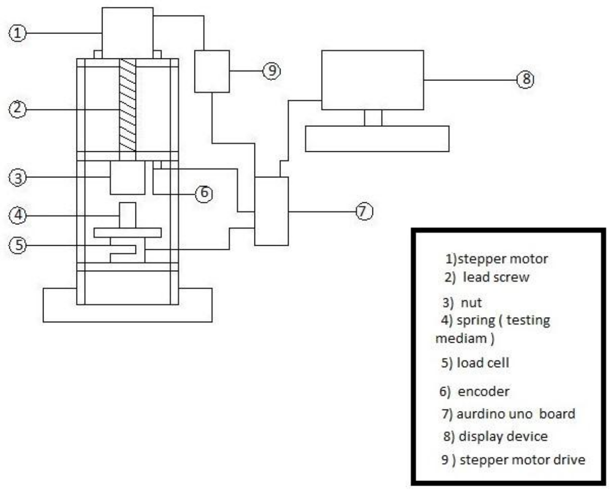

Fig. 2 Proposed set-up

The spring stiffness testing machine consists of two plates, two side pillars, a base, a mechanism which create linear motion and a displacement sensor. The assembly consists of an upper plate and a lower plate. Spring is attached between the set of two plates. The upper plate is adjustable according to the height of spring and the lower plate is connected to the load cell mechanism. Some initial force is produced by the upper plate so that it can hold the spring between the set of two plates. The lower plate is stationary at its position. An applied force by the upper plate is to be measured along through load cell connected to lower plate. A stepper motor having a drive through computerized control Arduino circuit to applied a gradual load on the spring. This applied load resulting in a deflection which can measure against an encoder. Through this calculated displacement and load it is possible to measure the stiffness of spring.

1. Model on Fusion 360

Fig.3 Model on Fusion 360 (Not to scale)

2. Specifications of Components

Stepper Motor with Encoder: Stepper motor with encoder having 1000CPR and 18.9kg.cm.

Load Cell: Capacity of load cell is 100kg

Arduino Uno Board: The Arduino Uno board feature serial communication interfaces, including USB on some models, for loading programs from personal computers. For programming the microcontrollers, the Arduino platform provides an integrated development environment (IDE) based on the processing project, which includes support foe C and C++ programming languages.

Motor Controller or Drive Display Device Radial ball Bearing (6204): The 6204 ball bearing has two contact rubber seals one on each side of the ball bearing. And the ball bearing has two non-contact metal shields one on each side of the ball bearing

2. Actual Set Up

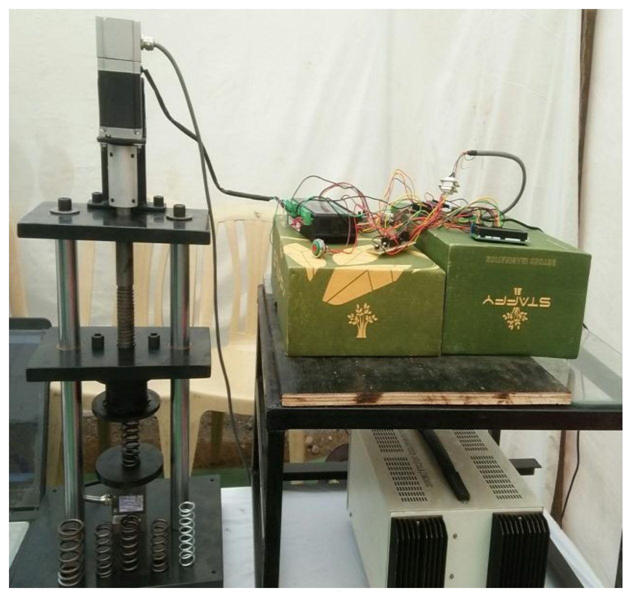

Fig.4 Actual set up

IV. EXPERIMENTATION ON TEST SECTION

A. Working

1. Firstly take the spring which is to be checked for determining its stiffness value.
2. Check whether it is tension spring or compression spring.
3. Adjust the height moving plate according to height of spring with minimum clearance possible between spring end and moving plate for accurate result of displacement of spring.
4. Give sum load up to 10 to 20gm to ensure the contact of spring ends with its supports.
5. Then set load zero by using button provided on load cell.

6. Then by using servomotor applied load gradually on the spring and compress to it.
7. Then an Ultrasonic sensor senses the position of upper plate then we get the deflection.
8. Load cell/pressure sensor senses the force in the form of compression or tension we get load.
9. In Arduino board inputs are load cell and ultrasonic sensor, it converts the inputs in form of digital display also Arduino board connected computer programming. And computer displays results.
10. Follow the above procedure more than one time and take the reading different load and deflection to calculate the stiffness of spring more accurately and precisely.

V. OBSERVATIONS

TABLE II READING FOR SPRING 1

S. No.	Load (kg)	Deflection(mm)	Stiffness(kg/mm)
1	10	11.43	0.8748
2	20	22.93	0.8722
3	35	39.98	0.8754
4	40	45.70	0.8752
5	70	79.96	0.8754

TABLE III READING FOR SPRING 2

S. No.	Load (kg)	Deflection(mm)	Stiffness(kg/mm)
1	10	28.95	0.3454
2	20	57.85	0.3457
3	35	101.4	0.3451
4	40	115.85	0.3452
5	70	202.80	0.3451

VI. CONCLUSION AND PERSPECTIVES

From above discussion, we concluded that time required for testing spring stiffness for different material and diameter is comparatively reduced as compared to conventional spring stiffness testing machine also reduces the fatigue to workers and thereby reducing inventory and investment cost of the company. Also, we have designed and developed a helical compression spring stiffness testing machine with stepper motor by using computer control and we found that the stiffness value for a given spring was accurate and precisely measured. Also, the cost of this machine is less as compared to conventional spring stiffness testing machine.

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