

## Design and Construction of a Spring Stiffness Testing Machine

Olugboji Oluwafemi Ayodeji<sup>1</sup>, Matthew Sunday Abolarin<sup>2</sup>,

Jiya Jonathan Yisa<sup>3</sup>, Alaya Garba Muftau<sup>4</sup>, Ajani Clement Kehinde<sup>5</sup>

(Mechanical Engineering Department, Federal University of Technology, Minna, Niger State, Nigeria)

**ABSTRACT:** A spring stiffness testing machine was produced which differentiates a good spring from bad one using hydraulic principle and locally sourced materials were used to produce at relative low cost and high efficiency. It also categorizes each spring by stiffness into one of several distinct categories based on its performance under test. This is to ensure that in the final assembly process, springs with similar performance characteristics are mated to ensure a better ride, more precise handling and improved overall vehicle or equipment performance. The construction of the machine involves basically the fabrication process which includes such operation as cutting, benching, welding, grinding, drilling, machining, casting and screw fastening. Taken into consideration under test, were types of compression springs with varying spring loading and their different displacement recorded at different pressures to compare their stiffness.

**Keywords** - spring, stiffness, coil, extension, compression.

### I. INTRODUCTION

For automotive springs, the most relevant performance characteristic is stiffness or “springiness” under load. On the coil line, assembly operators conduct performance testing on each spring at the end of the manufacturing process. These springs move through stages from raw steel into their final shape, with experienced assembler/operators monitoring all phases of production and at the end of the line, every spring undergoes a performance test on mechanical testing machine (Hydraulic system). For coil spring, a typical performance test include applying a series of variable loads to each spring, literally bouncing it up and down for a specified period of time at a high rate of speed to determine its stiffness quality. The results are collected via a gauge and compared to an established performance design standard. Due to a spring coil design, it generates side loads and moments in addition to axial loads. The most important part of maintaining an accurate load tester is the calibration and verification of the spring. When springs are used in a moving mechanism, their dynamic behavior has to be analyzed. However, the machine might not be able to test the stiffness for all forms of spring available on the automobile or equipment but to test only compressive spring.

A spring is basically an elastic body whose purpose is to detect or distort under loading conditions and consequently store energy and release it slowly or rapidly depending on the particular application. In 1932, Lucien Lacoste invented the zero-length spring. A zero length spring has a physical length equal to its stretched length. Its force is proportional to its entire length, not just the stretched length and is therefore constant over the range of flexures in which the spring is elastic [1]. Springs are usually made from alloys of steel [2]. Hooke’s law of elasticity is an approximation which states that the amount by which a material body is deformed (strain) is linearly related to the force causing the deformation (stress). The materials for which Hooke’s law is a useful approximation are known as linear-elastic or “Hookean” materials [3]. For systems that obey Hooke’s law, the extension,  $x$  produced is proportional to the load,  $F$ . When this holds, we say that the spring is a “Linear spring”. There are three basic principles in spring design: The heavier the wire, the stronger the spring, the smaller the coil, the stronger the spring and the more active the coils, the less load you will have to apply in order to get it to move a certain distance [4].

Extension and compression springs are literally on opposite sides of the spring spectrum. Extension springs are used primarily to hold two components together, while compression springs are best for keeping components from meeting one another. Both employ a coil design for elasticity and strength, but they work under two different principles of elastic potential energy. Torsion springs provide torque around the axis of the helix, rather than a force in line with the axis of the helix, as in compression and extension springs. The ends of the torsion spring are attached to other components that rotate around the middle of the spring. Springs are used to absorb and reduce shock, support moving masses or isolated vibration and apply definite force or torque. Few

examples of application of springs are in control valve, safety valve, torque converter, clutch manual transmission, brake system, damper, stamping machine etc.

### 1.1. Spring Testing Machine

There are many types of spring testing machine manufactured by foreign companies. This includes: SF1240 series spring testers is commonly used to test stiffness of all types of coil springs, disc springs and wire springs and spring-types components. This series features a robust dual column design with 40mm lead screw and two 50mm precision guide column for maximum stiffness.

Spring testing machine by FSA Canada conduct compression, shear, bending and hardness tests. It comes in two models, STM for helical coil springs and FST for leaf springs. The leaf spring testing machine model FST is used to test wide range of leaf/laminated springs for load rate as per IS 1.155 -1984 while the helical compression spring testing machine model STM is used to test wide range of helical compressions spring and disc springs.

Other types of testers are : Asphalt tensile designed to measure the strain at failure for asphalt binders at very low temperature and Creep and stress rupture tester for testing application of metallic materials.

### 1.1. Hydraulic

Hydraulic drive and controls have become more and more important, due to automation and mechanization [5]. Hydraulic refers to pressurized fluid, which can be oil, water or other liquids. It employs these to transmit energy from an energy generating source to areas where it is needed. In general, any application that requires a large force to be applied smoothly by small linear or rotary displacement unit (actuator) needs hydraulic and powered fluid technology. Pump converts mechanical energy into hydraulic energy [6].

Table1 Properties of spring materials

Material	Common size (mm)
Music wire	0.08 – 6
Oil tempered wire (OT)	0.25 -16
Chrome silicon, chrome vanadium	0.12 – 13
Stainless steel	0.125 – 13
Inconel, Monel, Beryllium, copper, Phosphor Bronze	0.25 – 3
Titanium	0.8 – 13

## II. DESIGN OF COMPONENTS.

The design procedure entails all the construction and design to specification of the feature and system used and also the standard parts.

### 1.2. The Spring Design

The basic equation for spring design are:

#### 1.2.1. Spring Load

$$P = \frac{F}{K} = \frac{\pi d^2 S}{8KD} \quad (1)$$

When  $P$  = maximum allowable load,  $F$  = nominal spring load,  $S$  = allowable fiber stress,  $D$  = mean coil diameter

$d$  = wire size,  $K$  = Wahl stress factor

$$K = \frac{4c-1}{4c-4} + \frac{0.615}{c} = \text{Wahl factor} \quad (2)$$

Where  $C = D/d$

$$f = \frac{8pD^2}{Gd^4} \quad (3)$$

Where  $G$  = Modulus of elasticity,  $F$  = deflection per coil

$$Su = \frac{(LF)Q}{(Dw)^x} \quad (4)$$

Where  $Q$  = expected ultimate strength of inch bar,  $x$  = factor,  $LF$  = loading factor

Loading factor (LF) for:

- 0.405 – light Service
- 0.324 – Average Service
- 0.263 – Severe Service [7]

### 1.2.2. Torsional Shear Stress

$$S_s = \frac{TC}{J} = \frac{16T}{\pi D W^2} = \frac{8FDm}{\pi D W^3} \quad (5)$$

Where  $A$  = wire cross sectional area,  $C$  = radius of wire cross section,  $J$  = Polar moment of inertia

$D$  = diameter of wire

$$J = \frac{\pi D^4}{32}$$

$$T = \frac{FDm}{2}$$

Where  $F$  = Transverse Shear Force

### 1.2.3. Deflection of springs:

$$\delta = \frac{8FD^2mNa}{GDW^4} = \frac{8FC^2Na}{GDW} \quad (6)$$

Where  $G$  = Shear modulus of wire material

$Na$  = Number of active coils

At a time  $t$ , the crank makes an angle  $\theta = \omega t$  with the line of traverse of the plunger whose

$$\text{Displacement } x = R(1 - \cos\omega t) \quad (7)$$

$$\text{Velocity } v = \omega R \sin\omega t \quad (8)$$

$$\text{Acceleration } f = \omega^2 R \cos\omega t \quad (9)$$

The instantaneous volume flow rate of the oil due to  $V$  is  $A\omega R\sin\omega t$  where  $A$  is the cross sectional area of the cylinder. The corresponding velocity of the oil in the pipe is;

$$V_s = \frac{A}{a} \omega R \sin \omega t \quad (10)$$

And acceleration

$$f_s = \frac{A}{a} \omega^2 R \sin \omega t \quad (11)$$

Where  $a$  = area of cross section of the suction pipe

$V_s$  = velocity at the suction

$f_s$  = acceleration at the suction

#### 1.2.4. Inertia force.

The mass of oil in the suction pipe is

$$m = \rho a L_s \quad (12)$$

Where  $\rho$  = density of oil

$L_s$  = Suction length

And the inertia force due to acceleration  $f_{is}$  [8]

$$f_{is} = m f_s = \rho a L_s \omega^2 R \cos \omega t \quad (13)$$

Or Head

$$H_{is} = \frac{1}{g} \times \frac{A}{a} L_s \omega^2 R \cos \omega t \quad (14)$$

Similarly, an inertia head in the discharge pipe can be expressed as

$$H_{id} = \frac{1}{g} \times \frac{A}{a} L_d \omega^2 R \cos \omega t \quad (15)$$

#### 1.3. The Reservoir Design

Area =  $L \times B$

Volume =  $L \times B \times h$  (16)

Where  $L$  = Length of the tank,  $B$  = breath of the tank,  $h$  = height of the tank.

### III. OPERATING PRINCIPLE OF THE MACHINE

The lever connected to the pump which is situated in the reservoir is raised and lowered; this movement causes the plunger to move with a motion which can be considered as simple harmonic. The plunger displacement causes a partial vacuum inside the cylinder the cylinder, leading to opening of the suction valve and lifting of the oil through the discharge pipe to the ram cylinder. The oil flows through the one way Non-return valve which is locked with the aid of the locker at the top of reservoir to the hose that connects the hydraulic circuit. The force generated forces the ram down for compression to take place and the corresponding pressure reading is taken. When the control knob (locker) on reservoir (top) is released, the pressure in the line is released and ram gradually coned back to its normal position. The escaped oil that could not be held back by seal passes through the opening at the bottom of cylinder back to the reservoir so that there is no loss of oil.

### IV. RESULT AND DISCUSSION

From the results obtained, it can be deduced that Sample 1 spring stiffness in TABLE 2 is within tolerance limit of  $\pm 0.3$  when subjected to various loading. At 2, 4, 6, 8 and 10 bars, the spring stiffness is within the limit. This suggests that the spring will give the optimal performance if used together with other springs of the same stiffness and properties. TABLE 3 shows that the Sample 2 spring stiffness is within tolerance limit when subjected to 2, 6 and 10 bars, but deviated from the limit at 4 bars and 8 bars. If this spring is used, the performance at certain loading will not be accurate and might cause damage to engine valve, piston and the connecting rod. This sample failed the test. Sample 3 spring stiffness as shown in TABLE 3 is within tolerance limit when subjected to only 4

Table 2 Reading of Pressure and Displacement of spring stiffness for Volkswagen Passat, Sample 1

Pressure (Load) bar	Displacement (Deflection) (mm)	Standard spring Displacement (deflection) (mm)	Difference (mm)	Tolerance Limit (mm)
2	5.0	4.7	0.3	±0.3
4	8.0	7.8	0.2	±0.3
6	9.5	9.4	0.1	±0.3
8	11.0	10.8	0.2	±0.3
10	11.8	11.6	0.2	±0.3

Table 3 Reading of Pressure and Displacement of spring stiffness for Volkswagen Passat, Sample 2

Pressure (Load) bar	Displacement (Deflection) (mm)	Standard spring Displacement (deflection) (mm)	Difference (mm)	Tolerance Limit (mm)
2	4.9	4.7	0.2	±0.3
4	8.2	7.8	0.4	±0.3
6	9.7	9.4	0.3	±0.3
8	11.2	10.8	0.4	±0.3
10	11.9	11.6	0.3	±0.3

Table 4 Reading of Pressure and Displacement of spring stiffness for Volkswagen Passat, Sample 3

Pressure (Load) bar	Displacement (mm)	Standard spring (deflection) (mm)	Difference (mm)	Tolerance Limit (mm)
2	5.2	4.7	0.5	±0.3
4	8.1	7.8	0.3	±0.3
6	10.0	9.4	0.6	±0.3
8	11.2	10.8	0.4	±0.3
10	12.1	11.6	0.5	±0.3

bars. At 2, 6, 8 and 10 bars loading, the spring stiffness deviated from the limit and thus are not suitable for use in an engine, if used, it will cause damage to the engine. It was discovered during test that same springs of the same material produced under the same condition vary in stiffness as a result of one being distorted or previously used and when used together in the valve of gasoline engine does not return valve on time and could damage the piston.

## V. CONCLUSION

For automotive springs, the most relevant performance characteristic is stiffness or “springiness” under load. For a coil spring, a typical performance test include applying a series of variable loads to each spring, literally bouncing it up and down for a specified period of time at a high rate of speed to determine its stiffness quality. The results are collected via a gauge and compared to an established performance design standard or master part for that specific spring type, each part is either accepted or rejected based on this precise data analysis. This work has been able to evaluate, design and construct a spring stiffness testing machine as a step towards making testing of spring stiffness easier and affordable by our automobile industries, hydro plants, local mechanics and also some manufacturing industries that use heavy equipment that has spring as an important integral of their part. However the machine might not be able to test the stiffness for all forms/types of spring available on the automobile/equipment.

## REFERENCES

- [1] A. Eugene, T.B. Avallon, *Marks' Standard Handbook for Mechanical Engineers* (10<sup>th</sup> Edition McGraw-Hill International.2001).
- [2] A.O. Jimoh, *Properties of Engineering Materials* (Kwara State Polytechnic, Ilorin, Nigeria.1992).
- [3] M. Mike, Measurement of the spring constant of a Helical Compression Spring (University of California, Davis.2004).
- [4] M. Askland, R. Donald, P. Pradeep and G. Phule, *The science and Engineering of Materials* (Fifth Edition, Thomson Engineering.2005).
- [5] J. Thomas, *Hydraulic Handbook* (5<sup>th</sup> Edition Trade & Technical Press Ltd. England, 1971).
- [6] J.M. Duke, *Essentials of Engineering Hydraulics*, (Macmillan Press Ltd 1980).
- [7] M.M. John, *Properties and Selection of Irons and Steel Metals Handbook* (Ninth Edition. ASM, Metal Park, Ohio.1988).
- [8] V.M. Faires, *Design of machine Element* (Macmillan Company, New York 1965).