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Manufacturing and Calibration of Conical Springs Lateral Stiffness Meter

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HIGHLIGHTS

- The meter able to use on conical and helical springs
- The meter is efficient for conical springs that wire diameter ≥ 4.36 mm.
- The meter read error rate disappears at wire diameter ≥ 1.2 mm.

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ABSTRACT

The spring is an important mechanical part of which widely used in many industrial applications. There is an urgent need to know its stiffness property before use in any application. Since the stiffness varies according to the method of using the spring in this research, it is suggested to calculate the lateral stiffness of spring by the moment effect. the device meter of the lateral stiffness of conical springs has been designed and manufactured working principle applying a torque to the head of the spring and calculating the angle of inclination. This research includes an experimental aspect (tensile test of steel wires, manufacture of the device lateral hardness meter, manufacture of four conical springs from steel wire inspected with diameters of 3.4, 3.8, 4, and 5 mm, and testing the springs with the manufactured device). As for the simulation aspect, it comprises calculating the lateral stiffness by numerical analysis using the solid work program. After extracting the hardness values practically by the device and comparing them with simulation values, the device proved its efficiency for small diameters after the experimental results have been compared with the results of the simulation, as the error rate increased with the increase in the diameter of the spring wire, so the highest acceptable error that could be reached by the device was 5% for the diameter 4.36 mm and zero error at the diameter 1.2 mm.

1. Introduction

Springs are mechanical parts that convert work into potential energy and convert potential energy into work. There are several ways to store that energy, either by applying a vertical force, which leads to changing the length and storing energy through it or by applying a torque around the longitudinal axis that leads to twisting the spring or a moment to storage by bending. Therefore, one needs a device to measure the relationship between the different types of load and the effect, and since there are devices for measuring longitudinal stiffness, one also requires a device that measures the lateral stiffness. There are several types of research about lateral stiffness, an experimental, theoretical, and verification with simulation for a helical rectangular section wire spring and found the stiffness matrix which described for all states of applied load and stiffness [1,2]. The study in 2021 was done on helical and conical springs, where the researcher assumes that they behave like beams, and they used two methods analyzed for measuring mechanical properties of the springs, by a two-dimensional model and finite element [3]. Dong, Bin, ET in 2021 deal with the non-linear behavior of the conical spring when compression or tension load affects it, which is dependent upon to be the basis for the analysis of vital tissues when exposed to these types of loads [4]. Vinita Varadharajan in [5] made a spring at the quasi-static state analytical model used as a base for haptic and visual simulation, also the author considered the analysis of vertical, shear forces, and tilting of the spring. Tomáš MICHÁLEK in [6] studied The effect of the lateral stiffness of the spring when adding rubber pads on its head, as well as finding an equation describing the lateral stiffness of the spring in the presence of pads and when the rubber pads were not present, depending on the Gross' theory. Likewise, the effect was calculated by the numerical method and the experimental method. The researcher concluded

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that the mathematical results unequivocally describe the lateral stiffness of the spring when adding the rubber pads, While Yipping Jiang [7] presented another mathematical model that describes the effect of lateral stiffness by the effect of rubber pads more simply, where the results were compared to the practical results, where they showed a great convergence to the results, which gives high reliability for the mathematical model, but only the effect of lateral forces and vertical forces on the spring was adopted. In the research, a device was designed to measure the lateral stiffness of the conical spring by applying torque to the head of the spring and measuring the angle of inclination to the head of the spring. From the relationship between the torque and the angle, the lateral stiffness can be calculated, so we need to manufacture a conical spring made of one of the materials commonly used in the manufacture of springs and test with this device. To find out the accuracy of the device, the experiment will be repeated using the simulation program for the same conditions that took place on the practical side, and the conditions are represented by the mechanical specifications of the wire made of the spring, so a tensile test is conducted on that wire to find out the mechanical specifications, the application of all the marginal conditions in the practical experiment from methods of fixation in the simulation Finally, highlight the same values that were used in the practical experiment. The final step is to compare the results after repeating the experiments on springs with different wire diameters to find out the accuracy and validity of the device in its use in various cases.

2. Experimental Work

2.1 Material Selection

In this aspect of the research, a suitable material for making conical springs is chosen. The choice of material will not be based on the strength of the metal and its mechanical properties, but it will be based on the following the material is available, it does not require special equipment to form it, it is cold formed easily and does not need heat, and finally, it is one of the materials from which the springs are made a habit. The choice fell on the Carbon Steel wires, as four-wire sizes 3.4, 3.8, 4, and 5 mm were chosen. The wires have been approved by Shanghai Jipan International Industrial Company Limited their Tolerance ±1% and depended on AiSi, ASTM, DIN, and JIS standards [8].

2.2 Tensile test

After the process of selecting the material for the manufacture of the conical spring according to the standards mentioned above, one must now test the selected wires mechanically using a tensile test to find out the mechanical properties. Since the material chosen is carbon steel in the form of wires, one must rely on Standard ASTM A370 [9]. For this test, the dimensions of the spacemen including the gauge length are 10 inches, plus 4 inches, which are used for fixation at each jaw 2 in, so the total length becomes 14 inches. Three specimens were used for each type of diameter, and the test was done at a 3mm/s strain rate at room temperature. Figure 1 shows the Tinius Olsen device used for testing and the way of fixing the spacemen.

Figure 1: (A) Tensile test device (Tinnitus Olsen device)(B) Tensile test spacemen

2.3 Spring Manufacture

The manufacturing process of the conical spring consists of three and a half active turns and two turns to provide a closed and ground type of ends, the length of it is 110 mm, the inner small diameter is 10 mm, and the inner large diameter is 58 mm. To manufacture the spring counting on [10, 11], one needs a shape consisting of three parts, cone with dimensions of 110 mm length, the small diameter is 9 mm and the large diameter is 57 mm, as it is notched to the number of turns required, and two cylinders start at each end of the cone with a length of 20 mm, as shown in Figure 2. A jaw has been made to fix the wire on the large side to start the lapping process that was done by the turning machine at a very low speed. After the lapping process is completed, the spring must be taped before removing it from the mold to avoid opening the spring in a strong way that may harm the worker.

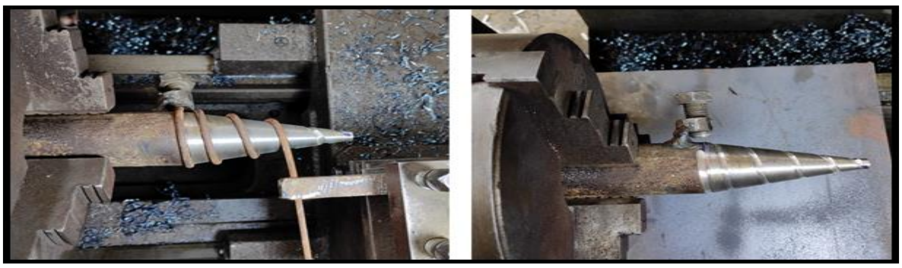

Figure 2: Mold for industry spring

2.4 Manufacture of lateral stiffness testing system

To test the conical spring mechanically to find the lateral stiffness, the small side is tightly fixed and a moment is applied on the large side and extracting the amount of angle resulting from this moment. The center of the large diameter and the center of the small diameter of the conical spring should be in one vertical plane. To provide this situation experimentally, a device was manufactured in Figure 3, through which a load calculated in kilograms by the reader was applied on a 400 mm arm to produce a moment according to the equation and Figure 4. To measure the angle, an angle reader was installed on the top of the large side of the conical spring. When using a reader to measure the load and another for angles, it must be ensured that the readings are true. Therefore, calibration of the load reader and the angle reader must first be done. The load reading was calibrated by using reliable and certified weights. The angles reader was calibrated by a calibration batten in the device. The spring test method is adopted by taking three times for each wire diameter of 3.4, 3.8, 4, and 5 mm. Tack 12 levels of moments were applied, and the angle was extracted at each level.

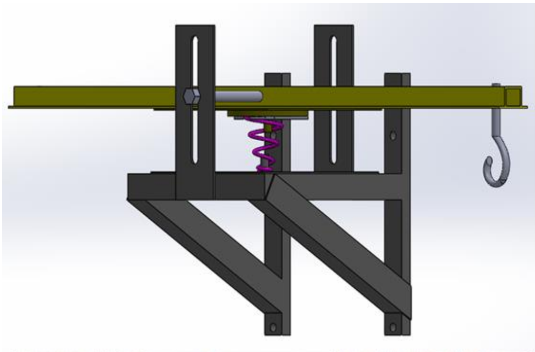

Figure 3: lateral stiffness testing system

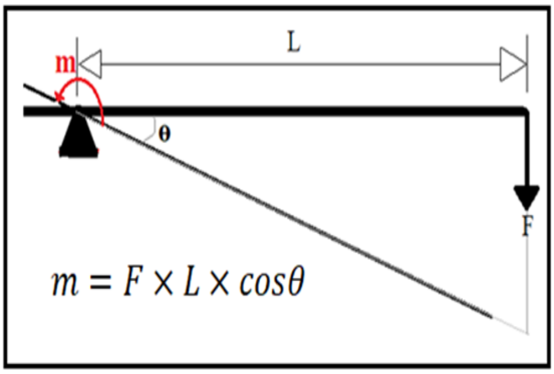

Figure 4: The process of converting force into the moment (force application method)

2.5 Simulation

A model identical to the conical spring was drawn by the Solid work program using the method helix /spiral and sweep. After that, the same program was used to make simulations depending on the practical results of the mechanical properties of the material used to manufacture the spring from the tensile test. To make the simulation closely matched to the real state of the spring stiffness measurement, the fixed option was chosen to fix the small side of the spring. The big side was used (on cylindrical face) option to make this side fixed except for the Axis-1 and applied moment on it, as shown in Figure 5. After that, the meshing process was done with curvature-based mesh, the rib octagonal size of the mesh element was (4.71 mm - 0.94 mm) the spring is consisting of 66040 elements and 106701 nodes, and finally, the solution that included 302604 degrees of freedom was started. the parameters of resolving simulation were 10E7 input maximum number of iterations for the iterative solver and 10E-4 the input stopping threshold.

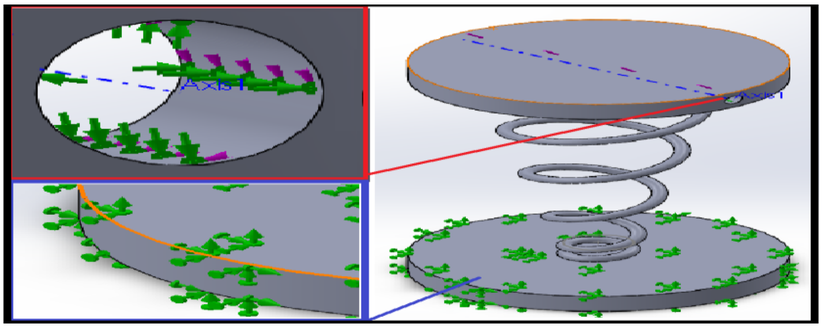

Figure 5: The boundary condition (the green color) and the moment applied (the purple color)

3. Results and Discussion

The results of the tensile test as shown in Figure 6 revealed the mechanical properties that will be adopted in the simulation process that the yield stress is 535 MPa, ultimate stress 810 MPa, Young's modulus 200GPa, and modulus of rigidity 78.7 GPa. The calibration of the spring lateral stiffness meter done on the load reader part was regulated by the equation that is evident by the relation between calibrated readings with device reading in Figure 7. The simulation process results were a deformation value calculated in millimeters, must convert it into an angular magnitude to describe the slop, took the highest deformation that is on the edge as shown as red color in Figure 8 and divided it to the distance between the red region and the center of the spring to get the sine of the angle of slope. When applied the moments ranging from 0.1 to 1.2 Nm on all springs, got the following results were obtained, for spring 3.4 mm, the angle slop was from 0.48 to 5.78 in the experimental values and 0.48 to 5.81 for simulation values, the lateral stiffness was 12.236 Nm/rad and 11.819 Nm/rad, respectively, Table 1 explains the values of angle slop at the minimum and maximum level of moment applied and the magnitude of lateral stiffness, Figures 9 to 12 show the relation between them. The error ratio between the experimental simulation results was calculated for all springs, which is in the order from spring 3.4 to spring 5 (3.52%, 4%, 4.5%, and 6%), from these results, a diagram can be drawn describing the relationship of the error ratio to the diameter of the spring wire, as shown in figure 12 The equation describing this relationship as shown in the previous figure and included in Eq. 1 can determine the range in which the meter can be used depending on an acceptable error rate, which is from 0% to 5%. The limit for this equation goes to 0%, and 5% must be taken to determine this range, also according to equations 2 and 3, the results revealed that the highest acceptable error was at diameter 4.36mm and zero error was at diameter 1.2 mm.

$$\mathrm{d} = 0.632\mathrm{Error} + 1.2027 \quad (1)$$

$$d = \lim_{Error \to 0\%} (0.632\mathrm{Error} + 1.2027) = 1.20\ mm \quad (2)$$

$$d = \lim_{Error \to 5\%} (0.632\mathrm{Error} + 1.2027) = 4.362\ mm \quad (3)$$

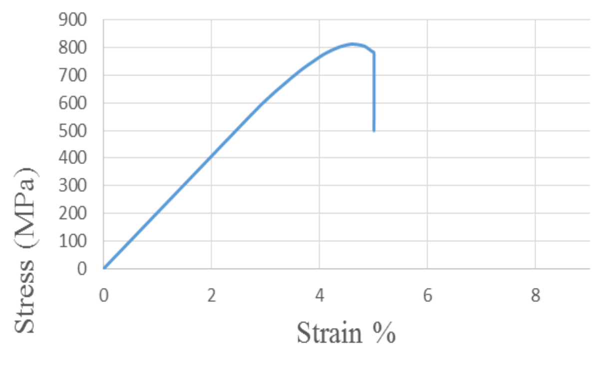

Figure 6: Stress-Strain curve for the used wire

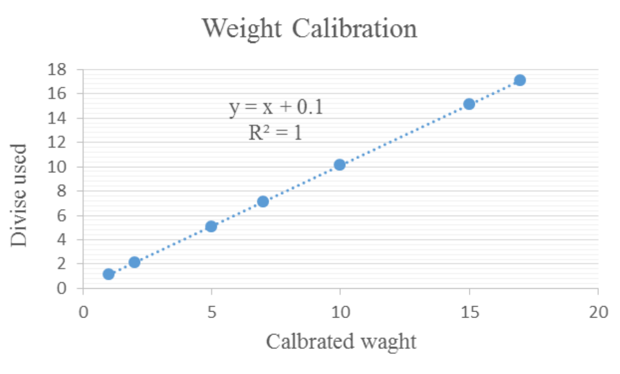

Figure 7: Weight calibration relationship

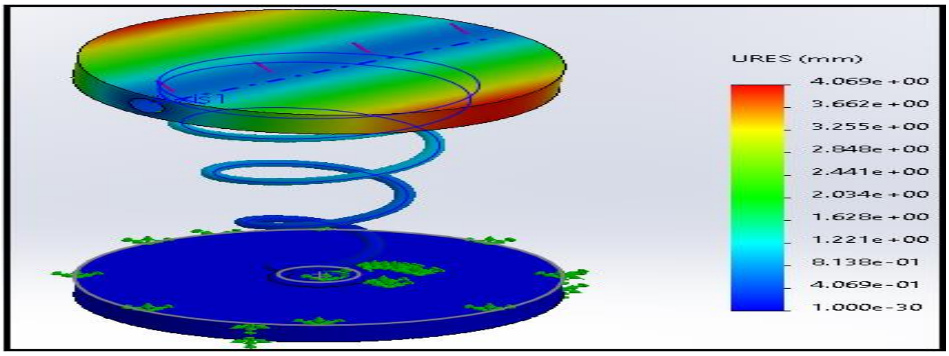

Figure 8: The deformation distributed in the head of spring

Table 1: The min and max values of slop angle and lateral stiffness magnitude

	Moment (N m)	**d=3.4(mm)**		**d=3.8(mm)**		**d=4(mm)**		**d=5(mm)**	
		Angle (deg)	***L.S (Nm/rad)***	***Angle (deg)***	***L.S (Nm/rad)***	***Angle (deg)***	***L.S (Nm/rad)***	***Angle (deg)***	***L.S (Nm/rad)***
exp	0.1-1.2	0.46-5.61	12.236	0.29-3.54	19.309	0.23-2.90	23.819	0.09-1.16	58.95
sw	0.1-1.3	0.48-5.81	11.819	0.30-3.7	18.556	0.25-3.01	22.792	0.10-1.23	55.602

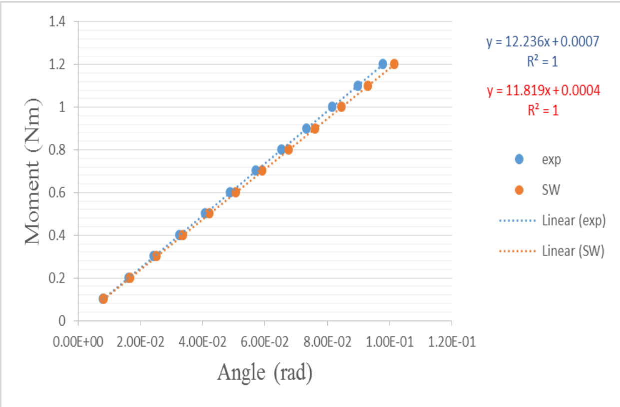

Figure 9: Moment-Angle relationship for 3.4 mm conical spring

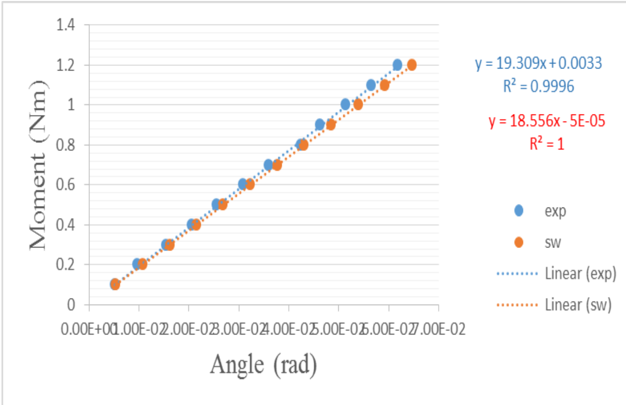

Figure 10: Moment-Angle relationship for 3.8 mm conical spring

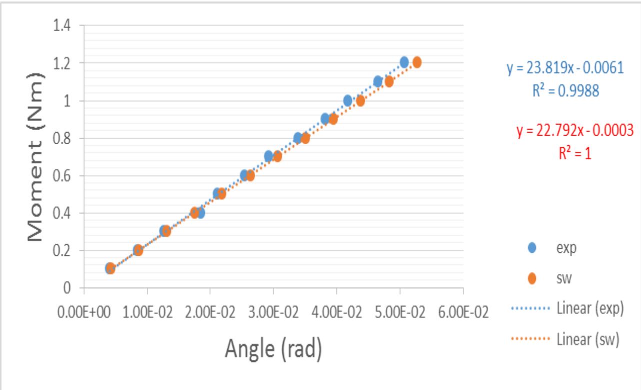

Figure 11: Moment-Angle relationship for 5 mm conical spring

Figure 12: Diameter- error ratio relationship

4. Conclusions

A comparison was made between the two methods to reach the extent of accuracy and acceptability for them, where the error rate was calculated between the experimental and simulation results of the springs made of wire diameter 3.4, 3.8, 4, and 5 is 3.52%, 4%, 4.5%, and 6%, respectively. Where the spring lateral stiffness meter has acceptability of diameters from 4.362 mm and below until it reaches zero for diameter 1.2 mm. The mentioned error ratios indicate that the design of the meter and the high degree of simulation reach a great degree of realism. The inferred equation can be relied upon as a determinant of the degree of error and acceptability of the device.

Author contribution

All authors contributed equally to this work.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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