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Optimal Design of Helical Torsion Spring for Engine Valve Timing Mechanism

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Abstract **- A design methodology is evolved and arrived at optimal configuration with respect to geometry for helical torsion spring for engine valve timing mechanism. Within the space constraint maximum working stress experienced by the spring should be within acceptable value. Optimal geometry is chozen for meeting this requirement. Two geometries (Round and square) are considered for carrying out the intended study. Outcome of the exercise is molded in a form that replicate a hand calculator for using which, designers need not possess expertise in any software. This GUI based software developed in MATLAB facilitates an 'exe' file which can be executed from any computer for which neither computer nor the designer should possess software. Working with this software will be as comfortable and similar to that of calculator in a typical computer. Using this software optimal design parameters of the intended spring are worked out. This software will be extremely useful for quickly arriving at optimal configuration for any combination of input design parameters. For running this software designer has to key in the input values in empty boxes corresponding input parameters. Maximum working stress values experienced by the helical torsion spring with round wire and square wire are compared with maximum allowable stress. In addition to this angular deflection values experienced by the spring with round and square wires are also compared. Based on these observations square wire is recommended for configuring helical torsion spring for engine valve timing mechanism.**

Keywords – Helical torsion spring, round wire, square wire, GUI, MATLAB, etc.

1. INTRODUCTION

In a piston engine, valve timing mechanism takes care of precise timing of the opening and closing of the valves. Helical torsion spring used in engine valve timing mechanism works between the frame and the valve and is used to close the valve and also to maintain the contact between the valve stem and the rocker arm.

Helical torsion spring in a typical valve timing mechanism is shown in Fig. 1.

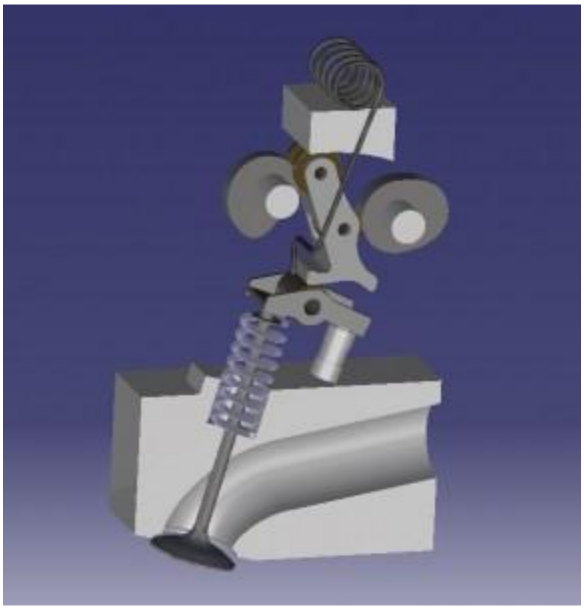

Fig. 1. Helical torsion spring in valve timing mechanism

Helical torsion springs are identical to that of helical compression/tension with respect to basic shape. However its ends will be shaped such that the spring can be loaded by a twisting moment (Torque) about the axis of the spring coil. Due to the pattern of stressing, main

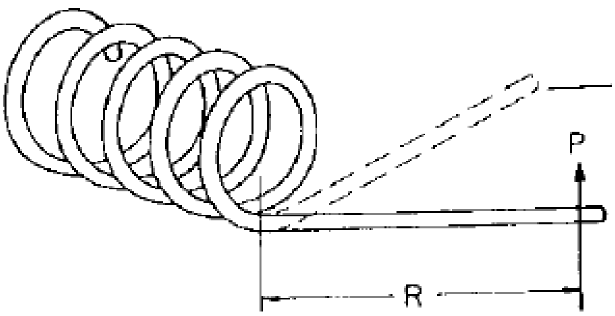

Fig. 2. Typical way of loading helical torsion spring stress will be flexural against helical tension/compression spring in which main stress will be shear. Typical way of loading helical torsion spring is shown in Fig. 2.

The spring is assumed to be wound around a cylindrical rod, one corner of it will be attached to the rod whereas the other end will have a straight portion that projects radially out. When the spring will be loaded by a force 'P' at a radius 'R' from the centre (Axis) to wind ht spring, then the moment resulting to twist the spring will be 'PxR'.

In general due to certain advantages associated with manufacturing aspects, helical torsion springs are made of round wire. Situations when higher energy storage is needed with in the given space constraints, square wire is preferred. This is due to the reason that in bending, square geometry will have greater proportion of spring subjected to stresses near the maximum value than that of circular wire. Hence for the common maximum stress higher energy storage may be achieved with in a given volume of spring for square wire.

Helical torsion spring needs to fit into the space allocated in the engine valve timing mechanism. Within the space constraint maximum working stress experienced by the spring should be within acceptable value. Optimal geometry needs to be chozen for meeting the aforementioned requirement.

To begin with existing literature is referred for design procedure that needs to be adopted for the intended requirement.

Review of basic stress distribution, properties of helical coil springs is carried out. Detailed discussion on the parameters affecting the quality of coil springs is also discussed. Factors influencing strength of coil spring, FEA analyses by the researchers for coil spring analysis are also studied. Reduction in weight is a necessity of automobile industry. Thus the springs are to be configured for higher stresses with small dimensions. This needs critical design of coil springs. This leads to crucial material and manufacturing processes. Decarburization which was not a major consideration in the past now becomes essential, to have better spring design [1]. In this study, the nonlinearity in moment and angular displacement of torsion springs is studied analytically and experimentally. It is shown that the inclined angles at both ends have direct effects on the nonlinearity of a constant-pitch torsion spring. Also, an algorithm for determining the friction between the spring coils in close-wound torsion springs is proposed. From the comparison to experimental data, it is found that the spring rates are different at forward and backward strokes. The dynamic equations for the close-wound torsion spring is also derived by considering the friction between the springcoils, and two different natural frequencies are found in simulation [2]. This paper presents a new method of calculation of the change of axial twisting angle of compressed helical spring's end-coils in the case of rotary - free supports. The propriety of derived formulas was experimentally verified. The method is easy in application and gives results much closer to experiment than the presently used method that can be found in literature [3]. Springs are loaded by harmonic forces very often. High cycles fatigue damage and failure can be found during its service loading. This paper shortly describes stress concentration factor for helical springs on the inner diameter of the spring wire and its evaluation by using FE Method. These results have been compared with correction functions published in the literature. The fatigue safety factor has been derived for three typical loading regimes of springs. All cases are demonstrated in the Haigh diagram. It has been showed that loading cases with constant operational pre-stress give lowest safety factor then the proportional or constant middle stress regimes [4]. The main functions of automobile suspension systems are to isolate the structure and the occupants from shocks and vibrations generated by the road surface. The suspension systems basically consist of all the elements that provide the connection between the tyres and the vehicle body. A spring is an elastic object used to store mechanical energy. It is an elastic body that can be twisted, pulled, or stretched by some force. It can return to their original shape when the force is released. It is a flexible element used to exert a force or a torque and, at the same time, to store energy. The force can be a linear push or pull, or it can be radial, acting similarly to a rubber band around a roll of drawings. The torque can be used to cause a rotation. The main objective of this research paper is to through some light on the fatigue stress analysis of springs used in automobiles. Theoretical, Numerical and Experimental methods are used for the analysis of springs but Finite Element Method is the best for its analysis and calculating the fatigue stress, life cycle and shear stress springs [5]. A finite element model is developed to investigate the instantaneous as well as long-term (time-dependant) structural response of a pre-loaded torsional spring. Torsional springs belong to a class of spiral springs that are commonly made out of Elgiloy - an alloy of Cobalt, Chromium, Nickel and Iron. Elgiloy has very high yield strength, and is commonly used as a spring material in clocks. The research involves development of a detailed component-level model, using Abaqus/Standard, to investigate the instantaneous static moment-rotation response, and the long-term stress relaxation response of the spring system, along with, understanding the sensitivity of this response on the various design parameters. Frictional self contact, large deformation and nonlinear material behavior (plasticity and creep) are among the major challenges in solving this problem. The modeling effort also involves understanding the experimentally-observed hysteresis associated with the cyclic moment versus rotation response, and development of simple analytical models which can approximately describe the structural response of a typical torsional spring system with varying parameters [6].

Most of the existing literature focuses on design of conventional helical compression springs in the perspective of evolving optimal design. Hence there exists a great need to evolve a design methodology to arrive at optimal configuration with respect to geometry for helical torsion spring for engine valve timing mechanism.

2. DESIGN INPUTS

- Minimum bending moment, M_1 = 5.53 N-m
- Maximum bending moment, M_2 = 7.3 N-m
- Spring index, C = 4
- Number of turns, n = 4
- Material of spring: Music wire
- Desired life = 1,00,000 cycles
- Young's modulus, E = 200 GPa
- Volume is identical for both square and round wires
- Mean coil diameter is also identical for both

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3. DESIGN FOR ROUND WIRE

Size of the wire for helical torsion spring can be expressed as

$$d = 0.00215\, M_2^{0.35}$$

Mean coil diameter of spring can be expressed as

$$D = C \cdot d$$

Maximum allowable stress can be expressed as

$$\sigma_{limit} = 10.205\, \frac{M_2}{d^3}$$

Stress range ratio can be expressed as

$$s_r = \frac{M_2 - M_1}{M_2}$$

Curvature correction factor for stress can be expressed as

$$A = 0.24 s_r^2 - 0.6792 s_r + 1.2125$$

Corrected vale of maximum allowable stress can be expressed as

$$\sigma_{limit\text{-}corr} = A \cdot \sigma_{limit}$$

Maximum working stress experienced by the round wire spring can be expressed as

$$\sigma_{max} = 10.147\, \frac{M_2}{d^3}$$

In general spring will have clamped ends because of which stress concentration may be anticipated in the vicinity of the ends specifically when sharp bends are present. This particular stress concentration needs to considered particularly when spring is subjected to fatigue or cyclic loading. Correction factor for cyclic (Fatigue) loading can be expressed as

$$k_1 = \frac{4C^2 - C - 1}{4C(C-1)}$$

Corrected vale of maximum working stress can be expressed as

$$\sigma_{max\text{-}corr} = k_1 \cdot \sigma_{max}$$

Maximum angular deflection experienced by the spring with round wire due to maximum bending moment can be expressed as

$$\varphi = 3670\, \frac{M_2\, n\, D}{E\, d^4}$$

4. DESIGN FOR SQUARE WIRE

As the objective of the present work is to arrive at the optimal design for same volume (Weight), size of the square wire is worked out as follows

Area of round wire = Area of square wire

$$\frac{\pi}{4} d^2 = a^2$$

In which

a: Size of square wire

From the above

$$a = 0.886\, d$$

Spring index for square wire can be expressed as

$$C_s = \frac{D}{a}$$

Maximum working stress experienced by the square wire spring can be expressed as

$$\sigma_{max} = 6\, \frac{M_2}{a^3}$$

Correction factor for cyclic (Fatigue) loading can be expressed as

$$k_2 = \frac{3C^2 - C - 0.8}{3C(C-1)}$$

Variation of correction factor for cyclic (Fatigue) loading with spring index is compared between round wire and square wire in Fig. 3.

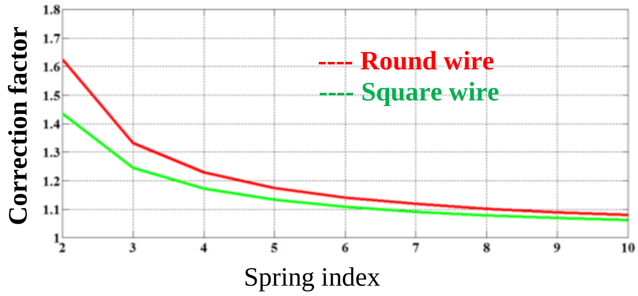

Fig. 3. Variation of correction factor

Corrected vale of maximum working stress can be expressed as

$$\sigma_{max\text{-}corr} = k_2 \cdot \sigma_{max}$$

Maximum angular deflection experienced by the spring with square wire due to maximum bending moment can be expressed as

$$\varphi = 2160\, \frac{M_2\, n\, D}{E\, a^4}$$

5. GUI BASED SOFTWARE USING MATLAB

As mentioned earlier outcome of the exercise should be molded in a form that replicate a hand calculator for using which, designers need not possess expertise in any software. Optimization model formulated in earlier section is embedded in this software. This GUI based software facilitates an ‘exe’ file which can be executed from any computer for which neither computer nor the designer should possess MATLAB software. The following inputs are required to be keyed in as input parameters.

- Minimum moment
- Maximum moment
- Spring index
- Number of turns

Pushbuttons are provided for displaying the following output parameters for both round wire and square wire.

- Maximum allowable stress
- Wire size
- Maximum working stress
- Angular deflection

Front end of the software with the associated features for inputs and outputs is shown in Fig. 4.

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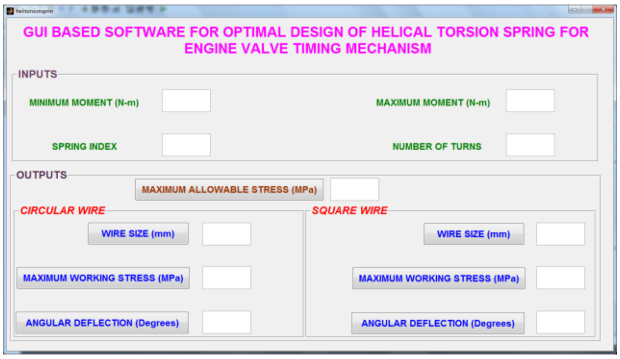

Fig. 4. Front end of the software

Working with this software will be as comfortable and similar to that of calculator in a typical computer. Using this software optimal design parameters of the intended spring are worked out. Front end of the software displaying outcome of the design exercise along with the input parameters is shown in Fig. 5.

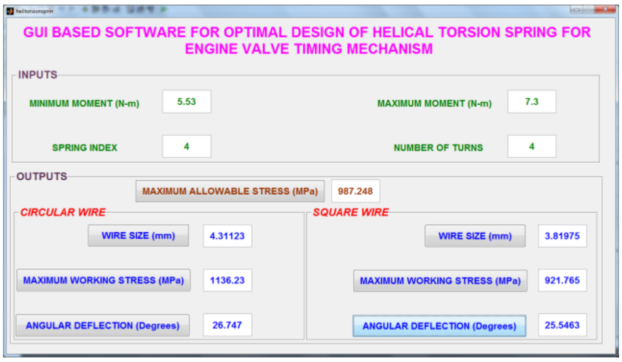

Fig. 5. Software panel after execution

This software will be extremely useful for quickly arriving at optimal configuration for any combination of input design parameters.

For running this software designer has to key in the input values in empty boxes corresponding input parameters. However designer needs to stick to unit consistency as visible in the front end. Upon clicking the specific pushbutton desired output will be displayed in empty boxes corresponding to output parameters.

6. RESULTS AND DISCUSSION

Outcome of design exercise is summarized in Table 1 and subsequently design parameters are compared for configurations with round and square wires.

Table 1 Outcome of optimization

Sl. No.	Parameter	Configuration	
		Round wire	Square wire
1.	Wire size	4.3 mm	3.8 mm
2.	Maximum working stress	1136 MPa	921 MPa
3.	Angular deflection	26.7^0	25.5^0
4.	Maximum allowable stress	987 MPa	

Variation of maximum working stress with maximum moment is compared between round wire and square wire in Fig. 6.

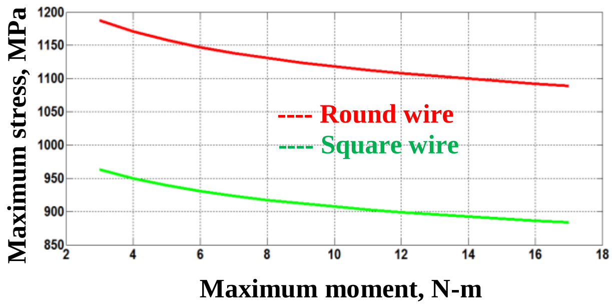

Fig. 6. Variation of maximum working stress

Variation of maximum angular deflection with maximum moment is compared between round wire and square wire in Fig. 7.

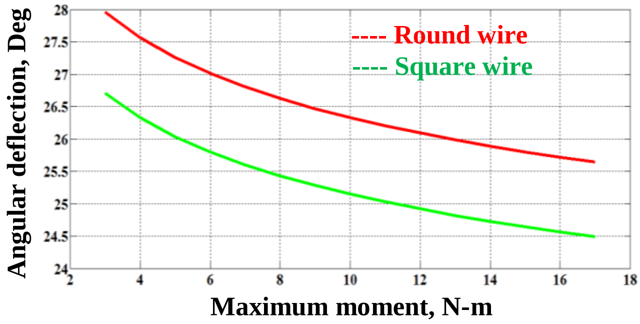

Fig. 7. Variation of angular deflection

- Maximum working stress experienced by the helical torsion spring with round wire is more than the maximum allowable stress.
- Whereas maximum working stress experienced by the same spring with square wire is less than the maximum allowable one.
- In addition to this angular deflection experienced by the spring with square wire is less than that of round wire.
- For a given maximum moment wide gap exists between maximum stress experienced by round wire and square wire.
- Same is the case with respect to maximum angular deflection experienced by both.

7. CONCLUSIONS

A design methodology is evolved and arrived at optimal configuration with respect to geometry for helical torsion spring for engine valve timing mechanism. Within the space constraint maximum working stress experienced by the spring should be within acceptable value. Optimal geometry is chozen for meeting this requirement. Two geometries (Round and square) are considered for carrying out the intended study. Outcome of the exercise is molded in a form that replicate a hand calculator for using which, designers need not possess expertise in any software. This GUI based software developed in MATLAB facilitates an 'exe' file which can be executed from any computer for which neither computer nor the designer should possess software. This software will be extremely useful for quickly arriving at optimal configuration for any combination of input design parameters. Maximum working stress experienced by the helical torsion spring with round wire is more than the maximum allowable stress. Whereas maximum working stress experienced by the same spring with square wire is less than the maximum allowable one. In addition to this angular deflection experienced by the spring with square wire is less than that of round wire. For a given maximum moment wide gap exists between maximum stress experienced by round wire and square wire. Same is the case with respect to maximum angular deflection experienced by both. Based on these observations square wire is recommended for configuring helical torsion spring for engine valve timing mechanism.

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