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Experimental Investigation on Torsional Rigidity of Power Screws

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Abstract: The lead crews or power screws are very important components in machine tools, power transmission equipment and in general machinery. These components are often subjected to twisting moments. As cross section of power screw is not solid circle, the torsion expression available in simple torsion theory is not useful for the estimation of torque carrying capacity. In this paper two analytical models have been developed to evaluate torsion rigidity of power screws. To validate the results obtained from these developed models, an experimental set up is built up in this work.

Key Words: *Lead screw, torsion rigidity, stress function.*

I. INTRODUCTION

The torsion problem of non circular members, in general had been important field in solid mechanics for many years. The exact solution of the torsion problems for a circular shaft is obtained in the simple torsion theory literature. When the section of the shaft is not circular, the stress and torque relation does not satisfy the conditions of outer surface which is helical wrap in case of power screw. In simple torsion theory, the cylinder is twisted by the couples, so that any cross section is turned, relatively to any other, through an angle proportional to the distance between planes of section. The traction of any cross section at any point is tangential to the section, and is at right angles to the plane containing the axis of the cylinder and the points. The magnitude of this traction at any point is proportional to the distance of the point from the axis. This approach is followed on two cross sections: solid and square coiled spring(See Fig,1.1) super imposed one on other as shown in Fig.1.1 and developed analytical models in this paper. The main object of the paper is to verify the values of torsion rigidity obtained from developed analytical models with the experimental values. The experimental set up described in this paper is also a simple one: that involves a mechanical twisting structure and an optical lever.

Fig1.1:Square sectioned Coli Spring

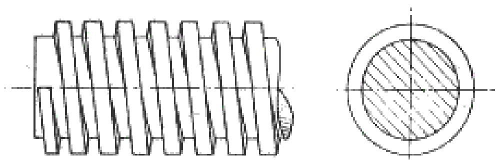

Fig 1.2:Spring imposed on shaft

The paper is organized as follows: Section two reviews the literature of torsion problems elated to non circular shafts. The development theoretical models are clearly explained in section three. The description of experimental set up and the results obtained from the experiment are given in sections four and five respectively. Section Six draws conclusions

II. REVIEW OF LITERTURE

Analytical solution for the torsion analysis based on theory of Saint Venant can be readily found in various text books (2,5,6) for simple ,homogeneous, and isotropic section..Romanelli et al(13) have solved non circular problem of regular polygon using a complex variable pproach.Equations have been evaluated as a function of number of axes of symmetry of the regular polygonal cross section taking 50 terms in the corresponding summations. The results have been found to agree well with the values by the other investigators. Nitzsche et al (13) have given method of determining the stresses and deformations including warping of curved thin walled open closed cross section beams and tubes to variable torque. The method entails solving four coupled linear differential equations .Booker et al (14) have obtained analytical solution to the problem of torsion of multi layered rectangular section using the Saint Venant theory . No theoretical expressions on threaded cross section members have been developed by any author sofar.Due to mathematical difficulties encountered for obtaining closed form solutions of above cross sections; several investigators have developed approximate analysis using numerical techniques. Among them Ely and Zinkiewicz (8) and shaw F.S.(9) used the finite difference approach. Hermann, L.R. (11) ,Krahula and Lauterbach (12) preferred the more versatile finite element technique. From the above literature it is seen that the problem of torsional rigidity evolution of lead or power screws is not discussed any where either using theory of Saint Venant approach or any other approach. In this paper two approximate analytical models developed and then their results are verified with experimental investigation.

III. DEVELOPMENT OF APPROXIMATE ANALYTICAL MODEL

Saint Venant's theoy of torsion for circular cross section gives the following governing differential equation:

$$\mathbf{A\, d^2\varphi / dx^2 - 2B\, d^2\varphi / dxdy + C\, d^2\varphi / dy^2 + 2\varphi = 0} \qquad \mathbf{(2.1)}$$

Where A, B and C are constant and φ is stress function to be assumed to satisfy the given boundary conditions. The above equation can be applied for regular cross section members and cannot be applied to lead screws because the boundary representation is not a curved surface as that of regular cross sections. Therefore, two simple models are postulated from simple theory of torsion expression which is given by

$$\mathbf{T / J = G\theta/L = \tau/r} \qquad \mathbf{(2.2)}$$

Here T is torque, J is polar moment of inertia , G is Rigidity modulus and L is length member.

Model-1: The first model is nothing but a circular shaft with a characteristic diameter equal to mean diameter of the screw. In this modeling the lead screws as assumed as a uniform circular rod. After introducing such an assumption the above governing equation can be used for evaluation of stress function. The torsion rigidity is defined as the torques carrying capacity of member of unit length with an angle of twist of one radian. Applying this definition to equation (2) , the torsion rigidity is given as

$$\mathbf{T = GJ} \qquad \mathbf{(2.3)}$$

Where $J = \Pi D^4/32$ and D is Mean diameter.

Model-2: In this model the threaded profiles assumed to be helical spring of a wire with square cross section. The wire dimensions are same as the thread dimensions, i.e. the side of the square of the cross section is half of the pitch. This spring is assumed to be super imposed over the core shaft. Therefore the torsion rigidity offered by the lead screw is equal to the sum of the torsion rigidities offered by the spring and the core shaft.

The torsion equation for helical spring is

$$\mathbf{\theta = 12 T_s D n / E a^4} \qquad \mathbf{(2.4)}$$

D is mean diameter of Coil equal to mean diameter of lead screw.

E is youngs modulus, N is number of turns.

The torsion equation in terms of length and pitch is given as

$$\mathbf{T_S = E\, a4\ \theta\ p / 12\ \pi\ DL} \qquad \mathbf{(2.5)}$$

From the definition of torsion rigidity, equation (5) can be written as

$$\mathbf{T_S = Ea^4\ p / 12\ \pi\ D} \qquad \mathbf{(2.6)}$$

The torsion rigidity of core shaft is

$$\mathbf{T_C = GJ_C} \qquad \mathbf{(2.7)}$$

Where $\mathbf{J_C = \pi\, d_c^4/32}$

Adding equations (6) and (7), the torsion rigidity of the lead screw is obtained as follows:

$$\mathbf{T = T_S + T_C} \qquad \mathbf{(2.8)}$$

In this model there can be slip between the core shaft and the inner surface of the coiled spring. This slip condition can be introduced by making the surface displacements equal.

IV. DESCRIPTION OF EXPERIMENTAL SETUP

The drawing of experimental set up is shown in Fig.3.1, in which front view and side view are drawn. It has two plane frames of about 1m height and made up of I section using welding technique. The frame A is fixed to the floor using foundation bolts. On the frame B an adjustable screw is arranged, which can move up and down, as a simple support, without any friction for the lead screw to eliminate bending effect. Fixture C is mounted on frame A to clamp the lead screw rigidly. Another fixture D is mounted on lead screw to apply the twisting moment. The fixture has four arms which are right angled to each other .The arms are joined together by bars of same diameter to have increased stiffness for arms. The twisting moment is applied on the lead screw by loading the arms. For this purpose, three pulleys are mounted on frame B as shown in Fig.1.The pulleys are mounted on levers which are welded to the frame B Under the twisting moment applied , the lead screw twists by an angle. This angle is measured using an optical lever method. There are two bulbs are mounted on the lead screw. Therefore, the differential twisting angle can be measured. The screen is kept about 5m away from the set up to minimize the error. The photo graph of set up is shown in Fig.3.2.

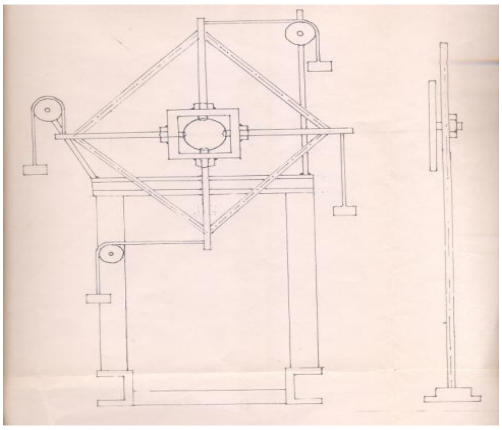

Fig.3.1: Drawing Experimental Set Up

Fig.3.2: Photograph of Set up

V. RESULTS AND DISCUSSION

The table.5.1 is shows the data of power screws that are investigated in the experiment.

Model -1: To implement model-1, it is required to evaluate mean diameter which is evaluated with simple substitution and given in a single row matrix. The element of matrix represents the mean diameter corresponds to nominal diameters chosen to power screws as shown in Table2.1.

D= [16.7500 20.7500 22.5000 26.5000 36.0000 39.7500 42.5000 46.5000] **(5.1)**

Table.5.1: Basic dimensions for square threaded power screws(ISO 4694-1968)

S.No.	Nominal Diameter (mm)	Core diameter(mm)	Pitch(mm)	Area of core(mm^2)
1	18	15.5	2.5	188.69
2	20	18.5	2.5	298.64
3	24	21	3	346.36
4	28	25	3	490.87
5	38	34	4	907.92
6	42	37.5	4.5	104.47
7	45	40	5	1256.64
8	48	45	5	1452.20

With the use of equation (2.3), the torsion rigidity is evaluated and given in the following single row matrix.

T1 $=10^{10}$[0.0618 0.1457 0.2014 0.3875 1.3197 1.9616 2.5634 3.3675] **(5.2)**

Model-2: By considering the square cross section helical spring on the solid shaft of core diameter, the equation (2.8) is used to evaluate torsional Rigidity of power screws that are considered in Table.1. The values of Torsion rigidity of various power screws considered for experiment as per the model-2 are given in the following single row matrix.

T2 = 10^{10}[0.0454 0.1136 0.1528 0.3069 1.0500 1.5538 2.0114 2.6862] **(5.3)**

The experimental determination of torsion rigidity involves to choose appropriate loads to be hanged for square arm and the the evaluation of the twist angle of lead screws with the observation of shadows of screw under loading on the screen. The evaluation of the torsion rigidity is done with the following expression:

$$\mathbf{T_{EXP} = (W*R_{arm}*L_{screw})*(1/\theta)} \qquad \mathbf{(5.4)}$$

Where W is Loads hanged, and θ twist angle of power screw.

The experimental values of torsional rigidity are included in the following single row matrix.

$T_{EXP}=10^{10}$[0.0477 0.1146 0.2507 0.4584 0.9167 1.2892 1.8144 2.4064] (5.5)

The correlation of theoretical results and the experimental results for eight power screws is shown in Fig.4.1. It can understand that torque carrying capacity of all power screws examined increases as nominal diameter increases. The experimental values are very nearer to the model-1 for the lead screws having nominal diameter less than 30mm.The model-2 values are slightly more than the experimental values for the screws above 300mm nominal diameter.

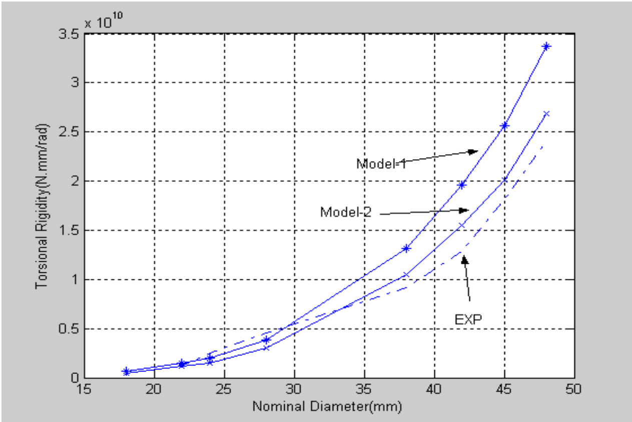

Fig.4.1: Correlation between theoretical models and Experimental values

VI. CONCLUSIONS

Torsional rigidity of lead screws is determined theoretically and experimentally in the present paper. An experimental set up is designed and fabricated to test the lead screws or power screws for torsional rigidity. Optical lever method is employed for finding out for the angle of twist. Lead screws with various sizes and pitches are taken as test specimens and are tested. Two theoretical models are developed for evaluating torsional rigidity. The experimental results are found close to model -1 for power screws up to 30mm nominal diameter. Model-2 results are nearer to experimental results for screws having more than 30mm nominal diameters.

VII. ACKNOWLEDGEMENT

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