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Review Paper on Design and Analysis of Solid and Hollow Helical Coil Spring

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Abstract:

Helical coiled springs are used as an integral part of many mechanical systems. Helical spring is also used in several industrial applications like balancing, brakes, vehicles suspensions in order to satisfy required functions. It applies forces, store or absorb energy, provide the mechanical system with the flexibility and maintain a force or a pressure. A mechanical spring is defined as an elastic body which has the primary function to deflect or distort under load, and to return to its original shape when the load is removed. The main objective of this review paper is to analyze various types of methods, formulas and theories used for the calculation of different stresses in helical coil spring.

Keywords-Helical spring, hollow and solid cross section, Particle damping, Analysis

Introduction:

Helical (Or) Coil Spring

A coil spring, also known as a helical spring, is a mechanical device which is typically used to store energy and subsequently release it, to absorb shock, or to maintain a force between contacting surfaces. They are made of an elastic material formed into the shape of a helix which returns to its natural length when unloaded.[1]

Types Of Helical Spring

- Open coiled helical spring
- Closed coiled helical spring

Open Coiled Helical Spring

It is also known as **compression spring**. Since the open-coiled helical springs are not wound very tightly, the pitch of the spring is much greater. Due to the space between the coils, one round of the spring does not lie in the same plane as the axis of the helix. Hence, no two turns of a spring will lie in the same plane. As compared to closed coiled helical springs, where the angle formed between the turn and the helical axis is 90˚, the turns of the open coiled helical springs form an inclined angle with the helical axis. The pitch and the distance between the coils is the major point of distinction between the two types of helical springs.[1]

Closed Coil Helical Spring

It is also known as **tension or extension** spring because the wire undergoes torsion. Here, the torsional stress is extremely high. It is caused by the twisting of the spring. It also mitigates any bending stress. If the helix is said to lie in a plane, then the turns of the spring are at right angles to the axis of the helix. This is possible because the springs are wound very tightly.[1]

Applications of helical spring:

Open coiled helical spring:

Open coiled helical spring is used many applications. Give below some application is mentioned.

- Ball point pens
- Pogo sticks
- Valve assemblies in engines
- Automobile shock absorbers

Closed coiled helical spring:

Open coiled helical spring is used many applications. Give below some application is mentioned.

- Garage door assemblies
- Vice-grip pillars
- Carburettors
- Cycle stand

Desgin Calculation Of Helical Spring

Chinnamahammadbhasha ISSN: 2395 -0056 lays down the design calculation of a helical spring made from circular section wire. The shock absorber is made up for four different materials. There are spring steel, phosphor bronze, beryllium bronze, and titanium alloy. The stress intensity and displacement vector are less titanium alloy then other materials. So the best material of spring is Titanium is best. [3]C.Madan Mohan Reddy is covers that design calculation of helical spring shock absorber. At the same time he's is give a comparative study of theoretical value, analytical values, and experiment values of chrome vanadium steel and hard drawn steel. [4]Pinjarla. Poornamohan, is focus on design calculation of helical spring and also introduction of FEA. The shock absorber is made from spring steel and beryllium copper. By comparing of the results for materials the stress value is less then spring steel compared to beryllium copper. So spring steel is better for making helical spring. [5]ThoratSwapnil C, is compared the two type of design one is 8mm wire diameter and another one is 10mm wire diameter. The results of the both design the 10mm wire more suitable for making two wheeler suspensions system. [6]

Design procedure:

Design calculation of solid spring

$\tau = k8WD/\pi d^3 = k8WC/\pi d^2$

$D = Cd$

$\delta = 8WC^3 n/dG$

$n' = n + 2$

$K = W/\delta$

$L_S = n'd$

$L_F = n'.d + \delta_{max} + (n' - 1) \times 1$

$p = L_f/n' - 1$

$W_s = \rho * \pi d^2 * \pi D n'/4$

Where,

D= Mean diameter of the spring coil

d=diameter of the spring wire

n=Number of active coils

G= Modulus of rigidity for the spring material

W=Axial load on the spring

τ =Maximum shear stress induced in the wire

C=Spring index =D/d

p= Pitch of the coils,

W_S=Weight of solid wire spring

Design calculation of hollow spring

$\tau = K8WDd_0/\pi(d_0^4-d_i^4)$

D=Cd

$\delta=8WD^3n/(d_0^4-d_i^4)G$

n'=n+2

$K=W/\delta$

$L_S=n'd_0$

$L_F = n'.d + \delta_{max} + (n' - 1) \times 1$

$p=L_f/(n'-1)$

$W_H=\rho*\pi*(d_0^2-d_i^2)*\pi Dn'/4$

Where,

d_o=outer diameter of the spring wire

d_i=inner diameter of the spring wire

W_H=Weight of hollow wire spring

Weight Reduction Technique:

Dhareshwar S Patil, [2] ISSN – 2455-0620 is proposed that hollow helical spring idea. Hollow spring is made up of same dimension of spring index, same material and same spring rate. Making the hollow spring is achieve the all properties of a solid helical spring and also with a benefit of weight reduction.Making the spring wire hollow we can achieve the all properties that a solid wire spring can have with benefit of reducing the weight of spring. As seen in this study weight reduced is 22.44 % analytically as well as by ANSYS and is 24.87 % physically. Thus material cost is reduced by the same amount.

L. Del Llano-Vizcaya et al. (2006) In this paper author used a critical plane approach, Fatemi–Socie and Wang–Brown, and the Coffin–Manson method based on shear deformation. The stress analysis was carried out in the finite element code ANSYS, and the multiaxial fatigue study was performed using the fatigue software nCode and compared with experimental results in order to assess the different criteria. A failure analysis was conducted in order to determine the fatigue crack initiation point and a comparison of that location with the most damaged zone predicted by the numerical analysis is made. The M (Manson) method to estimate strain-life properties from the monotonic uniaxial tension test, gives better predictions of the spring fatigue lives than the MM (Muralidharan) method.[12]

C. Berger, B. Kaiser et al. (2011) In this paper the author presents a long-term fatigue tests up to a number of 109 cycles on shot peened helical compression springs with two basic dimensions, made of three different spring materials. The test springs were manufactured of oil hardened and tempered of SiCr and SiCrV-alloyed valve spring steel wires and of a stainless steel wire with diameters of 1.6 mm and 3.0 mm with shot peened. Method to be used experimental procedure the VHCF-test on spring. It becomes obvious that the various spring types in test exhibit different fatigue properties and different failure mechanisms in the VHCF regime.[13]

Chang-Hsuan Chiu et al. (2007) In this paper the author present, four different types of helical composite springs were made of structures including unidirectional laminates (AU), rubber core unidirectional laminates (UR), unidirectional laminates with a braided outer layer (BU), and rubber core unidirectional laminates with a braided outer layer (BUR), respectively. It aims to investigate the effects of rubber core and braided outer layer on the mechanical properties of the aforementioned four helical springs. According to the experimental results, the helical composite spring with a rubber core can increase its failure load in compression. Therefore, author wants to say that the shock absorbers with high performance might be expected to come soon.[14]

Y. Prawoto et al. (2008) author gives an automotive suspension coil springs, their fundamental stress distribution, materials characteristic, manufacturing and common failures. A coil's failure to perform its function properly can be more catastrophic than if the coil springs are used in lower stress. As the stress level is increased, material and manufacturing quality becomes more critical. This paper discusses several case studies of suspension spring failures. The finite element analyses of representative cases were finite element modeling in metallurgical failure analysis synergizes the power of failure analysis into convincing quantitative analysis.[15]

Mehdi Bakhshesh et al. (2012) In this paper author used helical spring is the most common used in car suspension system, steel helical spring related to light vehicle suspension system under the effect of a uniform loading has been studied and finite element analysis has been compared with analytical solution and steel spring has been replaced by three different composite helical springs including E-glass/Epoxy, Carbon/Epoxy and Kevlar/Epoxy. Numerical results have been compared with theoretical results and found to be in good agreement.[16]

C. Berger, B. Kaiser (2006) In this paper the author presents the first results of very high cycle fatigue tests on helical compression springs. The springs tested were manufactured of Si–Cr-alloyed valve spring wire with a wire diameter between 2 and 5 mm, shot-peened and the fatigue tests are continued up to 108cycles or even more. The aim should be to elaborate results about and insights concerning the level of the fatigue range in the stress cycle regime up to 109cycles, about the mechanisms causing failures and about possible remedies or measures of improvement.[17]

Analysis of Helical Spring

Jinhee Lee, is said that pseudospectrol method is applied to the free vibration analysis of helical spring. In the spectral methods it is assumed that u(x), the solution to the differential equation with homogeneous boundary condition, can be approximated by a sum of K basis functions fk(x).[7]DammakFakhreddine is focus an efficient two nodes finite element with six degrees of freedom per node, capable to model the total behaviour of a helical spring. The formulation, which includes the shear deformation effects, is based on the assumed forces hybrid approach. The resultant forces approximation verifies exactly the resultant equilibrium equations. [8]M. Gürgöze, S. Zeren, n n the technical literature, many vibrational systems from the real life are modelled as Bernoulli–Euler beams to which are attached an arbitrary number of spring-mass systems. There is a vast amount of publications on this subject, some of which are cited representatively. [9]Rajkumar V. Patil, P. Ravinder Reddy and P. Laxminarayana, From the analysis of both theoretical and practical data, it is clear that values from theoretical and practical data related to cylindrical and conical are closer to each other with difference of 2% - 4% between them. Hence the newly developed equation by the authors for conical springs gets verified. [10]P. D. Belapurkar, S.D. Mohite, M.V. Gangawane, D. D. Doltode are told that mechanical springs used in any machine hold its own stiffness value. This stiffness/ spring ratechanges according to different springs and its application. Stiffness of any spring is an important factor as faras its application is considered. Hence in industries many methods are used to test and calibrate springs. Manymethods are been used to test springs such as hydraulic actuators or by applying external load etc. [11]

Chaudhury and Datta [18] used analytical and numerical methods to analyze “prismatic springs of non-circular coil shape” and “non-prismatic springs of circular coil shape”. To obtain the axial deformation of the springs under axial load, several analytical formulations are demonstrated by the authors. Finite element analysis of the springs along with their results have been carried out and comparison was made between different springs and cylindrical spring. With that, their merits compared to a common spring were also established. The authors also presented a fairly accurate analytical formulation for obtaining the value and location of maximum shear stress for all the springs (with maximum error of 7–8%). “Analytical formulation” for the “linear elastic buckling” of two springs with circular coil shapes was also done. The findings have shown that the maximum stress was found to be on the higher side for non-prismatic profiles with circular coil shape, independent of the profile the cases concerned .

Yildirim, [19] using the “transfer matrix method”, neglected the initial axial loading and analyzed the free vibrations of helical springs. The author developed a competent procedure to get the overall dynamic transfer matrix which consisted of greater number of coils and large helix angles. Applying the transfer matrix which was resolved numerically, the natural frequencies were attained precisely by the “iteration method for any boundary conditions”. Analysis included, “governing equations for a cylindrical helical bar” and their respective solutions by the “transfer matrix method”. Numerical determination of the overall transfer matrix was also performed. Review of Studies on Helical Compression Springs with a Perspective of Material, Methods and Failure

Chassie et al. [20] further worked on the research done by Becker and Cleghorn for the “buckling of compression springs” with an inclusion of the added effect of “torsion about the axis of the spring”. The researchers stated equations which “govern the initial deflections” and the “buckling behavior of a helical spring” under combined “compression” and “torsion”. The work done by these authors show that as the value of the “slenderness ratio” rises beyond a certain range, the helical spring will buckle at a “small axial compression”. The authors also claimed convey that there is a certain “critical slenderness ratio”, below which the “spring” will not “buckle”. This is shown in the buckling curve. This is dependent upon the “number of turns" of the spring and the magnitude of the "angle of twist". If the angle of twist is increased, the spring would progressively become unstable and would buckle at a smaller deflection. The authors examined various effects on the buckling of the "helical spring". Namely, the number of turns, "angle of twist", "spring index" and "slenderness ratio".

Močilnik et al. [21] discussed a well-known criterion for fatigue limit in order to find maximum fatigue limit of biaxial loaded hollow spring bar. The authors present simple fatigue experiments on spring steel. The different stress states examined were "cyclic torsion" without and with different static compress "normal stresses". The goal of the work was to figure out the optimum "normal stress" on a plane which was in "stress based long life fatigue analysis" and to show agreement between described criterions and experimental results.

Jiang et al. [22] discussed the difficulty related to formulate and satisfy the "governing equations" and "boundary conditions" at the surface of helical spring. Also, the exact analytical solution is difficult to obtain except for few cross sections as circular and rectangular. The results obtained by solving analytically and by FEM for same spring.

Li et al. [23] have established a mathematical model to calculate the curvature, twist of the strands of a stranded wire spring under an axial load. The authors have stated that the spring helix angle and the strand helix angle are major factors which decide the curvature and twist of the spring. These angles have a significant effect on the magnitude of the contact force. The strand helix angle is vital and it decides the number points at which the contact force is maximum.

Fakhreddine et al. [24] attempt to broaden the work done by Taktak et al. [24]. The paper presents "stress analysis" of an "isotropic cylindrical helical spring". A mixed-hybrid formulation was done by the authors to come to a conclusion. They developed a finite "spring element" with two nodes. The proposed model features better accuracy compared to other models. The totality of the spring can be modelled by only one element. Also, distribution of different "stresses" along the "spring" and through the "wire surface" is achievable without the need to mesh the "structure" or its "surface".

Watanabe et al. [25] attempt to develop a new type of suspension spring which could be used in the suspension system of rally cars. The authors tried to develop a rectangular wire type helical spring. The authors in their conclusion also gave their view regarding the stress in different parts of the developed spring. In the end, the authors proposed on how the newly developed spring could be manufactured.

Conculsion:

The study carried out in this work mainly concerned with the dimensions, material and weight reduction in solid and hollow helical coil spring.

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