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REVIEW OF DESIGN AND NUMERICAL ANALYSIS OF HELICAL SPRING USED IN AUTOMOBILE

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ABSTRACT
The main functions of automobile Helical Springs used to isolate the structure and the occupants from shocks and vibrations generated by the road surface. 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 main objective of this research paper is to through some light on the fatigue stress analysis of springs used in automobiles. Theoretical and Numerical 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.

Keywords- *Helical Spring, Maximum shear stress, stiffness, Deflection, fatigue stress, Finite element method.*

I. INTRODUCTION
Suspension systems have been widely applied to vehicles, from the horse-drawn carriage with flexible leaf springs fixed in the four corners, to the modern automobile. The suspension of a road vehicle is usually designed with two objectives; to isolate the vehicle body from road irregularities and to maintain contact of the wheels with the roadway. Isolation is achieved by the use of springs and dampers and by rubber mountings at the connections of the individual suspension components. From a system design point of view, there are two main categories of disturbances on a vehicle, namely road and load disturbances. Road disturbances have the characteristics of large magnitude in low frequency such as hills and small magnitude in high frequency such as road roughness. Load disturbances include the variation of loads induced by accelerating, braking and cornering. Therefore, a good suspension design is concerned with disturbance rejection from these disturbances to the outputs. Roughly speaking, a conventional suspension needs to be “soft” to insulate against road disturbances and “hard” to insulate against load disturbances. Therefore, suspension design is an art of compromise between these two goals. Today, nearly all passenger cars and light trucks use independent front suspensions, because of the better resistance to vibrations. The main functions of a vehicle’s 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 tires and the vehicle body. The suspension system requires an elastic resistance to absorb the road shocks and this job is fulfilled by the suspension springs. The suspension system requires an elastic resistance to absorb the road shocks and this job is fulfilled by the suspension springs. A spring is defined as an elastic machine element, which deflects under the action of the load & returns to its original shape when the load is removed. Mechanical springs are used in machine designs to exert force, provide flexibility, and to store or absorb energy. Springs are manufactured for many different applications such as compression, extension, torsion, power, and constant force. Depending on the application, a spring may be in a static, cyclic or dynamic operating mode. A spring is usually considered to be static if a change in deflection or load occurs only a few times, such as less than10,000 cycles during the expected life of the spring. A static spring may remain loaded for very long periods of time. The failure modes of interest for static springs include spring relaxation, set and creep.

The main objectives of spring are as follows:
- **To apply force:** A majority industrial, e.g. To provide the operating force in brakes and clutches, to provide a clamping force, to provide a return load, to keep rotational mechanisms in contact, make electrical contacts, counter balance loading, etc.
- **To control motion:** Typically storing energy, e.g. wind-up springs for motor, constant torque applications, torsion control, position control, etc.

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- **To control vibration:** used in essence for noise and vibration control, e.g. flexible couplings, isolation mounts, spring and dampers, etc.
- **To reduce impact:** Used to reduce the magnitude of the transmitted force due to impactor shock loading, e.g. buffers, end stops, bump stops etc.

In practical situations, springs are used to provide more than one of the above functions at the same time. Because of superior strength and endurance characteristics under load, most springs are metallic. However, other resilient materials, e.g. polymers, where special properties such as a low modulus and high internal damping capacity are required.

II. CLASSIFICATION OF SPRING

Leaf spring: Fig.1 shows the plate spring or leaf spring in which the major stresses are tensile and compressive. Leaf springs may be of cantilever type or semi elliptical or elliptical. A leaf spring consists of flat leaves or plates of varying lengths clamped together so as to obtain greater efficiency and resilience.

Fig.1

Cylindrical helical spring: Fig.2 shows cylindrical helical spring which may be in compression or tension. The major stresses produced in this are shear due to twisting. The load applied is parallel to the axis of spring. The cross-section of the wire may be round, square or rectangular. These springs are wound in the form of a helix of a wire.

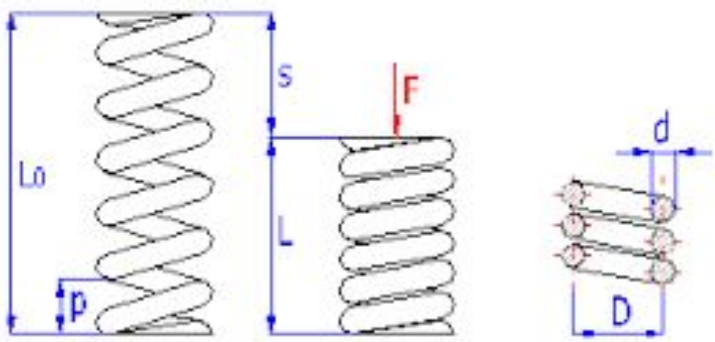

Fig.2

Helical conical spring: Fig.3 is shown a helical conical spring. The major stresses produced in this are also shear due to twisting. If the radius of the coils of a helical spring is constant, then it becomes a cylindrical helical. If a helical spring works in torsion, i.e. the torsional moment is applied about the axis of the helix, then the spring obtained is helical torsion spring. Major stresses produced in this spring are tensile and compression due to bending.

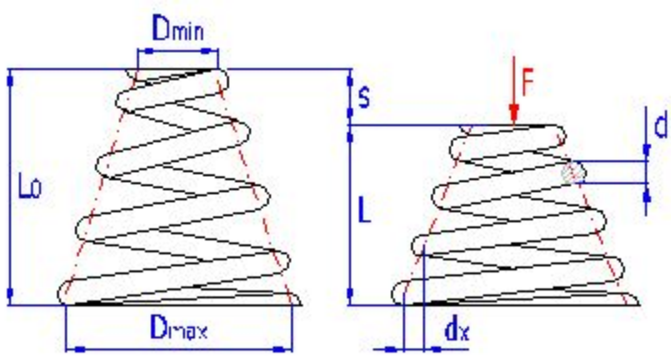

Fig.3

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Spiral spring: If the angle of helix is zero as shown in Fig.4, then it is a spiral spring, consists of a flat strip wound in the form of a spiral and loaded in torsion. The major stresses produced in this are tensile and compression due to bending by load.

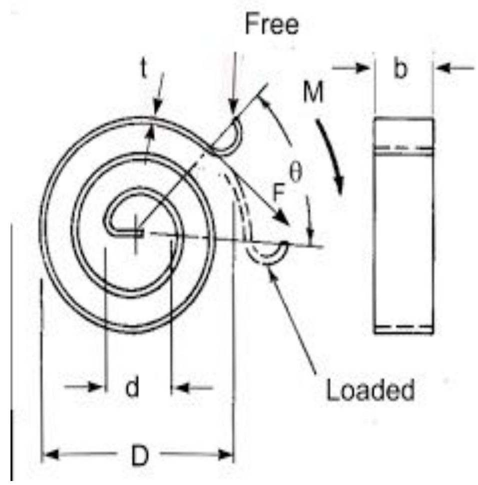
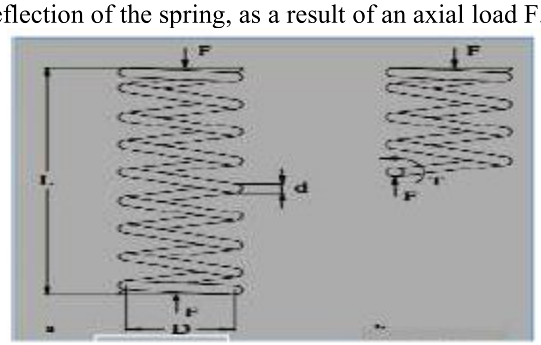


Fig.4

III. STRESSES IN HELICAL SPRINGS OF CIRCULAR WIRE

To determine the stress generated in the spring; consider a helical spring subjected to an axial load F.
Let
D= Mean Diameter of the spring coil,
d = Diameter of the spring wire,
n = No. of active coils,
G = Modulus of rigidity for the spring material,
F = Axial load on the spring,
= Max. Shear stress induced in the wire
C = spring index = D/d
P= Pitch of the coils, and
= Deflection of the spring, as a result of an axial load F.



(a) (b)

Fig.5. (a) Helical Spring With axial load (b) free body diagram

If we remove a portion of the spring, the internal reactions will be a direct shear and a torque T = F×D/2 where each will cause a shear stress, and the maximum shear will occur at the inner surface of the wire which is equal to:

$$\tau_{max} = Tr/J + F/A$$

Substituting T= F× D/2, r= d/2, J = /32 d^4,A= I/4 d^2; gives

$$\tau = \frac{8FD}{\pi d^3} + \frac{4F}{\pi d^2}$$

Defining the spring index which is a measure of coil curvature as:

C = spring index = D/d, for most springs C ranges from 6 to 12 we get:

$$\tau = \frac{2C+1}{2C}\left(\frac{8FD}{\pi d^3}\right) = K_s \frac{8FD}{\pi d^3}$$
$$K_s = \frac{2C+1}{2C} \;;$$

Where Ks is called the "Shear stress correction factor" This equation assumes the spring wire to be straight and subjected to torsion and direct shear. However, the wire is curved and the curvature increases the shear stress and this is accounted for by another correction factor K_C and thus the equation becomes:

$$\tau = K_c K_s \, 8FD / \pi d^3$$

Where Kc is the "curvature correction factor".

The two correction factors are combined together as a single correction factor K_B where:

$$K_B = K_c \times K_s = \frac{4C+2}{4C-3}$$
$$\tau = K_B \frac{8FD}{\pi d^3}$$

Deflection of Helical Springs:
The deflection-force relation can be obtained using Castiglione's theorem. The total strain energy in the spring wire has two components torsional and shears.

$$U = \frac{T^2 L}{2GJ} + \frac{F^2 L}{2AG}$$

Substituting for T, A & J and knowing that L= DN Where N = Na is the Number of active coils, we get:

$$U = \frac{4F^2 D^3 N}{d^4 G} + \frac{2F^2 DN}{d^2 G}$$

Applying Castiglione's theorem to get the deflection "F";
Since c= D/d, we can write

$$\delta = \frac{\partial y}{\partial x} = \frac{8FD^3 N}{d^4 G} + \frac{4FDN}{d^2 G}$$

[1+ $1/c^2$ = the effect of transverse shear is neglected]
Knowing that the Spring Rate, k= F/

$$k = \frac{d^4 G}{8D^3 N_a}$$

Where Na= Number of active coils

IV. CONCEPT OF SPRING DESIGN

The design of a new spring involves the following Considerations:

- Space into which the spring must fit and operate.
- Values of working forces and deflections.
- Accuracy and reliability needed.
- Tolerances and permissible variations in Specifications.
- Environmental conditions such as temperature, presence of a corrosive atmosphere.
- Cost and qualities needed.

The designers use these factors to select a material and specify suitable values for the wire size, the number of turns, the coil diameter and the free length, type of ends and the spring rate needed to satisfy working force deflection requirements. The primary design constraints are that the wire size should be commercially available and that the stress at the solid length be no longer greater than the torsional yield strength.

Spring materials:

One of the important considerations in spring design is the choice of the spring material. Springs are usually made from alloys of steel. The most common spring steels are music wire, oil tempered wire, chrome silicon, chrome vanadium, and 17-7 stainless. Other materials can also be formed into springs, depending on the characteristics needed. Some of the more common of these exotic metals include beryllium copper, phosphor bronze, Inconel, Monel, and titanium. Titanium is the strongest material, but it is very expensive. Next come chrome vanadium and chrome silicon, music wire, and oil tempered wire. The stainless steel materials are cold rolled & drawn, heat treated after forming, resists corrosion when polished, good temp. resistance all than material. Some of the common spring materials are given below.

Structural Steel: This is cold drawn, cheapest spring steel. Normally used for low stress and static load. The material is not suitable at zero temperatures or at temperatures above1200^0C.

Chrome Vanadium: This alloy spring steel is used for high stress conditions and at high temperature up to 2200^0C. It is good for fatigue resistance and long endurance for shock and impact loads.

Chrome Silicon: This material can be used for highly stressed springs. It offers excellent service for long life, shock loading and for temperature up to 2500^0C.

Stainless steel: Widely used alloy spring materials.

The following table shows the physical properties of spring materials:

Table: - 1 Physical properties of spring materials

Material	Analysis		Tensile Properties			Torsional Properties of wire			Properties of Material
	Element	percentage	Ultimate Strength, MN/m^2	Elastic Limit, MN/m^2	Modulus of elasticity, MN/m^2	Ultimate Strength, MN/m^2	Elastic Limit, MN/m^2	Modulus of torsion, MN/m^2	
Structural Steel	C Mn	0.60-0.70 0.60-1.20	1035 2060	685 1380	0.200×10^6	830 1520	520 90	0.07845×10^6	Cold drawn but lower quality wire
Chrome Vanadium	C Mn	0.45-0.55 0.50-0.80	1380	1240	0.206×10^6	965	690	0.07845×10^6	Cold rolled & drawn
Chrome Silicon	C Mn	0.55-0.65 0.60-0.90	About the same as chrome Vanadium			About the same as chrome Vanadium			Hot & Cold rolled, used as lower cast mat.

Stainless steel	C Cr Si	0.25-0.40 12-14 0.30-0.75	1180 1725	930 1380	$0.193x10^6$	830 1650	550 830	$0.07551x10^6$	Cold rolled & drawn, resists corrosion Good Temp

V. LITERATURE REVIEW

Abhimanyu Singh al

In the present scenario due to cutting edge competition among industries, worldwide focus is more and more on enhancing the design feasibility, manufacturing process and selection of material of the product. This thesis is a sincere effort of applying the concept of reverse engineering which is being used by the designers in order to redesign the product to achieve several targets. Along with implementation of RE in this thesis attempt is also made to analyse different engineering materials. As per as reverse engineering is concerned a front suspension system of a automobile is taken and complete drawing/measurement is taken approximately and modelled in CREO design software .Further to analyse the model created it is meshed in ANSYS and analysis of coil spring is done by assignment of materials like structural , stainless and chromium vanadium steel .Overall intention of the thesis is to understand the concepts of reverse engineering , designing and analysis with knowledge of engineering materials by using suspension model.

Mr. J. J. Pharne al

All two-wheelers are provided with a facility of a horn to be used to make aware of the presence of the vehicle on road and to maintain a safe distance between two vehicles or to communicate for any other safety reasons. The horn is a crucial element as it is directly related to safety of the vehicle and the person using it. Thus the horn is most important element in the vehicle system and hence it is expected to function properly for a longer time. Most problems of failure of two wheeler horns are due to fatigue failure of spring element in warranty period. A finite element model for helical compression springs subjected to cyclic loads (compression) is developed for fatigue stress analysis. In the design modification of this kind of spring both the elastic characteristics and the fatigue strength have to be considered as significant aspects. A typical helical compression spring used for two wheeler horn is chosen for study under fatigue loading condition. Fatigue analysis is done in ANSYS 14.0 software. The results developed have been compared with the experimental observations. A new design modification is done by introducing another spring coaxially.

N.Lavanya al

The suspension system is used to observe the vibrations from shock loads due to irregularities of the road surface. It is perform its function without impairing the stability, steering (or) general handling of the vehicle. Generally for light vehicles, coil springs are used as suspension system. A spring is an elastic object used to store mechanical energy and it can be twist, pulled (or) stretched by some force and can return to their original shape when the force is released. The present work attempts to analyze the safe load of the light vehicle suspension spring with different materials. This investigation includes comparison of modeling and analyses of primary suspension spring made of low carbon-structural steel and chrome vanadium steel and suggested the suitability for optimum design. The results show the reduction in overall stress and deflection of spring for chosen materials.

Dammak Fakhreddine al

This paper presents 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. The developed model proves its accuracy compared with other elements. This element permits to get the distribution of different stresses along the spring and through the wire surface by only one element.

Supriya Rahul Burgul al

In the Internal Combustion Engine, valve opening and closing is done by cam follower mechanism with the help of helical compression spring. As per the failure data, percentage ratio of premature fatigue failure of an exhaust valve spring of a constant speed I.C. engine is more. So the springs must be designed for reliability. The major loading on the springs happens during the start/stop time causing an oscillatory displacement. The springs must be designed to support the fatigue process. For safety, the life of the spring is expected to be about 50,000 cycles as per the standards, for particular frequency of applied load. Static and fatigue analysis of compression spring used for IC Engine valve of a two-wheeler is carried out using simulation software for better design features, better performance and long life. The spring is modelled using CAD software CATIA V5. This is further evaluated using FEA software (CAE) for Fatigue Analysis (MSC Fatigue) since the spring is subjected to cyclic loading. The analysis established the expected life of the spring while it is subjected to the predetermined loads during its operation. The analysis for fatigue life has been done by making few design changes and performing numbers of iterations. By comparing the fatigue life of modified springs higher life spring design is finalized. To verify new design the Fatigue test experimentation is carried out on the fatigue test machine.

Rahul Tekade al

Shock absorbers are devices that smooth out an impulse experienced by a vehicle, and appropriately dissipate or absorb the kinetic energy. Almost all suspension systems consist of springs and dampers, which tend to limit the performance of a system due to their physical constraints. Suspension systems, comprising of springs and dampers, are usually designed for passengers' safety, and do little to improve passenger comfort. To meet the current demands of high speed and safety we must designed and developed such a shock absorber which can sustain more and more vibrations and also improves the safety.

Mr. S. S. Gaikwad al

The work is focused on quantifying the fatigue life analysis of a spring. A fatigue testing machine used to assess the fatigue life variation. The suitability of stainless steel compression spring on two-wheeler horn selected for analysis. Material is selected upon the fatigue life and tensile strength factor. The objective is to present experimentation, modeling and analysis of compression spring for fatigue. Experimentation is carried out using fatigue life analysis fatigue testing machine (M08) is used. Modeling is done using CATIA V5 and ANSYS. Analysis is carried out by using HYPERMESH as a pre-processor NASTRAN as a solver And Hyper view as a post processor.ANSYS14.0 software also used for analysis for better understanding and comparison result with NASTRAN.The axial fatigue study was performed using the fatigue software MSC-FATIGUE as well as in ANSYS. It is observed that the fatigue life of spring is very good. It is safe for design and manufacturing.

Sid Ali Kaoua al

This paper presents a 3D geometric modelling of a twin helical spring and its finite element analysis to study the spring mechanical behaviour under tensile axial loading. The spiralled shape graphic design is achieved through the use of Computer Aided Design (CAD) tools, of which a finite element model is generated. Thus, a 3D 18-dof pentaedric elements are employed to discretise the complex ''wired-shape" of the spring, allowing the analysis of the mechanical response of the twin spiralled helical spring under an axial load. The study provides a clear match between the evolution of the theoretical and the numerical tensile and compression normal stresses, being of sinusoidal behaviour. The overall equivalent stress is values increases radially from 0^0 to 180^0, being maximal on the internal radial zone at the section 180^0. On the other hand, the minimum stress level is located in the centre of the filament cross section.

B. Pyttel al

Long-term fatigue tests on shot peened helical compression springs were conducted by means of a special spring fatigue testing machine at 40 Hz. Test springs were made of three different spring materials – oil hardened and tempered SiCr- and SiCrV-alloyed valve spring steel and stainless steel. With a special test strategy in a test run, up to 500 springs with a wire diameter of d = 3.0 mm or 900 springs with d = 1.6 mm were tested simultaneously at different stress levels. Based on fatigue investigations of springs with d = 3.0 mm up to a number of cycles N = 109 an analysis was done after the test was continued to $N = 1.5 \times 10^9$ and their results were compared. The influence of different shot peening conditions were investigated in springs with d = 1.6 mm. Fractured test springs were examined under optical microscope, scanning electron microscope (SEM) and by means of metallographic micro sections in order to analyse the fracture behaviour and the failure mechanisms. The paper includes a comparison of the results of the different spring sizes, materials, number of cycles and shot peening conditions and outlines further investigations in the VHCF-region.

VI. CONCLUSION

The literature review discussed above that the design of mechanical springs used in automobiles is quite necessary to do it's deign analysis which involves stress distribution analysis, maximum displacement and different mode of failure. The springs undergo the fluctuating loading over the whole span of service life. In addition, various design software's like ANSYS, Solid Works, Pro-E, CATIA, Autodesk Inventor, etc., have been used for performing the stress analysis of mechanical springs. Almost in all of the above cases, fatigue stress, shear stress, maximum displacement calculation, play significant role in the design of mechanical springs. This study shows that shear stress and deflection equation is used for calculating the number of active turns and mean diameter in helical springs. Comparison of the theoretical results obtained by the shear stress equation and Finite Element Analysis (FEM) of springs provides the better solution of the problems arises in the existing design of the mechanical spring. In future, it will help the designers for predicting the safe design of mechanical springs used in the automobiles to get better and comfortable ride.

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