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Finite element analysis approach for enhancement of fatigue life of suspension coil spring

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ABSTRACT

This paper deals with the Finite Element Analysis approach for Enhancement of fatigue life of passenger car Suspension Coil Spring. Suspension system is very essential part of the automobile vehicle. Stability and Comfort is totally depended on the Suspension system. Coil spring being a part of suspension system subjected to numerous influences in service life. The suspension system for a small sized car, especially for the front wheels, uses Macpherson struts. This system uses helical springs to offer resilient suspension system absorbing shocks during motion of the vehicle. The process of absorbing the shocks is brought about by storing and releasing the shock energy on a gradual time scale. The effort for this work is to determine the fatigue life of the existing coil spring on the car and identify areas of improvement over the fatigue life. Finite Element Analysis approach deployed for the structural analysis using Preprocessor while the fatigue life predicted using solver. For this work, experimentation performed on the existing suspension coil spring for validating the performance parameter identified as `Stiffness' of the spring. The load vs. displacement recorded using load cells with data logger to display results. The results of Experimental work compared for results with the numerical methodology and vice-versa. The concurrence of the result offered validation for this thesis work. Variants of Suspension coil spring will be proposed for study and analysis of improved fatigue life by changing the design configuration and alternative material having better mechanical properties. Recommendation will be made at the conclusion stage of the dissertation work in terms of enhanced fatigue life of Suspension Coil Spring with optimized design.

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I. INTRODUCTION

A coil spring, also known as a helical spring, is a mechanical device, which is typically used to store energy due to resilience 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.

Coil Springs play a major role in any car's suspension system. Coil springs are the metal coils, which compress to the pressure or absorb shocks as the car is driven. The way coil spring is built allows it to ensure the smoothest ride even on good roads.

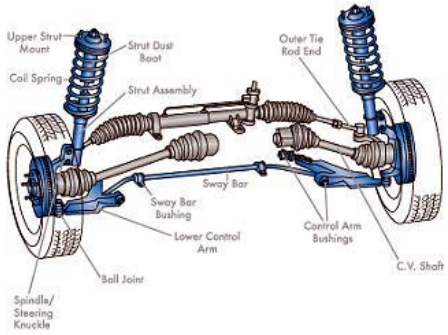

Figure 1: Suspension Spring (Coil)

Springs are vital to vehicles because they support the weight of your car and allow it to remain stable even in rough driving conditions. They have the ability to expand when you hit dips on the road and compress when you encounter bumps or cut into hard corners. can also keep your trunk off of the ground and determine ride height, which in turn influence steering and suspension. There are different types of springs for each kind of automobile and truck depending on your vehicle's suspension design, but the most common is the coil spring. The energy absorption capability of a spring is measured as a spring rate. The spring rate is the ratio of energy absorbed; per distance the spring is flexed. A coil spring is a length of flexible wire wound into a coil. The coil shape allows the spring to flex in a linear path against itself. Coil spring rate is determined by coil wire material (steel, titanium, carbon fibre, etc.), coil wire thickness, and the length of the active coil wire. Helical compression springs are known in which the wires or rods employed for their manufacture have a constant circular cross section over their entire length. The end windings of these springs are particularly in danger of breaking, mainly at those points where they lift off from the spring discs. At these points, which in theory constitute the clamping points of the helical spring, there occur, during use, rolling and friction movements between the end windings and the spring discs. After a short time these movements destroy the corrosion protection layer of the spring wire and its outer layer, which has been reinforced by shot peening and loaded with internal pressure stresses.

II. Problem Statement

The coil spring being a part of suspension system; it is subjected to numerous influences in service life. The suspension springs are also subjected to road conditions and driving maneuvers. Hence it is needed to check the fatigue strength of spring to have better and problem free service life. The fatigue strength of suspension springs is vitally affected by material properties, coating and environmental influences. There will be chances of accident if spring fails. The accident may lead to injury to the occupants and/ or damage to the vehicle. In this dissertation work we will be analysing the suspension spring for passenger car in order to predict its fatigue life. The intended effort is directed towards the future launch for the variant of the passenger.

Figure 2: Macpherson Strut (Coil spring)

III. Scope and Objective

A. Scope

The design of the existing spring shall be evaluated using Computational Methodology while engaging suitable CAE tools. The geometry of the spring shall be the input for this work which shall undergo Finite Element Analysis to determine its fatigue life. Conclusion phase is to include physical experiment for validating ‘stiffness’ of the spring. Recommendation to be offered upon comparison using Test Report

B. Objectives

Following objectives are defined to achieve the desired goal:

1) Study of the application of suspension spring.
2) Benchmarking the existing variant for FE analysis
3) Performing validation using physical experimentation as alternative methodology
4) Proposing the design alternatives while engaging analytical methodology (FEA)
5) Recommendation for improved fatigue life

IV. Importance of Spring Design & Analysis

The suspension system significantly affects ride and handling of the vehicle that is 'vibrational' behaviour including ride comfort, directional stability, steering characteristics and road holding. Generally, suspension system can be broadly classified as dependent and independent types. Independent suspension (i.e. double wishbone, McPherson and multilink) leads to better ride and handling capabilities. It is important to analyze the suspension systems that have been designed to predict the behavior of the system than followed with improvements. The suspension must be properly designed because it is a crucial subsystem in vehicle in order to:

- Carry the weight of vehicle and also its weight (unsprung weight).
- Keep the wheels perpendicular to the road for maximum grip resultant good ride and handling performance.
- Take the forces for accelerating or breaking the vehicle.

- Ensure that steering control is maintained during maneuvering.
- Take the forces involved when cornering the vehicle.

V. LITERATURE REVIEW

Literatures survey study gathered regarding the information about the fatigue stress for the helical compression spring. Springs are mechanical shock absorber system. 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 researchers throughout the years had given various research methods such as Theoretical, Numerical and Experimental. Researchers employ the Theoretical, Numerical and FEM methods. Study concludes Finite Element method is the best method for numerical solution and calculating the fatigue stress, life cycle and shear stress of helical compression spring.

Senthil Kumar, Vijayarangan, [1] studied the fatigue life of composite leaf spring is predicted to be higher than that of steel leaf spring. Life data analysis is found to be a tool to predict the fatigue life of composite multi leaf spring. It is found that the life of composite leaf spring is much higher than that of steel leaf spring.

S. S. Gaikwad, P. S. Kachare, [2] depicts about how to prevent the accident and to safeguard the occupants from accident, horn system is necessary to be analyzed in context of the maximum safe load of a helical compression spring. In this work, helical compression spring is modeled and static analysis is carried out by using NASTRAN software. It is observed that maximum stress is developed at the inner side of the spring coil.

Y. Prawoto, A. Nishikawa, [3] investigated a discussion about automotive suspension coil springs, their fundamental stress distribution, materials characteristic, manufacturing and common failures. An in depth discussion on the parameters influencing the quality of coil springs is also presented.

Matthias Decker1, Steffen Rödling1, Manfred Hück, [4] depicts fatigue strength of suspension springs in service life is subject to numerous influences. Besides the mechanical loading, determined by the kinematics of the suspension system, road conditions and driving maneuvers, fatigue strength of suspension springs is vitally affected by material properties, coating and environmental influences. Typical failure modes of suspension springs and their causes can be divided into several groups like static and cyclic loads, geometry and dimensions, manufacturing influences, mechanical defects of coating or steel surface, corrosion, fretting corrosion and imperfection of steel purity. This paper covers influence of mechanical loading taking into account the influences of the kinematics of the suspension system, environmental conditions and steel purity. This leads to a comprehensive experimental validation strategy for suspension springs. Also statistical effects are discussed that have to be taken into account for a safe proof out.

Taufik M. Mulla, Sunil J. Kadam, Vaibhav S. Kengre, [5] “Finite Element Analysis of Coil Spring for Three Wheeler Automotive Front Suspension” deals with the stress analysis of a helical coil compression spring, which is employed in three wheeler’s auto-rickshaw belonging to the medium segment of the Indian automotive market. In the design of this kind of spring both the elastic characteristics and the fatigue strength have to be considered as significant aspects. In addition to this particular elastic property, as a consequence of the research effort in reducing the mass of components typical of the automotive industry, these springs have to face very high working stresses. The structural reliability of the spring must therefore be ensured. So for this purpose the static stress analysis using finite element method has been done in order to find out the detailed stress distribution of the spring.

Gadhia Utsav D., Prof. Sumant P. Patel, [6] investigated about Suspension system is a very essential part of the automobile vehicle. Stability and comfort is totally depended on the suspension system of vehicle. Basically, suspensions are employed to deal with hump in road surface, in other words, enhancing ride comfort. The function of suspension system is to absorb vibration due to irregularities of road conditions. So in every car suspension system must be designed for the capacity of the vehicle. It means passenger should be designed for 5 people.

N. Lavanya, P. Sampath Rao, M. Pramod Reddy, [7] gives information about 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.

S. N. Gundre, P. A. Wankhade, [8] depicts about the finite element analysis of a helical compression spring, which is employed in electric three wheelers as per considering various road conditions in India. In the design of this kind of spring both the elastic characteristics and the fatigue strength have to be considered as significant aspects. In addition to this particular elastic property, as a consequence of the research effort in reducing the mass of components typical of the automotive industry, these springs have to face very high working stresses. The structural reliability of the spring must therefore be ensured. So for this purpose the static stress analysis using finite element analysis gives Von-Mises stresses and total deflection of helical compression spring at various loads.

P. S. Valsange, [9] gives report of a review of fundamental stress distribution, characteristic of helical coil springs. An in depth discussion on the parameters influencing the quality of coil springs is also presented. Factors affecting strength of coil spring, F.E.A. approaches by the researchers for coil spring analysis are also studied. Reduction in weight is a need of automobile industry. Thus the springs are to be designed for higher stresses with small dimensions. This requires critical design of coil springs. This leads to critical material and manufacturing processes. Decarburization that was not a major issue in the past now becomes essential, to have better spring design.

VI. Design Of A Helical Compression Spring under Axial Load

The primary design constraints are that i) the wire size should be commercially available and that the stress at the solid length be no longer greater than the torsional yield strength. ii) Functioning is expected to be stable. The maximum shear stress at the inside of the coil given by, τ_{max} = KB*8*P*D/ (π*d3), Where, K = (4C+2)/ (4C-3)and is called as Bergstrasser's factor and used for considering stress correction because of curvature effect and C = D/d is called as spring index. Stress obtained by the imperial result can be cross checked by finite element method for better understanding of the stress distribution. The deflection of spring end δ can be calculated as $\delta = (8PD^3N/Gd^4)$ where, P is the axially applied load.

VII. Adopted Methodology

The static and fatigue analysis has been performed on the existing available compression spring using CAE tools. Number of iterations has been performed for design parameters to finalize a new design for higher fatigue life

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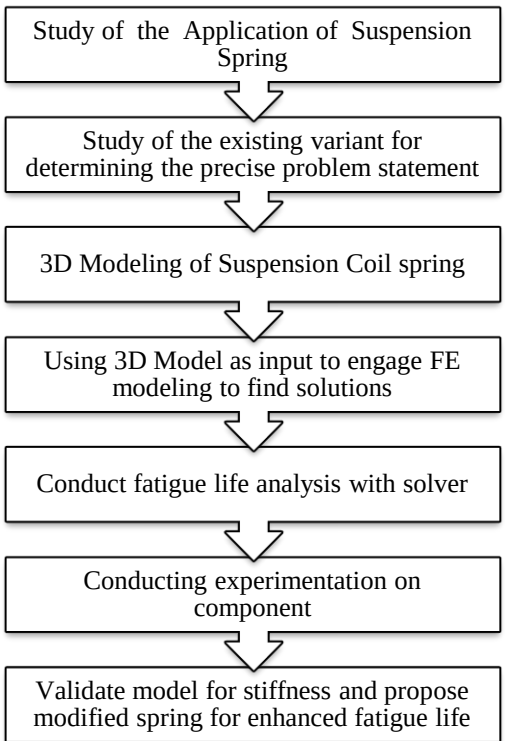


Figure 3: Flow Chart of Methodology

The above said work was planned in following phases.

Phase I: Study and review of the design for existing suspension coil spring

Journal Papers and Printed data/ catalogues are referred for understanding the previous work done. Study is undertaken for identifying reasons attributable to failure of the spring.

Phase II: Analysis for the compression spring using CAE.

3D CAD model i.e. the Geometry of the spring is used for deploying Finite Element analysis including Fatigue analysis. Results are captured in the form of output parameters (response) like maximum deflection of spring, maximum shear stress and the fatigue life of the spring (no. of cycles).

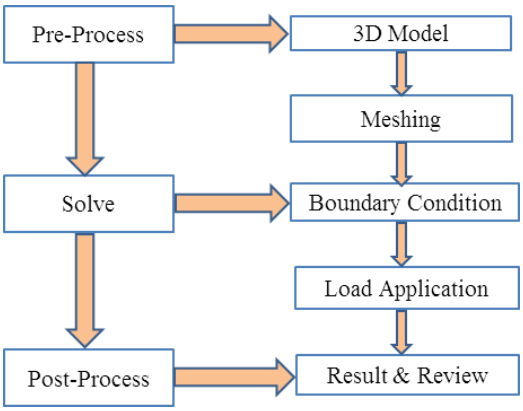
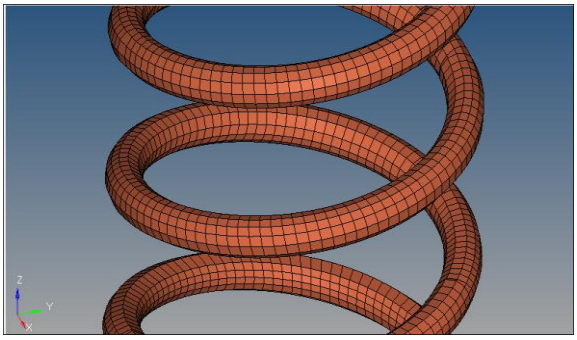


Figure 4: Typical Flow Chart of FEA

A. FEA Pre-processor:

a) Meshed CAD Model of Suspension Spring :



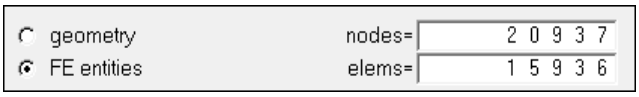


Figure 5(a): Meshed Coil

b) Material properties defined for Static Analysis :

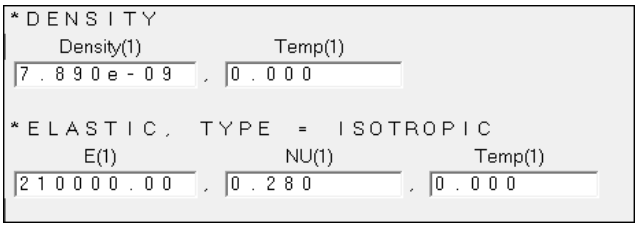


Figure 5(b): Material properties parameters

c) Loading and Boundary Conditions :

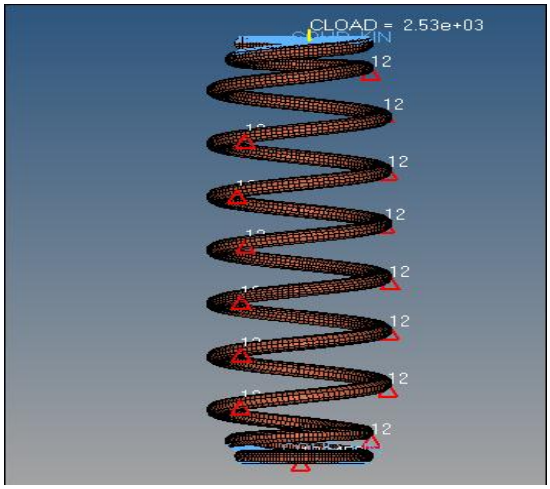


Figure 5(c): Boundary Condition

d) Solver Results for Static Structural Analysis :

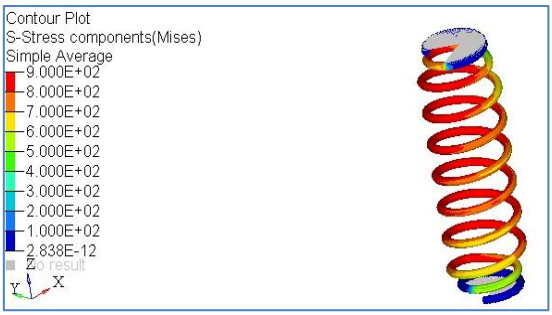


Figure 5(d): Stress plot

Figure 5(e): Displacement plot

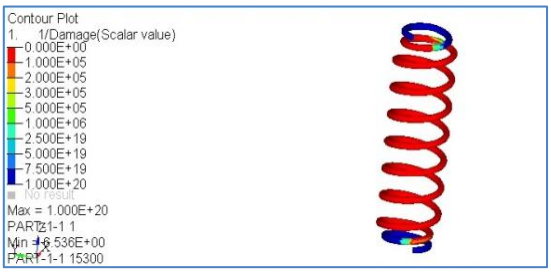


Figure 5(f): Fatigue plot

Phase III: Experimental Validation for Stiffness as performance parameter for existing spring

Figure 6 shows the test setup deployed for determining the stiffness of the suspension spring. Readings are recorded while applying gradual load with the corresponding deformation. Display attached to the machine offered corresponding values and plot for Load Vs Displacement i.e. stiffness of the component.

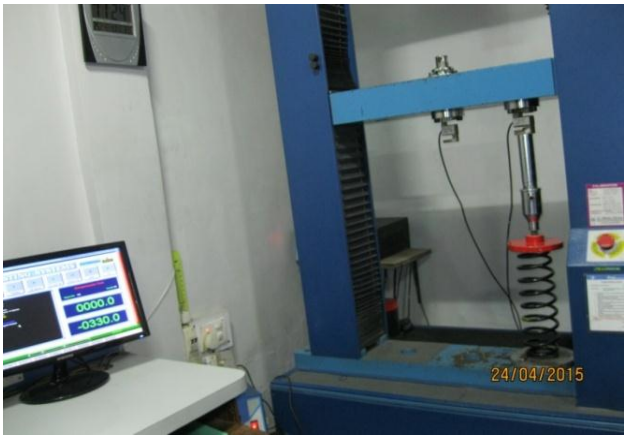


Figure 6: Experimental Set-up

VIII. RESULT AND DISCUSSION

The results from the experimentation are used for validation of Static analysis results. This validation will be taken as an input for enhancement of the fatigue life through solver.

TABLE I

COMPARISON OF DISPLACEMENT VARIATION

Load (N)	FEA (mm)	Experimental (mm)	% Variation
2525	167	160.154	4.3

IX. FUTURE SCOPE

By taking into account the results from the analysis, the new design for the existing compression spring will be proposed. Modification in design parameters such as pitch values and wire diameter will be suggested to enhance the fatigue life of an original spring.

X. CONCLUSIONS

The mechanical properties of the suspension spring along with the configuration of the geometry like the diameter of the wire, the pitch, number of turns, etc affect the performance of the spring in a favorable or adverse manner. Solution offered by Analytical / Numerical techniques has been validated through physical experimentation. The Fatigue life analysis of the suspension coil spring using a FEA technique interface offered credible design inputs which will be used concurrently while designing the spring. The modified design based upon the analysis further subjected to analysis to check the new outcome. This process of iteration will yield to an optimized design which will fit the objective or function.

Expected Outcomes:

- Enhanced fatigue life offer versatility in the use of the spring
- Catastrophic failure can be avoided while improving the safety aspect of the vehicle
- Improvement in `Ride' and `Comfort' of the vehicle as a secondary outcome

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