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ANALYSIS FOR SUSPENSION SPRING TO DETERMINE AND IMPROVE ITS FATIGUE LIFE USING FINITE ELEMENT METHODOLOGY

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ABSTRACT

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 would be 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 would be deployed for the structural analysis using NASTRAN or suitable solver while the fatigue life would be predicted using `MSC Fatigue' or suitable. For this work, experimentation shall be performed for validating the performance parameter identified as `Stiffness' of the spring. The load vs. displacement shall be recorded using load cells with data logger to display results. The results of Experimental work shall be compared for results with the numerical methodology and vice-versa. The concurrence of the results shall offer validation for this thesis work. Variants shall be proposed for study and analysis. Recommendation shall be made at the conclusion stage of the work in terms of generic specs or configuration of the spring.

KEYWORDS: *Fatigue life, Helical Spring, Strut, Suspension System, MSC Fatigue.*

I. INTRODUCTION

A spring is a device that absorbs energy from an applied force. Energy is stored in the spring until the force is released, at which point the spring returns to its original uncompressed position. 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 fiber, etc.), coil wire thickness, and the length of the active coil wire.

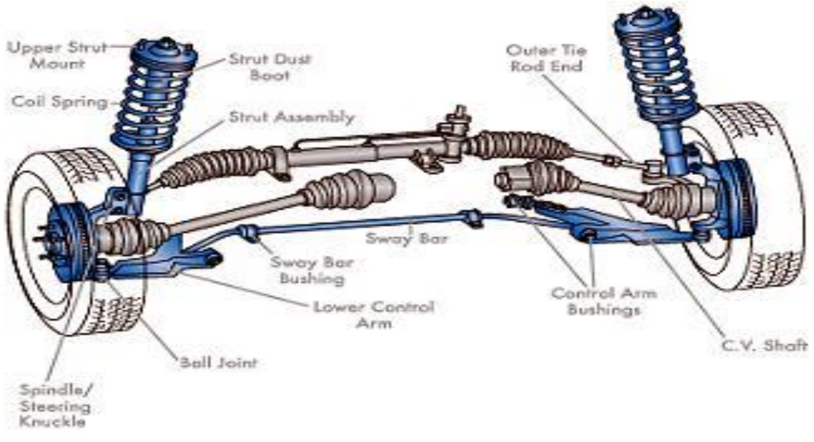


Figure 1: Suspension Spring (Coil)

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. A coil spring (also called helical spring) is a kind of torsion spring which can store energy and release it later when needed. It can also absorb shock and maintain the force between two contacting surfaces. Together with a shock absorber, coil springs are pre-assembled as one coil over unit before installation. While the coil spring compresses and stretches to keep you safe as you drive, the shock absorber keeps you from road noise, bumps, and vibrations that you might encounter while doing so. All in all, a coil over is essential in your vehicle's suspension because it gives you optimal damping, good handling and braking, and a comfortable ride all at the same time.[49]
One of the indispensable parts of the suspension system is the coil spring. This suspension part is actually a helically-shaped steel bar that absorbs the shock resulting from the tires' contact with the road. When your vehicle's front wheels run over a bump or a pothole, the coil spring compresses and absorbs the impact. As soon as the road becomes even again, the spring releases the energy and returns to its original state. Because of this shock-absorbing function, your vehicle's coil springs are usually built to be tough and damage-resistant[50]

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 project work we will be analyzing the suspension spring for passenger car in order to predict it's fatigue life. The intended effort is directed towards the future launch for the variant of the passenger car to be offered by the sponsoring company.

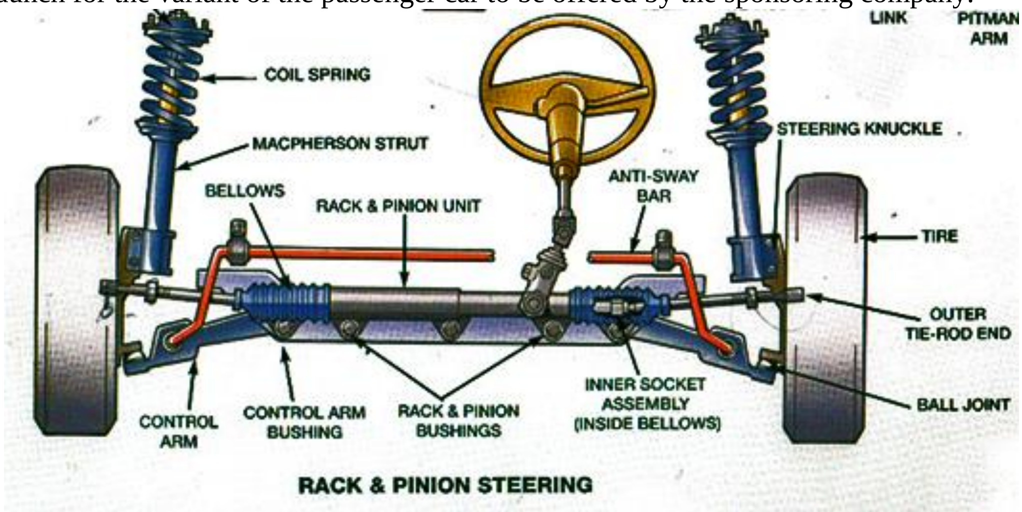


Figure 2: Suspension Spring (Coil) (Front View)

2.1 Probable Solution

Deployment for Analytical approach of problem solving could bring about insights into the problem at hand. Material properties of the existing spring could be reviewed for possible alternatives. The design configuration of the spring can also be reviewed for anticipating enhanced fatigue life. Geometry of the spring in terms of straight cylinder or conical orientation of the coils along with addition of co-axial spring could be deliberated upon for checking performance. The cross-section of the wire could be altered to check its effect on the response parameter. One or more of the above could be assessed based on feasibility of finding solution in the given scope of the project work.

III. LITERATURE SURVEY

In this section, 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.[19]

Some literature outlines an approach to a long-term fatigue tests up to a number of 10^9 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.[15]

Here is the list of few Research papers discussed about developing and validating procedures for predicting the fatigue stress analysis:-

SenthilKumar, Vijayarangan

In this paper 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

This paper 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 modelled 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.

Matthias Decker, Steffen Rödling

This paper covers the 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.

Santosh Krishnaji Sindhe, S. G. Bhatwadekar

This paper give more information for theManufacturer to improve the fatigue life of the leaf spring. Itcan help to reduce cost and times in research andDevelopment of new product. Recently, manufacturer onlyrely on fatigue test with constant amplitude loading, and thisstudy will help to understand more the behavior of the leafspring and the simulation of fatigue life.

Gadhia D, Sumant Patel

Author gives information about Existing suspension system which is used in Wagon-R car, is having problem of decreasing active length of spring on increasing weight in car. Decrease in active length of spring actually decrease working length of suspension system. With less working length suspension not functions properly. In all independent and dependent suspension system when connected to the vehicle some dead weight (weight of body) is acted on suspension.

Gajendra Rathore, Upendra

In this paper author provide the information about the fatigue stress for the helical compression spring. The researchers throughout the years had given various research methods such as Theoretical, Numerical and Experimental. Researchers employ the Theoretical, Numerical and FEM methods. This 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.

Y. Prawoto, A. Nishikawa
This paper is 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.
N.Lavanya, P.Sampath Rao, M.Pramod Reddy
Paper depicts work in optimum design and analysis of a suspension spring for motor vehicle subjected to static analysis of helical spring the work shows the strain and strain response of spring behavior will be observed under prescribed or expected loads and the induced stress and strains values for low carbon structural steel is less compared to chrome vanadium material also it enhances the cyclic fatigue of helical spring. The following points are drawn from the analyses results.
Koutaro WATANABE, Hideo YAMAMOTO
Various formulae are devised for calculating the stress correction factor of helical springs. However, different formulae are commonly used in different countries, such as Wahl's formula in Japan and Bergsträsser's formula in Europe. Those formulae for calculating stress correction factor have limitations when applied to suspension helical springs, which have increasingly larger initial pitch angles as the strength of materials for spring wire increases, because those formulae omit the effect of the initial pitch angle. Accordingly, in order to solve this problem, a simplified calculation formula and a chart of the maximum shear stress and maximum principal stress that take initial pitch angles into consideration were devised using the design of experiments and FEM analysis.
T. Mulla, S. Kadam
The elastic behavior and the stress analysis of springs employed in the TWV's front automotive suspension have been presented and discussed in this paper. The results obtained by a fully 3D FE analysis also stress ranging from 1.5 to 4 per cent, with reference to the applied loads, obtained when compared with the values calculated by using simple analytical model which is found in textbooks. The stress distribution clearly shows that the shear stress is having maximum value at the inner side of the every coil. The distribution of the stress is similar in every coil. So the probability of failure of spring in every coil is same except end turns. In such case residual stress in every coil may be important factor which influence the failure.
Conclusion of Literature Survey:
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. Simulation using Finite Element Modelling techniques offer insight into the nature of the stresses, deflection or any other response parameter responsible for the performance of the spring. Experimentation for fatigue life is not feasible in most of the cases. The experimental setup for recording stiffness of the spring might be feasible for pursuing research further.

The above literature review presents that the helical compression springs becomes quite necessary to do the complete stress analysis of the spring. These springs undergo the fluctuating loading over the service life. In addition, FEM software has been use for performing meshing simulation. Almost in all of the above cases, fatigue stress, shear stress calculation play more significant role in the design of helical compression springs. This study shows that shear stress and deflection equation is used for calculating the number of active turns and mean diameter in helical compression springs. Comparison of the theoretical obtained result by the shear stress equation to the Finite Element Analysis result of helical compression springs is the mode of our present work, by this analysis it will possible in future to provide help to designers for design of spring against fatigue condition.

IV. PROJECT OVERVIEW

4.1 Project 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

4.2 Project Objective:

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

4.3 Proposed Methodology:

To analyze the suspension spring in this project work we shall be using finite element methodology. The FEM is widely used now-a-days in industries due to its various advantages. In recent decades with development in mathematics and computers very efficient FEA software were developed (like **ANSYS, NASTRAN, RADIOSS, FEM FAT, nCode , MSC Fatigue** etc.) in combination with high computational powered work stations (computers) are working very efficiently. The Design process is compromise of things (design may change several time from designers mind till it comes to actual practice). Such as manufacturability, maintainability, reliability, factor of safety, cost, size and shape. Selecting best design is mere permutation and combination. As it is a balancing act among numerous design parameters, finite element modeling might come in handy as analytical methodology for addressing this problem.

Theoretical Work- Literature review: The survey over the published literature on Analysis of suspension coil spring & fatigue life etc. will be carried out by referring journals like SAE journal, International papers, US patents, etc.

Mathematical Model: Preliminary investigation into the nature of loads with its magnitude and its corresponding effect on the stiffness of the spring could be calculated using empirical formulae. The prediction for fatigue life could be made based on the equations available in the mathematical domain. Approximations for the feasible responses could be attempted using this methodology.

Analytical Methodology: The numerical / computational / analytical approach for problem solving shall be deployed for this work using suitable Finite Element Modelling software like HyperWorks, MSC software, ANSYS or modules supporting the prediction for fatigue life.

Software Used & to be Used:

- 3D modeling: CATIA (Dassault Systemes)
- Pre-processor: HyperMesh (Altair Engineering)
- Solver: Abaqus (Dassault Systemes)
- Post-processor: HypeView (Altair Engineering)

4.4 Flow Chart for Methodology:

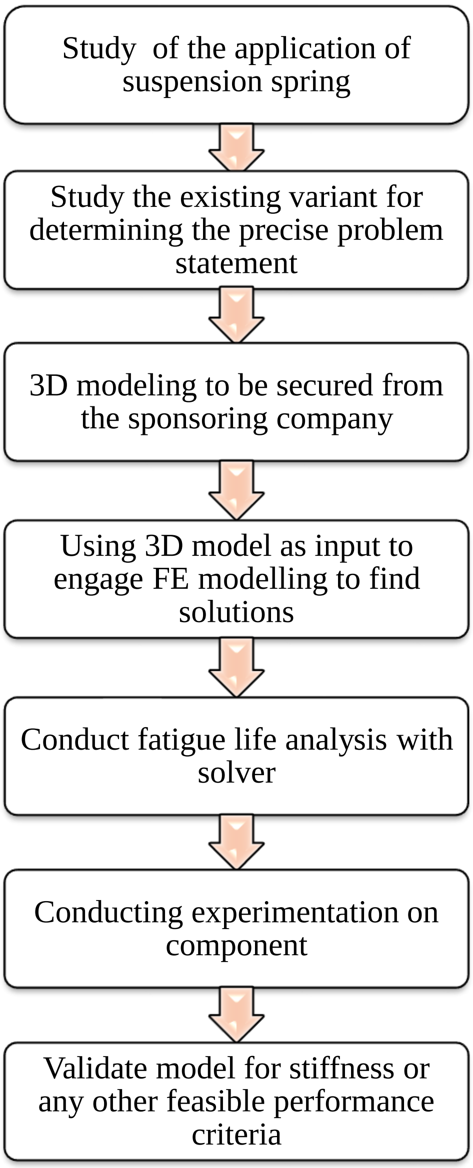


Fig 3: Principles of Vehicle dynamics

4.5 Design Selection

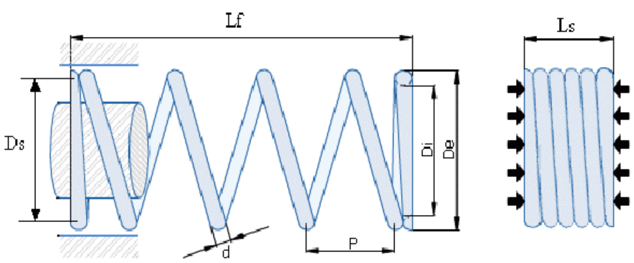


Figure 4: Spring geometry

- <u>d (wire diameter):</u> This parameter describes the diameter of wire used as material for spring.
- <u>Di (internal diameter):</u> Internal diameter of a spring can be calculated by subtracting the doubled wire diameter from the external diameter of a spring.

- De (external diameter): External diameter of a spring can be calculated by adding the doubled wire diameter to the internal diameter of a spring.
- Ls (Solid length): Maximal length of a spring after total blocking. This parameter is shown in the picture on right.
- Lf (free length): Free length of compression springs is measured in its uncompressed state.
- P (pitch): Average distance between two subsequent active coils of a spring.
- Ds (spring diameter): Spring diameter is mean diameter of spring. That is calculated by subtracting wire diameter d from external diameter De.

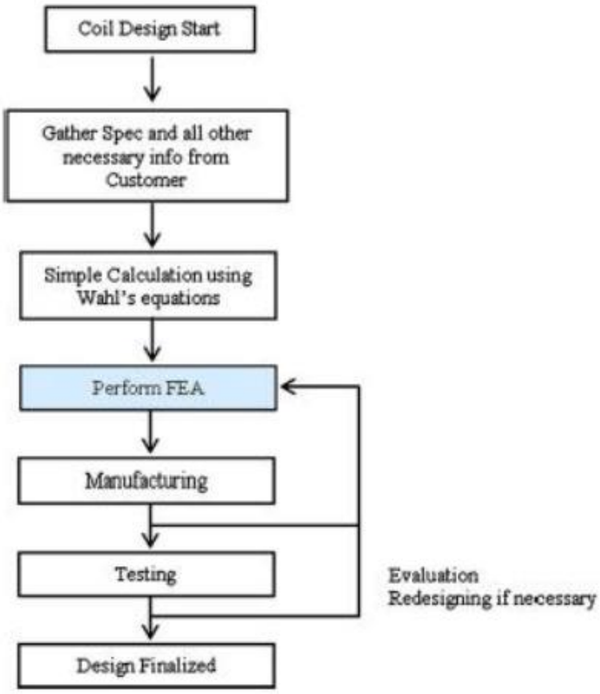


Figure 5: Flow chart of spring design

4.6 Fatigue Analysis

"Fatigue is the process where repeated variations in loading cause failure even when the nominal stresses are below the material yield strength; and is made up of crack initiation and subsequent crack growth as a result of cyclic plastic deformation." (MSC/Institute of Technology, 1999)
Independent of the project, when the fatigue phenomenon is present, the flow shown in figure 5.5 indicates all the steps necessary to develop the project considering this aspect. The process requires several inputs, such as geometry, load history, environment, design criteria, material properties and process effects. With these inputs, fatigue design is performed through synthesis, analysis and testing. The process from design, analysis and test is highly interactive and iterative. The number of loops is directly related to the quality of the inputs, and the accuracy to predict the life of the component or system. In this work, the focus will be on just one part of the flow, which is related to stress analysis, fatigue life and cumulative damage models, and life prediction.

V. CALCULATIONS FOR SUSPENSION SPRING (COIL)

5.1 Calculations for Forces on Spring

Specifications of MARUTI Alto 800
Length: 3335mm
Width: 1440mm
Height: 1405mm
Wheel base: 2175mm

Front Track: 1295 mm
Kerb Weight: 650 Kgs
Seating Capacity: 5
Gross Weight = Kerb Weight + Passenger weight + Luggage weight

$W_G = 650 + (5*70) + (5*10)$

$W_G = 1050$ Kgs

From standard
The ratio of weight distribution is F/R: 49/51
Weight acting on each front wheel

$W = (0.49* W_G)/2$

$= (0.49* 1050)/2$

$W = 257.25$ Kg

So, the reaction force acting on wheel,

$P = W*g$

$= 257.25*9.81$

$P = 2525$ N (Approx.)

5.2 Calculations for Spring Design

Table 5.1: Parameters of Steel Suspension Spring

Parameters	Values	Units
Outside Diameter, OD	100	mm
Inside Diameter, ID	80	mm
Mean coil Diameter, D	90	mm
Wire Diameter, d	10	mm
Pitch, p	40	mm
Number of Active Coils, N, Nos	9	
Total Number of Coils, Nt, Nos	10	
Free Length, L_0= p*Nt	400	mm
Solid Length Ls = d*N	100	mm
Spring Index, C = D/d	9	

Bergstrasser factor,

$K_B = (4C+2)/ (4C-3)$

$= (4x9+2)/ (4x9-3)$

$K_B = 1.15$

Shear stress on spring is

$\tau = K_B*8*P*D/ (\pi*d^3)$

$= 1.15*8*2525*90/ (\pi *10^3)$

$\tau = 665.5$ Mpa

Spring material EN47 (Chrome Vanadium wire) values of A=2005 MPa.mm^m & Exponent (Constant) m = 0.168
Tensile Strength,

$S_{ut} = A/d^m$

$= 2005/4^{0.168}$

$S_{ut} = 1588.43$ Mpa

Torsional Yield Strength, $S_{sy} = 0.45S_{ut} = 803.07$ Mpa
Modulus of Elasticity, G = 77200 Mpa
Spring Rate,

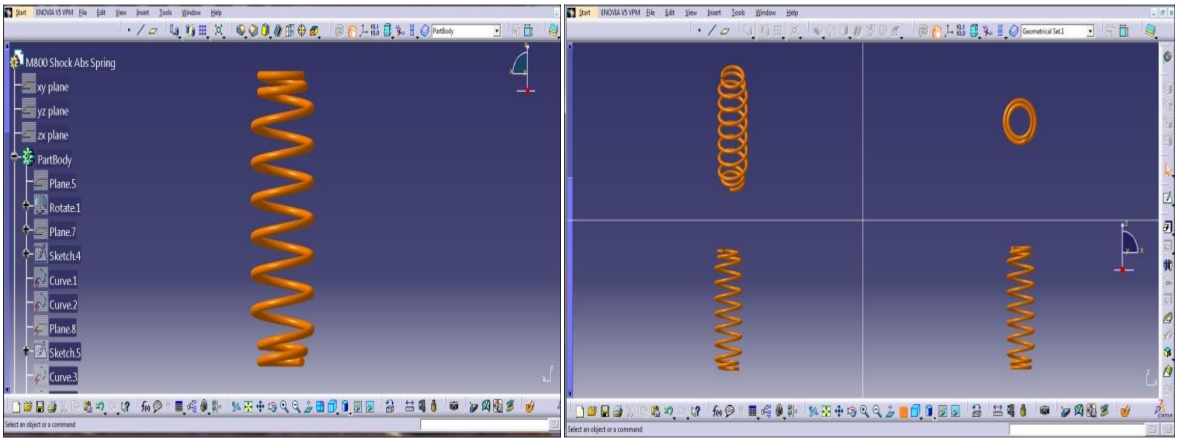
$k = G*d^4/ (8D^3N)$

$= 77200*10^4/ (8*100^3*9)$

$k = 10.72$ N/mm

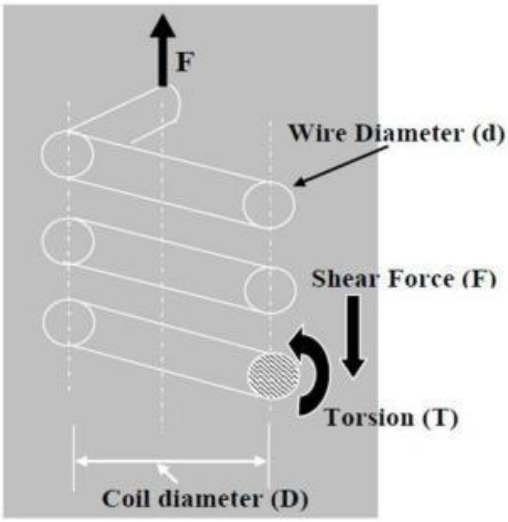
Deflection, y = F/k = 235.5 mm

VI. HELICAL SPRING FATIGUE ANALYSIS (FE MODELING)



6.1 CAD Model of Suspension Spring

CAD model prepared using CATIA V5, which will be further used for Static and Fatigue Analysis of the Suspension spring



6.2Forces acting on the Suspension spring

Different Force acting of suspension spring are identified. Only Axial force is considered as it contributes 90% and rest is neglected for analysis

VII. LAYOUT & DESIGN SET-UP

Figure 9 – Typical Test setup for Physical Experimentation

Figure shows the typical test setup for determining the stiffness of the suspension spring. The gradually increasing load will be applied and corresponding deformation is determined. The load from the load cells present on the UTM machine will be applied gradually. Display attached to the machine will give a corresponding plot for load Vs displacement i.e. stiffness of the component.

Validation (For project stage – II):

Validating the stiffness of the component by comparing results obtained from experimentation with results of FEA analysis. Will be finding out fatigue life by FEA analysis and that will be compared with the finite life obtained from mathematical calculation. The experimentation work for finding fatigue life will not be done; as it will required more time and also it is costlier. The stiffness of the spring is considered as a `response' parameter for validation.

VIII. CONCLUSION

The Fatigue life analysis of the suspension coil spring using a FEA technique interface would offer credible design inputs which can be used concurrently while designing the spring. The modified design based upon the analysis should further be subjected to analysis to check the new outcome. This process of iteration yields an optimized design which fits the function and helps the Design Engineer to validation his design over the virtual interface followed by physical test further to validation for improvement of fatigue life.

Expected Outcomes:

- Enhanced fatigue life would offer versatility in the use of the spring
- Alternative materials might result in lower cost or lesser lead times for procurement
- Catastrophic failures can be avoided while improving the safety aspect of the vehicle
- Ride and comfort of the vehicle might be improved as a secondary outcome

REFERENCES

[1] Mechanical Engineer's Reference Book By: Edward Smith

[2] Y. Prawoto, M. Ikeda, S.K. Manville, A. Nishikawa., Design and failure modes of automotive suspension springs, 21 February 2008

[3] M Senthil Kumar, S Vijayarangan., Analytical and Experimental Studies on Fatigue Life Prediction of Steel and Composite Multi-leaf Spring for Light Passenger Vehicles Using Life Data Analysis, 06 May 2007

[4] S. S. Gaikwad, P. S. Kachare., Static Analysis of Helical Compression Spring Used in Two-Wheeler Horn, 3 February 2013

[5] Koutaro W, Hideo Y., Simplified Stress Calculation Method for Helical Spring, 2010
[6] B. Pyttel, I. Brunner, B. Kaiser, C. Berger, M. Mahendran., Fatigue behaviour of helical compression springs at a very high number of cycles – Investigation of various influences, 10 January 2013
[7] M. M. Patunkar, D. R. Dolas., Modelling and Analysis of Composite Leaf Spring under the Static Load Condition by using FEA, 2011
[8] Pöllänen, H. Martikka., Optimal re-design of helical springs using fuzzy design and FEM, 2010
[9] K. Michalczyk., Analysis of the influence of elastomeric layer on helical spring stresses in longitudinal resonance vibration conditions, 2013
[10] Manish Dakhore, Bhushan Bissa., Failure Analysis of Locomotive suspension coil spring using Finite Element Analysis, 2013
[11] Pankaj Saini, Ashish Goel, Dushyant Kumar., Design and Analysis of Composite Leaf spring for light vehicles, 2013.
[12] Khashayar Teimoori, Muhammad Hassani, Milad Khorami, Salar Mirzaei, Ali Sahebi, "Analytical Vibrating Solutions of the New Designed Car with the Comparisons", International Journal of Advances in Engineering & Technology, Vol. 5, Issue 2, pp. 347-355, Jan. 2013.
[13] P. S. Valsange., Design of Helical compression spring, 2012
[14] Gundre, Wankhede., A Finite Element Analysis of Helical Compression spring for Electric Tricycle vehicle automotive front suspension, 2013
[15] T. Mulla, S.Kadam, V. Kengar., Finite Element Analysis of Helical Coil Compression spring, 2012
[16] Rathore, Joshi., Fatigue stress analysis of Helical compression spring, 2013

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