IARJSET
ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
ISO 3297:2007 Certified
Vol. 5, Issue 4, April 2018

Optimization of Coil Spring for Three Wheeler

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Abstract: The helical compression spring used in suspension system or shock absorber is a mechanical device designed to smooth out or damp shock impulse and dissipate kinetic energy. A helical coil compression spring which used in transport three wheeler is belonging to the medium segment of the Indian automotive market. The detailed assessment of the problem of three wheeler vehicle's front suspension system is studied in this project. It is observed that, the vehicle drifts towards one side due to high weight of suspension system. This problem can be solved by redesigning and optimizing front suspension spring. 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. The design process can be viewed as an optimization process to find structures, mechanical systems, and structural parts that fulfill certain expectations towards their economy, functionality, and appearance. The experimental investigation is performed to calculate the stiffness and vertical acceleration of helical compression spring. The calculated results are to compare on common scale with theoretical and software results. After optimization the spring checked for its structural strength and if it did not meet the strength requirements the spring had to be redesign until the strength was meeting. Once optimization of the spring was done prototype of the spring were made. These springs have to face very high working stresses. The structural reliability of the spring must therefore be ensured. For the present experimental investigation the SP ST GRD II material was taken for spring manufacturing and performs the static and dynamic test. In static test the universal testing machine was used to find stiffness of spring and quarter car test rig used to find the vertical acceleration of helical compression spring.

Keywords: Deflection, coil spring, optimization, FEA, etc.

1. INTRODUCTION

When people think about automobile performance, they normally think of horsepower, torque and 0-100kmph acceleration. But all of the power generated by a piston engine is useless if the driver can't control the car. That's why the suspension system in an automobile is important and so much attention is given to it. The vehicle suspension system is responsible for the vehicle control, driving comfort and safety as the suspension carries the vehicle body and transmits all the forces between the road and the body. If a road were perfectly flat, with no road irregularities, suspension would not be necessary. But the roads are far from flat. Even the freshly paved highway roads have subtle imperfection that can interact with the wheels of a car. It's these imperfections that apply forces to the wheels that result in wheel acceleration. According to Newton's laws of motion, all forces have both magnitude and direction. A bump in the road causes the wheel to move up and down perpendicular to the road surface. The magnitude of this depends on whether the wheel is striking a giant bump or a tiny speck. Either way, the car wheel experiences a vertical acceleration as it passes over an in perfection. Without an intervening structure, all the wheels vertical energy is transferred to the frame, which moves in the same direction. In such a situation, the wheels can lose contact with the road completely. Then due to the downward force of gravity, the wheels can slam back into the road.
Thus we need is a system that will absorb the energy of the vertically accelerated wheels. Also, allowing the frame and body to tide undisturbed while the wheels follow bumps in the road. The solid axle must be attached to the body such that an up and down motion in the z-direction as well as a roll rotation about the x-axis is possible. So, no forward and lateral translation, and also no rotation about the axle and the z-axis, is allowed. There are many combinations of links and springs that can provide the kinematics and dynamic requirements. The simplest design is to clamp the axle to the middle of two leaf springs with their ends tied or shackled to the vehicle frame.
The elastic behaviour 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 highlighted the poor accuracy that can be provided by the classical spring model when dealing with these spring geometries. Relative errors on maximum shear stress ranging from 1.5 to 4 percent with reference to the applied loads, obtained when compared with the values calculated by using simple analytical model which was found in textbooks. The stress distribution clearly shows that the shear stress having maximum value at the inner side of the every coil.

Springs are mechanical shock absorber system. A mechanical spring is defined as an elastic body which has theprimary function to deflect or distort under load and to return to its original shape when the load is removed. Springs are mainly used in the industry for absorbing shock member energy and for resetting the part at its initial position upon displacement for a given function. Helical Compression springs are helical coil springs that resistance to a compressive force. Helical Compression springs having shapes like cylindrical, conical, tapered, concave or convex etc. Coil compression springs are wound in a helix usually out of round wire. The springs are designed to withstand the cycle of loading or unloading during operation. The front suspension helical coil compression spring used for three wheeler front suspension has high in weight so it needs to optimize in weight. Therefore in this present work it is proposed to carry out the numerical design and finite element analysis of helical compression spring used for front suspension in a three-wheeler transport vehicle so as to reduce the weight.

2. DESIGN OF OPTIMIZATION OF COIL SPRING

2.1 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.

On the basis of these factors material is to be selected 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.

2.2 Equations for Spring Design

To design the spring and determine the stress developed in the spring consider a helical spring subjected to an axial load P.
Let,
D = Mean diameter of the spring coil (mm)
D_o= Outside diameter of the spring coil (mm)
D_i = Inside diameter of the spring coil (mm)
d = Diameter of the spring wire (mm)
N = Number of active coils
N_t = Total number of coils
G = Modulus of rigidity for the spring material
P = Axial load on the spring (N or Kg)
τ= Max. Shear stress induced in the wire (N/mm^2)
C = spring index = D/d
p = Pitch (mm)
δ = Deflection of the spring, as a result of an axial load P
J = Polar moment of inertia of bar
L = Free Length (mm)
K = Wahl factor
l = Length of bar
k = Stiffness of the spring (N/mm)

The equations required for the design of the spring are as follows;
a) Spring Index (C) = D/d
b) Wahl's Stress factor (K) = $\frac{(4C-1)}{(4C-4)} + \frac{0.615}{C}$

c) Stiffness = $\frac{G \times d^4}{8 \times D^3 \times N}$ N/mm and divide by 10

 DOI 10.17148/IARJSET.2018.5413

for kg/mm

d) Shear Stress (τ) = $\frac{(K \times 8 \times P \times D)}{(\pi \times d^3)} = \frac{K \times 8 \times P \times C}{\pi \times d^2}$ N/mm^2

e) Solid Length = $N_t \times d$

f) Deflection (δ) = mm $\frac{P}{k}$

3. EXISTING SPRING DATA

The existing suspension spring weighing 2.9733 Kg is heavy hence needed to be optimized and a lighter design of the spring is needed. The existing suspension spring having wire diameter 12 mm, mean coil diameter 78 mm and free length 315mm.

Sr. No.	Specification	Value
1	Outside Diameter	90 mm
2	Inside Diameter	66 mm
3	Mean Diameter	78 mm
4	Wire Diameter	12 mm
5	Spring Index	5.5
6	Free Length	315 mm
7	Solid Length	168 mm
8	Number of Active Coils	12
9	Number of Total Coils	14
10	Ultimate Tensile Stength	1500 MPa
11	Material Grade	IS 4454 Grade II
12	Young's Modulus	2×10^5 MPa
13	Modulus of Rigidity	80×10^3 MPa
14	End Type	Closed and Ground

In case of three wheeler vehicle it is always very tricky to design front suspension system which also takes care of steering system attached to the same front wheel. To balance the functionality of both suspension and steering system one need to have a very strong supporting structure which gives sufficient strength to the design. It is always economical to have strong design with less weight without compromising its required strength. The present work deals with the optimization of front suspension spring of three wheeler transport vehicle.

The present work is about to optimize the front suspension coil spring in order to reduce its weight for the transport version of three wheeler vehicle. Final design was analysed by using Finite Element Analysis and compare with manual calculation and experimental testing results.

A helical compression coil spring which is employed in three wheeler transport vehicle which belonging to the medium segment of the Indian automotive market. 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. The design process can be viewed as an optimization process to find structures, mechanical systems and structural parts that fulfil certain expectations towards their economy, functionality and appearance. Structural design tools include topology, topography, and free-size optimization. Sizing, shape and free shape optimization are available for structural optimization. In the formulation of design and optimization problems, the following responses can be applied as the objective or as constraints: compliance, frequency, volume, mass, moment of inertia, centre of gravity, displacement, velocity, acceleration, buckling factor, stress, strain, composite failure, force, synthetic response, and external (user defined) functions. Static, inertia relief, nonlinear quasi-static (contact), normal modes, buckling, and frequency response solutions can be included in a multi-disciplinary optimization setup. Topology, topography, size, and shape optimization can be combined in a general problem formulation.

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4. BASIC CALCULATIONS REQUIRED FOR SPRING DESIGN

4.1 Mean Coil Diameter

$D= \frac{D_i + D_o}{2}$

$D = \frac{66+90}{2}$

D = 78 mm

4.2 Spring Index

$C = \frac{D}{d}$

$C = \frac{78}{12}$

C = 5.5

C is in between 5 to 9 so it is suitable for cyclic loading. Also it is suitable for manufacturing.

4.3 Wahl Factor

$K = \frac{4C-1}{4C-4} + \frac{0.615}{C}$

$K = = \frac{4\times5.5-1}{4\times5.5-4} + \frac{0.615}{5.5}$

K = 1.23

4.4 Provision of Guide

Free Length / Mean Coil Diameter =315/78

Free Length / Mean Coil Diameter = 4.038

As, Free Length / Mean Coil Diameter > 2.6 the guide is required for this spring according to thumb rule. Here the guide is provided so design is safe.

These all above calculations are common for all types of springs design in this present work report.

5. NUMERICAL ILLUSTRATION OF SPRING DESIGN

Now for optimisation purpose first finding the stiffness, load verses deflection for each spring.

5.1 Existing Design

Total number of coils = 14

Number of active coils = 12

a) Stiffness = $k_1 = \frac{G\times d^4}{8\times D^3\times N}$

$k_1 = \frac{80\times10^3\times12^4}{8\times78^3\times12}$

k_1 = 35.41 N/mm

k_1 = 3.64 kg/mm

b) Now calculating load for different deflections

Deflection (δ) = $\frac{P}{k_1}$mm

$10 = \frac{P}{3.64}$

P = 35.4 kg

5.2 New Design

Total number of coils = 12

Number of active coils = 10

a) Stiffness = $k_2 = \frac{G\times d^4}{8\times D^3\times N}$

$k_2 = \frac{80\times10^3\times12^4}{8\times78^3\times11}$

k_2 = 43.69 N/mm

k_2 = 4.36 kg/mm

b) Now calculating load for different deflections

Deflection (δ) = $\frac{P}{k_2}$ mm

$10 = \frac{P}{4.36}$

P = 43.6 kg

5.3 Maximum Shear Stress

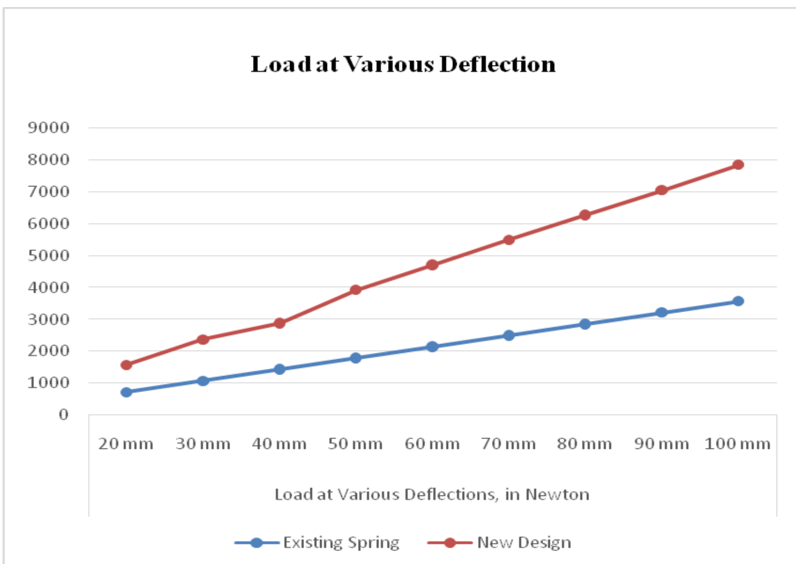
$$\tau = \frac{K \times 8 \times P \times C}{\pi \times d^2}$$

$$\tau = \frac{1.24 \times 8 \times 5000 \times 5.5}{\pi \times 12^2}$$

τ = 712.66 N/mm^2

6. NUMERICAL RESULTS

The load for different deflection was calculated and tabulated below with reference to above calculated stiffness for various springs. It has observed that the new design III has greater stiffness than remaining design. The graph was plotted with the help of above table and shown in fig. 5.3 From graph it is observed that the new design has maximum load carrying capacity among the remaining designs.



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