COMPARISON OF WEIGHTS OF STEEL AND COMPOSITE COIL SPRING FOR TWO WHEELER SUSPENSION SYSTEMS

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***Abstract*—Thepresent article givesinformation on design of steel and composite coil spring for two-wheelerapplication. The reason to develop the composite coil spring is to minimize the weight of coil spring. In this article, study has been done on a two-wheeler vehicle. Dimensions of the exiting steel coil spring are measured. The load on the spring has been calculated mathematically. Deflection, shear stress, weight and stiffness are calculated using dimensions of existing steel coil spring.The design of composite coil spring has been done as same stiffness as that of steel spring byusingtrial and error method. The metal coil spring weight was 0.782 kg and the newly developed composite coil spring has 0.244 kg. So, weight of the existing coil spring has been reduced by 70% using composite coil spring.**

Keywords—composite material, carbon fiber, steel coil spring, epoxy, composite coil spring.

I. Introduction

Spring is an elastic machine element. When the load is applied, the spring getsdeflects and when the load is removed then spring returns to its original shape. Spring is used in vehicle to absorb shock and vibrations. Also, it is used to store the energy. The composite materials have low weight as compared to metallic material. So, we can replace metal coil spring by composite coil spring. It has high strain energy, less weight and high corrosion resistance. The composite coil spring is the combination of two or more materials. The material used for the composite coil has fibers and matrix, the combination of both makes it a strong material.

Research has been carried out related to composite material coil spring of which some they are discussed. Max A. Sardou et al. [1] have present information on the practical reality of composite coil spring. They give information about how to manufacture the composite coil spring also gives the information about the physical properties of various composite materials which is used for manufacturing the coil springs, different test for manufactured composite coil springs. Daewon Jang and Sungbae Jang [2] have developed a light-weight carbon fiber reinforced plastic coil spring. The composite material properties of CFRP were predicted through analysis.

Nomenclature

D	Mean coil diameter
d	Wire diameter
N	Active number of turns
C	Spring index
ρ	Density
k	Stiffness
w	Weight of spring
τ	Shear stress
K	Wahl's factor
δ	Deflection
G_m	Shear modulus of matrix
$G_{f_{lt}}$	Shear modulus of fiber in longitudinal and transverse direction
V_f	Fiber volume fraction
E_m	Elastic modulus of matrix
E_f	Elastic modulus of fiber.

A spring rate of spring is accorded with design goal and various tests to verify the performance of the spring was performed. The developed suspension spring is lighter than half weight compared to conventional spring.Bok-Lok Choi and Byoung-Ho Choi [3] designed a carbon fiber reinforced epoxy composite coil spring by using numerical methods.CFRP coil spring manufactured using the resin transfer molding (RTM) process. Ply angle in composite beam is used to determine the optimum wire diameter of the coil spring.The static spring rate of CFRP coil spring is calculated in Finite element analysis. The analytical test was taken to verify the result of FEA. Ekanthappa J. et. al. [4] has carried out research on the fabrication and experimentation of the glass epoxy helical spring reinforced with graphite powder. Modified filament winding technique is used for fabrication of spring. Two types of composite coil spring are developed; first is glass/epoxy and the second is glass/ epoxy+ graphite power. The mass of composite coil spring is 40% less than metal coilspring.Chang-Hsuan Chiu et. al. [5] has done an experimental investigation into the mechanical behaviors of helical composite springs. Four different types of helical composite spring's structure were made. The experimental test is carried out to investigate the effects of rubber core and braided outer layer on the mechanical properties of the aforementioned four helical springs.The helical spring with a BUR structure has the highest mechanical properties as comparing the four types of helical composite springs.Aimin Yu and Ying Hao [6] have studied the effect of warping on the natural frequencies of a symmetrical cross ply laminated composite non- cylindrical helical springs. Investigate a composite helical spring having a rectangular cross - section. Improved Riccati transfer matrix by iteration is used for calculating natural frequencies of springs. The effect of a different stacking sequence of the natural frequency of rectangular cross section is studied.Faruk Firat Calim [7] has studied dynamic analysis of composite coil springs of arbitrary shape.The two of composite coil spring having different shapes are taken. The shapes of composite springs are hyperboloidal and barrel. The dynamic behavior of both coils is calculated; also, the fundamental natural frequency of both the spring is calculated at 5, 7 and 9 Number of active turns.Md. Musthak and M. Madhavi [8] have developed high strength helical coiled springs using carbon pre-peg epoxy-based composite. They select the three types of composite materials are carbon fiber, glass fiber and combination of carbon and glass fiber for development of coil spring. They designed the carbon/epoxy coil spring. The designed coil spring is analyzed in analysis software. The load applied in the spring is 1400N. Carbon/epoxy with ±45^0 orientation gives the better results. A T Kumbhar et. al. [9] has carried out the works on analysis and experimental validation of behavior of composite material helical compressive spring. The composite coil spring material is glass fiber.FEA analysis of the both coils are carried out for calculating maximum shear stress, maximum deflection and stress intensity. The composite coil spring is experimentally tested on the UTM. Suresh G. et. al. [10] studied on the fabrication and analysis of nano composite cylindrical helical spring. The paper gives the short information about the suspension springs, composite materials, needs of composite materials, polymer matrix composites (resin, thermosets and thermoplastics), process material, reinforcement and nano-clay.Four types of composite coil spring are manufactured. Four springs have 0%, 1%, 2% and 3% of nano-clay respectively. KarthikeyanS. S. et. al. [11]he carried out work on the design and analysis of helical coil spring suspension system by using composite material. Metal matrix composite is used for manufacturing of composite coil. Analysis software used to calculate static structural and shear stress analysis. The results show that weight of the system is reduced by 60% and volume of the system is reduced by 75%.

From the above literature its has been seen that research has been carried out extensively only on composite coil spring for different application, but the composite coil spring for the automotive two-wheeler application purpose has not been carried out yet. Thus, there is scope to check whether the composite material coil spring can be used for two-wheeler application purpose.

II. LOAD ON SINGLE COIL SPRING

This study has been done on Hero Passion Pro vehicle. The dimension of coil spring is taken as same vehicle.

Bike Weight = 116 kg
Weight of 1 person 75 kg
Weight of 2 person 75 + 75 = 150 kg
Total Weight = bike weight + 2-person weight
= 150 + 116 = 266 kg
Rear suspension rate = 65 %
65% of 266 = 172.9 kg = 173 kg
Considering dynamic loads will be double
W = 173 × 2 = kg = 346 × 9.81 = 3394.26 N
For single shock absorber weight = W/2
= 3394.26/2 = 1697.13 N
Load on the single shock absorber (P) = 1697 N

III. DESIGN OF EXSTING STEEL COIL SPRING

Calculation of exiting metal coil spring

The measured dimensions of Hero Passion Pro vehicle are:

Mean coil diameter (D) = 42.5 mm,
Wire diameter (d) = 7.5 mm,
Free length = 231.5 mm,
Active number of turns (N) = 17,
Total number of turns = 19,
Spring index (C)= $\frac{D}{d}$ = 5.67,
Load on spring (P) = 1697 N
Density (ρ) = 7800 kg/mm^3

1. The shear stress is given by

$$K = \frac{4C-1}{4C-4} + \frac{0.615}{C} = 1.26$$

$$\tau = K\left(\frac{8PD}{\pi d^3}\right) = \ 548.52 \text{ N}/mm^2$$

2. Deflection

$$\delta = \frac{8\ P\ D^3\ N}{G\ d^4} = 64 \text{ mm}$$

3. Stiffness

$$k = \frac{Load}{Deflection} = \ 26.51 \text{ N/mm}$$

4. Weight of spring (w)

$$w = \rho \times \frac{\pi^2}{4} \times d^3 \times c \times N = 0.7826 \text{ kg}$$

IV. MECHANICAL PROPERTIES OF COMPOSITES

Composite coil spring is developed for reducing the weight, without reducing its functional requirements. So, the selection of composite material depends upon its low density and high shear modulus. The mechanical property of composite fiber and resins is given in below.

Table 1: Mechanical properties of fibers and matrix [13]

Properties	Carbon Fiber HR	E-Glass fiber	Epoxy
Elastic Modulus in longitudinal direction (MPa)	230000	74000	4500
Elastic Modulus in transverse direction (MPa)	15000	74000	-
Shear modulus (MPa)	50000	30000	1600
Ultimate strength Tension (MPa)	3200	2500	130
Density (kg/m3)	1750	2600	1200

V. DESIGN OF COMPOSITE COIL SPRING

Designing of composite coil spring is done with trial and error method. The trial and error method consist of following steps:

1. Assume some wire diameter (d).
2. Find out induced stress and stiffness.
3. Check-up whether the stiffness is as per the requirements. If not, increase the wire diameter and repeat the above steps.
4. Repeat the above-mentioned procedure until the value of required stiffness comes.

Trial and error method 1: -

The parameter values given below are considered based on the actual metallic coil spring for the two-wheeler. The material properties are ranging above or equal to actual metallic spring. The method used to prepare the composite coil is Resin transfer molding (RTM). Thus, from the literature the volume fraction for RTM method ranges from 60 % to 80 %. The diameter of composite coil spring has taken larger than the metallic coil diameter because the value of shear modulus for metallic coil spring is greater compare to composite material. So the diameter for composite material range is taken from 7 to 15 mm.

Materials - Carbon Fiber HR as Fiber and Epoxy as Matrix

Assume,

Volume Fraction = 75%,

Coil Diameter = 12 mm,

Spring Index (C) = 5 & Number of active turns (N) = 3

Mean diameter (D) = Cd = 60 mm.

1. Shear Modulus [14]

$$G_{lt} = G_m \left(\frac{1}{(1 - V_f) + \frac{G_m}{G_{f_{lt}}} V_f} \right) = 5839.416\ MPa$$

Where, G_m is shear modulus of matrix, $G_{f_{lt}}$ is shear modulus of fiber in longitudinal and transverse direction, V_f is fiber volume fraction.

2. Ultimate Tensile Strength [14]

$$\sigma = \sigma_f \left(V_f + (1 - V_f) \times \frac{E_m}{E_f} \right) = 2415.65\ N/mm^2$$

Where, $E_m$is elastic modulus of matrix, E_f is elastic modulus of fiber.

3. The Wahl's factor is given as[12]

$$K = \frac{4C - 1}{4C - 4} + \frac{0.615}{C} = 1.31$$

4. Deflection (δ) [12]

$$\delta = \frac{8\ P\ D^3\ N}{G\ d^4} = 72.65\ mm$$

5. Stiffness (k) [12]

$$k = \frac{Load}{Deflection} = 23.35\ N/mm$$

6. Maximum Shear stress (τ) [12]

$$\tau = K \left(\frac{8\ P\ D}{\pi\ d^3} \right) = 196.56\ N/\ mm^2$$

The deflection results are not satisfactory for the application. Thus, this design was not selected.

Trial and error method 2: -

Materials - Carbon Fiber HR as Fiber and Epoxy as Matrix

Assume,

Volume Fraction = 75%,

Coil Diameter = 13.5 mm,

Spring Index (C) = 5&Number of active turns (N) = 3

Mean diameter (D) = Cd = 67.5 mm.

1. Shear Modulus

$$G_{lt} = G_m \left(\frac{1}{(1 - V_f) + \frac{G_m}{G_{f_{lt}}} V_f} \right) = 5839.416\ MPa$$

Where, G_m is shear modulus of matrix, $G_{f_{lt}}$ is shear modulus of fiber in longitudinal and transverse direction, V_f is fiber volume fraction.

2. Ultimate Tensile Strength

$$\sigma = \sigma_f \left(V_f + (1 - V_f) \times \frac{E_m}{E_f} \right) = 2415.65\ N/mm^2$$

Where, $E_m$is elastic modulus of matrix, E_f is elastic modulus of fiber.

3. The Wahl's factor is given

$$K = \frac{4C - 1}{4C - 4} + \frac{0.615}{C} = 1.31$$

4. Deflection (δ)

$$\delta = \frac{8\,P\,D^3\,N}{G\,d^4} = 64.58\,mm$$

5. Stiffness (k)

$$k = \frac{Load}{Deflection} = 26.27\,N/mm$$

6. Maximum Shear stress (τ)

$$\tau = K\left(\frac{8\,P\,D}{\pi\,d^3}\right) = 155.30\,N/\,mm^2$$

The design is safe as maximum shear stress is lower than permissible stress and the deflection results are satisfactory for the application. Thus, the design has been selected.

7. Weight of composite coil spring

$$w = \rho \times \frac{\pi^2}{4} \times d^3 \times c \times N = 0.244\,kg$$

VI. LIMITATION

The composite coil spring is designed for low weight vehicles such as two wheelers. As the composite material is brittle in nature the material gets easily cracked when large loads are applied. Thus, the major limitation to work on dissertation using composite material is application weight.

VII. CONCLUSION

The composite coil spring has been designed for Hero Passion Provehicle using Carbon/Epoxy material. With the use of composite material, significant weight reduction has beenobtained for the coil spring. The weight of the steel coil spring for vehiclewas found as0.782 kg which reduces to 0.244kg. This reduction in weight reduces consumption of fuel and increases the performance of the vehicle.

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