

COMPARATIVE DESIGN ANALYSIS OF LOAD ON PERFORMANCE INDICES OF HELICAL COMPRESSION AND SEMI-ELLIPTICAL LEAF SPRINGS APPLIED IN TRI-CYCLE AUTOMOBILE

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ABSTRACT

This research work describes the design analysis of helical compression and semi elliptical leaf springs of TVS king and Bajaj tricycle automobile. The objective is to investigate the load bearing capacity of the springs applied in the tricycle automobiles. In this work, spring stiffness, stress and deflection were chosen to analyse the bearing capabilities of the springs. Forces of 2.0-3.5 kN were applied to simulate the expected output for the spring stiffness, stress and deflection. The stiffness for the helical compression and semi elliptical leaf springs were determined as 8 N/mm and 13 N/mm respectively. The stress in the helical compression spring is greater but produced lower deflections than the semi elliptical leaf spring. The result obtained shows that semi elliptical leaf spring has high strength and high resistance to weight ratio than the helical compression. The application of the semi elliptical leaf spring in tricycle automobile will limit the effect on the driving torque of an engine and withstand the nature of bad roads due to pot-holes, gallops, shocks and other road irregularities in cities and villages.

Keywords: Tricycle automobile, design analysis, helical spring, leaf spring, stress and deflection

1. INTRODUCTION

Springs are the fundamental components that form the basis of many mechanical systems. They are load bearing elastic objects used to store and transfer mechanical energy. A spring can be defined as an elastic member which exerts a resisting force when its shape is changed. Most springs are assumed linear and obey Hooke's law i.e. it is distorted when loaded and recovers its original shape when the load is removed [1]. In engineering applications, springs are often used for their compression or load bearing ability and for dampening out the effects of shocks or impact loads. Other applications of springs

include cushioning, absorption or control of energy due to either shock or vibration as in cars, railway buffers, aircraft gears, shock absorbers and vibration dampers[2]. Springs are also used to measure forces as in spring balance and engine indicators to determine force capacity such as forces in brakes, clutches and spring loaded valves.

There are several types of springs, the common one consisting of a wire wound into a cylindrical or conical shape called helical springs. Some springs are fashioned without coil and the most common example is the leaf spring. The leaf spring is shaped like a shallow arc which is commonly used for automobile suspension system. An extension spring is a coiled spring whose coils normally touch each other. When force is applied to stretch the spring, the coil separate. This is in contrast to a compression spring which is coiled with space between successive coils. The coils are pushed closer together upon the application of force [2].

Other type of coiled spring is called torsion spring. It is designed so that the applied forces twist the coil into a tighter spiral. Common examples of torsion springs are found in clipboard and butterfly hair clips. Another variation of the coil spring is the watch spring which is coiled into a flat spiral rather than a cylinder or a coin. One end of the spring is at the spiral centre while the other is at the outer edge [1, 2]. Another type is the disc spring, which washer-like device is shaped like a truncated cone. Open core cylinder of solid elastic material can also act as spring. Non coiled springs generally functions as compression springs [3].

Steel helical spring has been replaced nowadays by three composite helical springs which include carbon, glass and Kevlar. Because of their weight reduction, they are usually applied as spring materials. One of the great challenging issues in the application of springs in an automobile is weight reduction [4]. The advantage of the leaf spring over helical spring is that the spring end may be guided along a definite path, as it deflects to act as a structural member in addition to the energy absorbing device [5]. The spring carries the brake torque, driving torque, lateral loads in addition to shocks. Leaf spring also has the advantage of spreading the load widely over the vehicle chassis.

The design and development of springs began in the nineteenth century. George B. Hansburg patented the first pogo-stick and improved on the design that was shipped from Germany to the Gimbel brother's department store in America [6]. The design was made of wood and had rooted on the journey over to U.S.A. An all-metal enclosed spring pogo-stick was designed and manufactures date a factory in Elmhurst New York. The pogo stick has had interesting spin-off applications as well.

[7] studied the feasibility for the implementation of fibre reinforced polymer in the manufacture of helical springs. The weight and stiffness of carbon and glass fibre roving springs were analysed. The weight of the carbon fibre roving spring is less than that of glass fibre and glass fibre/carbon fibre rovingspring. Consequently, the stiffness of carbon fibre is greater than that of the glass fibre and glass fibre/carbon fibre roving spring. Jadhav and Gawande [4] analysed the feasibility of adopting composite material for design of helical coil spring. The findings of their work showed that combination of composite and conventional material can be used to overcome low stiffness and weight of spring can be optimised.

Great effort has been made by automotive industries in the application of leaf spring. Daugherty [8], Rangendra and Vijayarangan [9] designed and analysed composite leaf spring for application in automobiles. It has been stated in their analysis that in order to meet the need for the conservation of natural resources through weight reduction, the composite materials are suitable for spring production. Multi leaf springs used in automotive vehicles normally consist of full and graduated length leaves. Recent development has been achieved in improving the quality of composite leaf springs based on microstructure mechanism [10].

Artificial genetics approaches for the design optimisation of the composite leaf springs were conducted. Ramakanth and Sowjanya [11] performed finite element analysis of multi leaf springs of three different combinations to find the bending stresses and perform static analysis of the three combinations. The study reveals that a material with minimum modulus of elasticity and maximum strength in the longitudinal direction is the most suitable material for leaf spring. The present work involved design analysis of helical compression and semi elliptical leaf springs of tricycle automobile. The objective is to investigate the load bearing capacity of the springs. Design parameters of existing helical and leaf spring of TVS king and Bajaj tricycle automobile were applied to investigate the load bearing capacity of the springs.

2. DESIGN CONSIDERATION AND ANALYSIS

In this work, helical compression spring of TVS king and semi elliptical leaf spring of Bajaj, automobile were considered for the design. Design parameters for the helical spring consists of the diameter of coil and wire, number of turns, free length, pitch, solid length, spring index and spring rate. The design parameters for the leaf spring include number of leaves, length of leaves, width of leaves, thickness and spring weight [2, 12]. The ability of the spring to withstands heavy load lies in the thickness, width and number of leaves applied in the design.

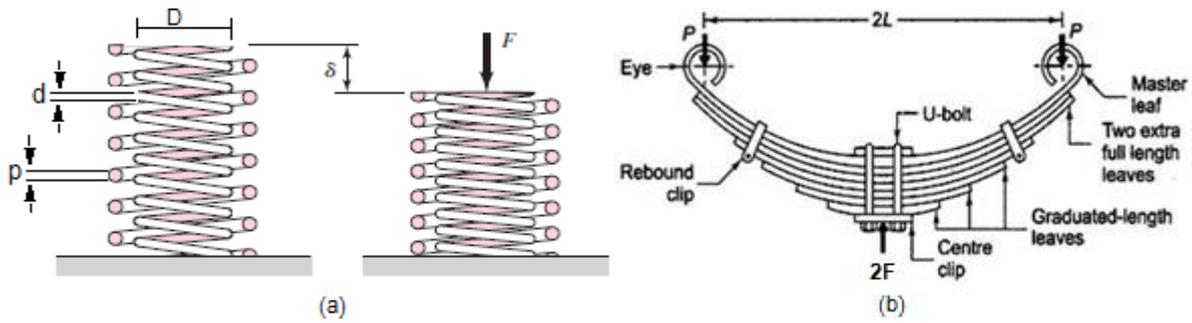


Figure 1: Schematic diagram of (a) helical compression spring (b) semi elliptical leaf spring

Figure 1(a) shows a helical compression spring made of a circular coil of diameter D and wire with diameter d, subjected to an axial load F. The load tend to rotate the wire by the twisting moment which induce storsional shear stress in the wire and the spring deflect by δ which is the difference between the free and compressed spring [13]. Also, the helical spring will experience a direct shear stress as a result of the direct load on the spring. This is a measure of the direct load per unit cross sectional area of the spring. The combined direct shear stress and the shear stress due to the twisting moment acting on the spring is defined by Eqn. 1. The positive and negative sign indicate the outer and inner edge of the wire. The spring index C is defined by D/d, the maximum shear stress induced in the wire is expressed in Eqn. 2 where K_s is shear stress factor [1, 14].

$$\tau_1 \pm \tau_2 = \frac{8FD}{\pi d^3} + \frac{4F}{\pi d^2} \dots\dots\dots (1)$$

$$\tau_{max} = K_s \times \frac{8FD}{\pi d^3} \dots\dots\dots (2)$$

The shear stress factor was further modified by Wahl stress factor K, denoted as the product between the shear stress factor and the stress concentration factor due to curvature for the deflection of the helical spring [12]. The springaxial deflection is a function of Modulus of rigidity for the material defined by Eqn. 3 where n is the number of turns.

$$\delta = \frac{8nFC^3}{Gd} \dots\dots\dots (3)$$

In the design analysis of the leaf spring, constant widths were considered [15]. The width is kept constant over the entire length of the spring while the thickness varies fora minimum at the two ends to maximum at the centre [16]. The leaf spring behaves like a simply supported beam subjected to bending stress and transverse shear stress as shown in Figure 1(b).

The central location of the spring is fixed to the wheel axle. Therefore the wheel exerts a force of 2F on the entire length of 2L at the centre where L is the length of the spring.

Eqn. 4 and 5 were applied to obtain the bending stress and the maximum deflection in full and graduated

$$\sigma_{max} = \frac{6FL}{nbt^2} \dots\dots\dots (4)$$

$$\delta = \frac{12FL^3}{Ebt^3(2n_g + 3n_f)} \dots\dots\dots (5)$$

leaves of the entire leaf spring [1, 15]. In these Eqns. n_f and n_g denotes full and graduated number of leaves, b is the width, n is the number of leaves and t is the thickness of the spring used in the analysis.

3. MATERIALS AND METHOD

The selection of spring material depends upon the service for which the springs are intended. The materials for helical springs should have high fatigue strength, high ductility, high resilience and it should be creep resistant. The material depends largely upon the application or service for which it has been designed. The spring's materials are classified for severe service, average service and light service conditions [2]. Here an emphasis is given to the light service condition which is applicable for the type of spring used in tricycle automobile.

Light service includes springs subjected to loads that are static or very infrequently varied. Alloy steel wire may be used for this type of springs for application at higher temperatures. Tungsten high speed steel or molybdenum is suitable, non-ferrous materials which include phosphorous bronze, beryllium copper, silicon bronze, nickel-silver alloys or nickel alloys monel, K-monel, inconel X and Z-nickel may be used in special cases to increase fatigue resistance and corrosion resistance and are of low cost [17]. Nowadays composites material are usually applied in conjunction with the steel spring to give high stiffness to weight ratio.

The method employed in this work involved the use of the design parameters of the helical compression and semi elliptical leaf springs of the TVS king and the Bajaj automobile to achieve the result. Forces of 2.0 to 3.5 kN in the interval of 0.5 and the design parameters of the helical compression and semi elliptical leaf spring were applied in Eqns. 1-5 to simulate the expected output for the maximum stress and deflection.

Table 1: Mechanical properties of materials for spring design applications

| Materials | Young Modulus(Gpa) | Modulus of Rigidity (Gpa) | Yield stress (Mpa) | Reference |
|----------------------|---------------------------|----------------------------------|---------------------------|------------------|
| Carbon steel | 210 | 80 | 700 | [2, 18] |
| Beryllium Copper | 128 | 49 | 1300 | [14, 16] |
| Phosphorus bronze | 105 | 44 | 770 | [2, 16] |
| Monel | 179 | 66 | 1100 | [14, 17] |
| Music wire | 207 | 80 | 215 | [16, 17] |
| Stainless steel wire | 196 | 70 | 520 | [1, 17] |

Typical example of the materials usually applied in the production of springs and their mechanical properties are given in Table 1. It can be observed that the material with high yield stress is beryllium copper, followed by Monel either K or L type. These two forms of metal are widely used for spring production [19]. Most of the helical springs used for this application are wound with a wire of diameter less than 10mm over a length of 15-20mm to which their strength depends on the size of the wire [1].

The material used for the leaf spring is usually a plain carbon steel having 0.90-1.0% carbon which is the most commonly used of all spring materials [2]. The plain carbon steel are least expensive, readily available easily worked and most popularly characterized by high strength, high hardness and ductility. Enhanced corrosion and wear resistance, high fatigue and impact strength when alloyed with some metals [3].

Table 2: Design specification for helical compression and semi elliptical leaf spring of TVS king and Bajaj tricycle automobile

| Specification | Capacity | Specification | Capacity |
|-------------------------|-----------------|-----------------------|-----------------------|
| Free length | 192 mm | Modulus of Rigidity | 80 kN/mm ² |
| Solid length | 96 mm | Maximum load given | 100 kg |
| Diameter of coil | 80 mm | Pitch of the coil | 18 mm |
| Diameter of wire | 8 mm | Number of turns | 10 |
| Total length | 580 mm | Modulus of Elasticity | 80kN/mm ² |
| Width of leaf | 50 mm | Maximum load given | 125 kg |
| Thickness of leaf | 6 mm | Spring weight | 12 kg |
| Full length master leaf | 2 | Total leaves | 7 |

Table 2 showed the design parameters for the helical compression spring of TVS king and semi elliptical leaf spring of Bajaj tricycle automobile. These properties were determined from direct measurement and the sample specifications of an existing helical and leaf springs of the tricycle automobile. The strength of the helical compression spring to withstand tensile load depend on the pitch size, number of turns in the coil and the ratio of the diameter of coil and wire defined as the spring index. In addition, the capabilities in the helical compression and semi elliptical leaf springs are related to their material property and the spring stiffness defined as the load per unit deflection. These properties were considered in determining the load bearing capacity of the springs. This is similar to the work of Kurna and Tank [20] where virtual testing methods for strength and stiffness evaluation provide useful information early in the design and save significant time and cost in leaf spring suspension. However, the virtual methods need validations which can be achieved by physical correlation via test rig.

4. RESULT AND DISCUSSIONS

The design analysis for helical compression and semi elliptical leaf springs of TVS and Bajaj tricycle automobile were carried out using the parameters in Table 2. The design parameters were obtained from measurement and the specifications of the existing helical compression and semi elliptical leaf springs of the automobile. Direct forces of 2.0 to 3.5 kN in the interval of 0.5N and the design parameters of the helical compression and semi elliptical leaf spring were applied in the Eqns. 1-5 to simulate the expected output for the maximum stress and deflection. The spring stiffness for the helical compression and semi elliptical leaf springs of the tricycle automobile were determined as 8 N/mm and 13 N/mm respectively. The result obtained for the maximum stress and deflection of the springs were shown in Table 3.

Table 3: Maximum stress and deflection for the helical compression and leaf springs

| Direct load (kN) | Helical compression spring | | Semi elliptical leaf spring | |
|---------------------|--|-----------------------------|---|-----------------------------|
| | Max. Shear stress τ_{max} (N/mm ²) | Deflection δ (mm) | Max. Bending stress: σ_{max} (N/mm ²) | Deflection δ (mm) |
| 2.0 | 318 | 83 | 184 | 43 |
| 2.5 | 398 | 104 | 230 | 53 |
| 3.0 | 477 | 125 | 276 | 64 |
| 3.5 | 557 | 146 | 322 | 74 |

The maximum shear stress and bending moment obtained for the helical compression and the semi elliptical leaf spring varies directly proportional to the force applied likewise the

spring deflection. It can be observed in Table 3 that the deflections for the semi elliptical leaf spring is about half of the helical compression. This shows that the semi elliptical leaf spring has high resistance to weight ratio than the helical compression and serve for the purpose intended. Therefore, it is suggested that the semi elliptical leaf spring should also be used for tricycle automobile applications because of its higher advantage of resistance to weight ratio in order to limit the effect on the driving torque of an engine and withstand the nature of bad roads due to pot-holes, gallops and other road irregularities in cities and villages.

In addition to difference in result obtained for the stiffness, maximum stress and deflection in the springs upon load application, the semi elliptical leaf spring is suited for application into the tricycle automobile as it can be guided along a definite path [5] even though, its material are expensive than the helical compression spring and the method of production involved many operations to obtain the finished product. For convenience and economic consideration, more emphasis should be given to increasing the diameter of the coil and wire for helical spring. This will improve the strength and the load bearing capacity of the spring.

5. CONCLUSIONS

This paper involved the design analysis of the helical compression and semi elliptical leaf springs of TVS king and of Bajaj tricycle automobile. Stiffness, stress and deflection were used to investigate the load bearing capacity of the springs. The spring stiffness in helical compression and the semi elliptical leaf springs were obtained as 8 N/mm and 13 N/mm respectively. Upon load application, the stress obtained in the helical compression is greater but produced lower deflections than the semi elliptical leaf spring. This shows that the semi elliptical leaf spring has high strength, high resistance to weight ratio than the helical compression spring. The application of the semi elliptical leaf spring in automobile tricycle will limit the effect on the driving torque of an engine and withstand the nature of bad roads due to pot-holes, gallops and other road irregularities in cities and villages.

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