Design and Structural Analysis of Rear Coil Suspension System

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Abstract -- Suspension system is the combination of various types of spring which include leaf spring, coil spring, air spring, rubber springs, torsion bar springs and shock absorber. In this research, rear coil spring design of Landcruiser Pardo is taken as existing design. The model of vehicle is Toyota Landcruiser Pardo (KD-KZ195W). This model holds the engine model 1KZ-TE with four cylinders which displacement is 2982cc. The overall length, width and height of vehicle are 4675mm, 1820mm and 1880mm. The design of existing coil spring is made of Stainless Steel. In this research different materials were analyzed. From the analysis, Chrome Vanadium Steel is suitable material which holds optimized functions and properties rather than two other materials. Because of this research, the optimized coil spring has the spring index of 7.849, spring rate of 67.56N/m, free length of 244.56mm and pitch of the spring wire as 0.04m. The maximum shear stress of optimized design with the value of 614MPa which is less than the existing design.

Index Terms- Design, rear coil, Structural analysis, suspension system; vehicle

I. INTRODUCTION

Suspension system plays an important role for a comfortable ride for passengers besides protecting the chassis and other working parts from getting damaged due to road shocks. In suspension system, the chassis frame supports the weight of the body, engine, transmission and the passengers. The frame mounted directly on the axle would be subjected to serve vibrations due to road irregularities. The basis frame structures in which the units mounted on it and the passengers would be seriously affected by these serve oscillations. Springs are elastic bodies, which are designed and constructed to give a relatively large elastic deflection under a given load. Springs have a variety of applications and made in many different forms [1,2,3].

A Spring is a flexible element used to exert a force or a torque at the same time to store energy. The force can be a linear push or pull, or it can be radial, acting similarly to a rubber band around a roll of drawing. The torque can be used to cause a rotation, to close a door on a cabinet to provide a counterbalance force for a machine element pivoting on hinge. Springs inherently store energy when they are deflected and retain the energy when the force that causes the deflection is removed. This is the primary design objective. The suspension system has two main basic functions, to keep the car's wheels in firm contact with the road and to provide a comfortable ride for the passengers. A lot of the systems work is done by the springs. Therefore, nowadays the focus of vehicle suspension design has switch from pure numerical analysis to the application of different algorithms which are designed based on optimization methods. The development of optimizing methods is connected with development of an automatic control of systems [4,5,6,7].

II. DESIGN OF HELICAL COIL SPRING

Coil springs used in passenger car rear suspensions are usually lighter duty than those found at the front. This is because the majority of the vehicle's weight is often toward the front. Coil springs on the rear of larger passenger cars, trucks are often variable-rate springs.

Table 1 Specification of existing coil spring of the vehicle.

Material	Stainless steel ASTM-A313
Total number of Coils, n'	7
Number of Active Coil,n	5
Mean Diameter,D	132.81mm
Wire Diameter,d	15.62mm
Inner Diameter, D_i	117.19mm
Outer Diameter, D_0	148.44mm
Free length,L_F	304.8mm

Solid Length,L_s	109.34mm
Pitch, p	50.61mm
Spring Index, C	8.5
Vehicle Weight	1980kg
Weight per person	90kg
Vehicle Capacity	6 person
Gross Weight	2520kg
Factor of Safety(FOS)	1.8
Modulus of Rigidity,G	75842.33MPa
Density,ρ	7805.73kg/m^3
Young's Modulus	203.4GPa
Poisson's Ratio	0.27
Yield Strength	767.39MPa
Ultimate Strength	2192.53MPa

Solid length of the spring $L_s = n' \cdot d$ (1)

Free length $L_F = n'.d + \delta_{\max} + 0.15\delta_{\max}$ (2)

Spring index C = D/d (3)

Spring rate $k = W/\delta = F/y$ (4)

Pitch $P = \dfrac{L_F}{n'-1}$ (5)

Stresses in Helical Spring of Circular Wire

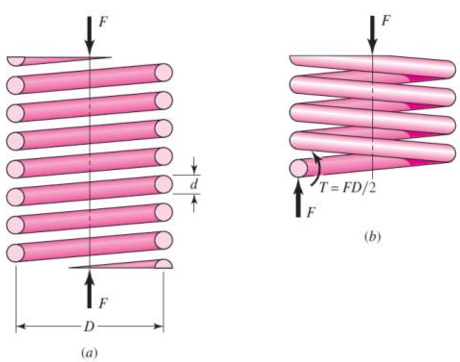

Fig 1(a)Axial load on helical spring and (b) Direct stress and torsional stress on helical soring

The twisting moment $T = W \times \dfrac{D}{2} = \dfrac{\pi}{16} \times \tau_1 \times d^3$

Torsional shear stress $\tau_1 = \dfrac{8WD}{\pi d^3}$ (6)

Direct shear stress $\tau_2 = \dfrac{4W}{\pi d^2}$ (7)

Maximum shear stress = $\tau_1 \pm \tau_2 = \dfrac{8WD}{\pi d^3} \pm \dfrac{4W}{\pi d^2}$

$= K_s \times \dfrac{8WD}{\pi d^3}$ (8)

$= K \times \dfrac{8WC}{\pi d^2}$ (9)

Deflection of Helical spring $\delta = \dfrac{8WC^3 n}{Gd}$ (10)

Buckling of Compression Spring

$W_{cr} = k \times K_B \times L_F$ (11)

For Vehicle

Unsprung Weight/ Vehicle weight = 0.15

Therefore Unsprung Weight/Mass m_1= 1980×0.15
= 297 kg

Sprung Weight/mass, m_2 = 2520-297 = 2223 kg(Full Load)

m_2 =1980-297=1683kg(Empty load)

For quarter car model with load distribution (40:60) in each of front and rear suspension, and only rear suspension system is considered on this research,

Unsprang Weight/Mass, m_1 = (297×0.6)/2=89.1kg

Sprung Weight/mass, m2 = (2520×0.6)/2=666.9kg

Load applied on the suspension system,

W = Gross Weight ×9.81= 24696 N

Since the load distribution of SUV type vehicles is the ratio in front and rear with (40:60)

Load applied on the rear coil spring susoension,

W = 60% of overall load = 14817.6N

Load applied on each coil spring of rear suspension,

W = 0.5×14817.6 = 7408.8N

m = 0.146 (exponent value)

d = 0.013in

A = 169kpsi.in^m

S_{ut} = A/d^m = 2192.53MPa

S_{sy} = 35% of ultimate strength = 767.39MPa

Torsional shear strength, $\tau = \dfrac{S_{sy}}{FOS}$ = 426.33MPa

$$\tau = \frac{8WD}{\pi d^3}$$

$$d = \left(\frac{8WD}{\pi\tau}\right)^{1/3}$$

d = 18mm

Spring index for the oil spring C = D/d = 8.5

Torsional shear stress $\tau_1 = \frac{8W.D}{\pi d^3}$ = 657.18MPa

Direct shear stress $\tau_2 = \frac{4W}{\pi d^2}$ = 38.61MPa

The resultant shear stress $\tau = \tau_1 + \tau_2$ = 695.8MPa

To consider the effect of curvature on maximum shear stress $\tau = K_W \frac{8FD}{\pi d^3}$ = 768.76 MPa

Deflection of spring $y = \frac{8FC^3 n}{dG}$ =169mm

The spring rate k = F/y = 43.84N/mm

Free length of the coil spring

$L_F = L_s + \delta_{\max} + 0.15\delta_{\max}$ = 303.67mm

Bulking of compression springs $W_{cr} = k \times K_B \times L_F$

W_{cr} = 30441.06N

Pitch of coil spring wire $p = \frac{L_F}{n'-1}$ =50.61mm

Pitch angle $\lambda = \tan^{-1}\left(\frac{p}{\pi D_m}\right)$ = 6.91degree

Maximum allowable stress

τ_{allow} = 0.35 × Yield stress = 768.83MPa

$\tau_{\max} \le \tau_{allow}$

So design is satisfied.

Table 2 Result data for Three Different Materials

Material	τ_{max} (MPa)	Deflection y (mm)
Stainless steel ASTM-A313	768.76	168.99
Carbon steel ASTM-A227	644.24	112.34
Chrome Vanadium steel ASTM A-231	614	109.67

Table 2 illustrates maximum shear stress values and deflection for Stainless Steel ASTM-A313, Carbon Steel ASTM A-227 and Chrome Vanadium Steel ASTM-A231. From theoretical analysis Chrome Vanadium steel ASTM - A231 is suitable material for coil spring.

III. STATIC STRUCTURAL ANALYSIS OF REAR COIL SPRING

Static structural behaviors of coil spring can be analyzed to predict the maximum stress acting on the spring structure and the deformation.

Table 3 Material Properties for Chrome Vanadium Steel ASTM-A231

Young's Modulus	206.4 GPa
Poisson's ratio	0.29
Density	7861.1 kg/m^3
Yield Strength	930.79MPa
Ultimate Strength	2068.42MPa

Fig 2. shows three-dimensional model of Helical Coil Spring which is added the properties of Chrome Vanadium Steel and is imported from the SolidWorks to ANSYS 17.0.

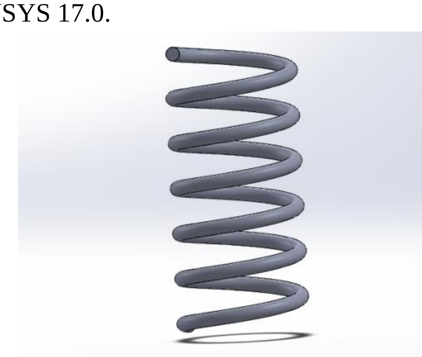

Fig 2 Three-Dimensional Model of Helical Coil Spring

Meshing is the process in which geometry is spatially discredited into elements and nodes as shown in Fig.3. This mesh along with material properties is used to mathematically represent the stiffness and mass distribution of the structure.

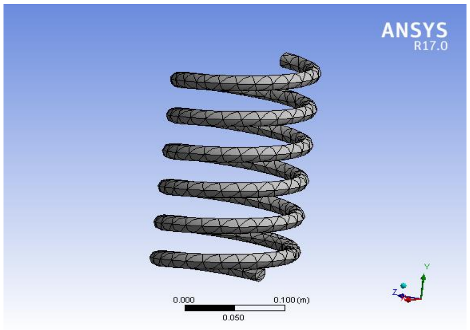

Fig 3 Meshed Model of Coil Spring for Structural Analysis

There are two boundary conditions for static structural; force which is sprung mass acting on the top of coil spring and fixed support at base end of the spring. The spring is mounted on the axle of the automobile; the frame of the vehicle is connected to the ends of the coil spring. Fig.4. shows the condition of force applied on spring.

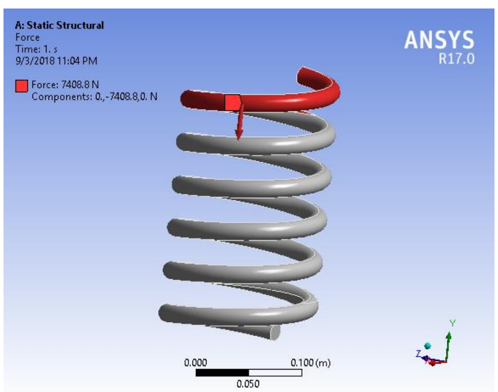

Fig 4 Apply Force on the top of Spring for Static Structural Analysis

Fig 4 also illustrates the applied conditions which is as a fixed support to spring.

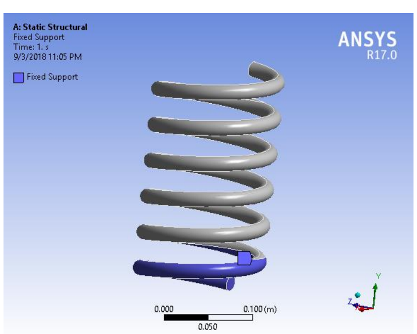

Fig 5. Fixed Support to the Spring

From Fig.5, the actual condition is as the spring is connected to the chassis frame of the car. This contact point is fixed-end point of the coil spring.

After finishing fixed and load, run the process to get maximum shear Stress and total deformation for static structural analysis of coil spring as shown in Fig.6.

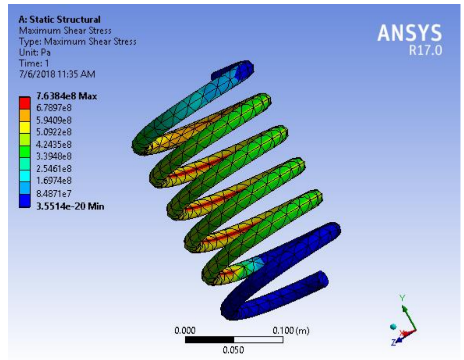

Fig 6. Maximum Shear Stress on Coil Spring for ASTM-A231

The maximum shear stress on the spring is 763.8MPa while the allowable stress is 930.78 MPa. The spring will work safely at this stress.

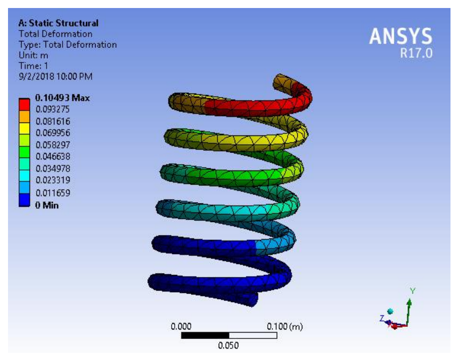

Fig 7 Total Deformation on Coil Spring for ASTM-A231

The total deformation on the spring using structural steel is 0.104m and occurs at the end point of the spring which is applied by load as shown in Fig.7

IV. RESULT AND DISCUSSION

This study focuses on the design consideration and calculation of the helical compression coil spring which is used as rear suspension of Landcruiser Prado.

The sprung-to-unsprung weight ratio is particularly important to the design of extremely low mass vehicles. The necessarily higher suspension frequency produces a rougher ride, which can be accentuated by smaller tires typical of smaller cars. Smaller diameter tires react more violently to bumps and potholes. Their reduced radius causes them to move deeper into depressions and climb more quickly over obstacles. With smaller, lighter vehicles, it is even more important to keep the ratio of sprung to unsprung weight as high as possible in order to reduce the undesirable effects of smaller tires. The proposed design coil spring is less than that of existing coil spring by using less space with smaller coil diameter, wire diameter and spring length than existing design.

After reviewing important and scientific literature, the relation between operating parameters and their importance have been discussed. While designing, the perfect suspension system at most care should be taken as it is highly difficult characterize and predict the relationship in between system components and their response to operating parameters. Many industrial and academic researchers are working in the field of suspension system design but due to complicated nature of suspension system behavior they are facing many problems. In suspension system working, as degrees of freedom increases i.e. movement direction are increased analysis of system becomes much complex as number of variable are also increased with degree of freedom. Suspension systems having less degree of freedoms can be easy to analyze as less variable are present.

In this research, the shock absorber has been redesigned so that the stress acting on the shock absorber is reduced. The proposed redesign will reduce the deformation and induced stress magnitude for the same applied loading conditions when compared. with the existing design. This in turn increases the life of shock absorber by reducing its failures. The analytical results conform to the simulation results from the ANSYS.

In theoretical analysis the maximum shear stress of Chrome Vanadium steel ASTM A-231 steel is 614MPa. In Numerical approach the maximum shear stress is 763.8MPa. The allowable stress is 930.78MPa. So the design is safe and satisfied.

V. CONCLUSION

The stress analysis of rear suspension helical coil spring used in Landcruiser Prado has been presented and analysed in this paper. The shear stress and deformation produced in the spring at the loading condition is in limit, so it is safe. Relative error of maximum shear stress reference to the applied load compared with the values calculated by using simple analytical formulae which were found in reference books. The shear stress is having maximum value at the inner side of every coil which shows stress distribution clearly. From above analysis, it has been observed that the stiffness of the suspension spring is increased which increases load carrying capacity of the system. Because of the reducing number of turns the weight of the spring is reduced. It has been observed that the weight of the system is reduced for same loading conditions. Therefore, the light weight system is achieved which will help to increase the fuel efficiency of the vehicle. Based on the modelling and analysis, it is concluded that the new design is suitable for used so it can be implemented.

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