Coil spring type analysis using the finite element method

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Abstract. Manoeuvre ability and driving comfort are the most important things in the automotive sector. Spring is a fundamental mechanical element that widely used in vehicle suspension applications. Holds loads perpendicular and absorbs shock loads from wheel vibrations so that they are not transmitted directly to the chassis. Therefore, the coil spring was made from a coil of high carbon steel rods in the form of a coil. The purpose of this article was to determine the differences in stress and strain strengths of several different types of coil springs. The types of springs used include the constant pitch spring, variable pitch spring, and barrel coil spring. Various types will be designed using Inventor software while the simulation used ANSYS 19.2 software. ANSYS engineering data used SUP 9 material and was subjected to a load of 6315 N. The results of the analysis showed that among the other three types, barrel coil spring has the lowest equivalent stress and maximum shear stress of 509.72 and 293.41 MPa, respectively, so it has the highest strength.

Keywords: analysis, coil spring, finite element method

1. Introduction
The suspension system consists of several main components, including springs, bumpers and stabilizers which play an important role in the automotive sector in the relationship between vehicle structures and transmitting all forces on the wheels [1]. Coil springs are used in light vehicle types and subject to a variety of dynamic and static loads [2]. Applying strength in storing or absorbing energy, has a mechanical flexibility system and maintains strength [3].

Coil Spring was made from a rod that was rolled to form a coil, with parameters of material diameter, inner or outer diameter, and number of turns per unit length [4]. In general, coil spring materials use SAE 5160, SAE 51420, and SAE 9260 carbon steels [5]. Formed by several processes, including heat treatment at a temperature of 950 °C for 1.5 hours, aiming to make it easier when the rolling process at an operating temperature of 850 °C reaches above the austenite temperature [6,7]. Quenching was performed with a certain holding time in oil with a temperature of 80°C resulting in a completely martensitic microstructure [8].

Components that were subjected to mechanical loads are designed for a certain period of time to determine the accepted risk of failure [9]. In normal operation, failure usually occurs gradually and is characterized by occasional loss of thickness and changes in the chemical or structural...
composition of the material [10]. Following up on E. Oberg, Ed [5] the hot rolling process carries a risk of decarburation, and can result in cracking on the surface of the material.

The explanation above showed that, in order to determine the toughness of the coil spring type, an effective and efficient design is required, including loading analysis and selection of material components. To determine the failure that occurred in the coil spring due to dynamic loading, hence, the simulation analysis is needed to know the occurs of distribution stress [11,12].

2. Method and materials

The type of coil spring designed includes constant pitch coil spring, variable pitch coil spring, barrel coil spring. Constant Pitch Coil Spring is commonly used in city vehicles with flat road contours. Variable Pitch Coil Spring is commonly used for Circle Track Racers. Specially designed for conventional overloads. Responsive and improves overall traction. Barrel coil spring is commonly used in SUV (Sport Utility Vehicle) types, functions to pass through difficult, steep, and on road terrain.

Table 1. Mechanical properties constant pitch coil spring

| Outer Diameter (D) (mm) | Inner Diameter (d) (mm) | Wire Diameter (mm) | Number of Total Coils | Free Length (mm) | Weight (kg) |
|------------------------|-------------------------|-------------------|-----------------------|------------------|-------------|
| 122                    | 98                      | 12                | 6-2                   | 350              | 2           |

Figure 1. Constant pitch coil spring design parameters

Table 2. Mechanical properties variable pitch coil spring

| Outer Diameter (D) (mm) | Inner Diameter (d) (mm) | Wire Diameter (mm) | VP 1 (mm) | VP 2 (mm) | Number of Total Coils | Free Length (mm) | Weight (kg) |
|------------------------|-------------------------|-------------------|-----------|-----------|-----------------------|------------------|-------------|
| 122                    | 98                      | 12                | 37.8      | 73.5      | 6-2                   | 350              | 2.2         |
2.1 Simulation
The simulation to determine the strength of the coil spring was carried out using ANSYS Workbench 19.2 and the torsion beam suspension system approach, where the front of the suspension resembling the letter H is directly linked to the car’s chassis via the bushing. Stress simulations are carried out by involving various loading conditions such as applying a force of 6315 N from the bottom up and using a 5 mm mesh. Deformation analysis was also carried out and the results form the basis for conducting a crack analysis [13,14].

2.2 Material Properties
The material of the coil spring is SUP 9 spring steel [15]. SUP 9 shows good heat deformability and hardening to be applied to coil springs.
Table 4. Mechanical properties SUP 9

| Properties          | Metric          |
|---------------------|-----------------|
| Tensile Strength    | ≥ 1225 MPa      |
| Yield Strength      | ≥ 1080 MPa      |
| Poissons Ratio      | 0.266           |
| Density             | 7850 kg m⁻³     |
| Hardness Brinell    | ≤ 321HB         |

2.3 Meshing and boundary condition

The meshing technique is used to divide several parts into small sizes each element is connected to one another by nodal depending on the accuracy of the analysis. Coil spring analysis under equal loading conditions $F = 6315$ N. Boundary conditions are fixed at the bottom (lower holder) and applied to the top (upper holder).

![Figure 4. Meshing coil spring and boundary condition coil spring](image)

Boundary conditions in Figure 4, the Cartesian coordinate system is located in the fixed holder section, the Z axis in the coordinate system corresponds to the spring axis, the X axis lies in the plane formed from the bottom holder base, the Y axis is perpendicular to the X and Z axes. To avoid interference between different springs and excess torque on the interacting surface, the spring device usually consists of one spring to the left and right of the vehicle. Then the total load received by the spring is the total load on the vehicle. Simplified vertical static spring stiffness [16].

$$K_s = \frac{F}{f} = \frac{Gd^2}{8nD^2}$$  \((1)\)

where $f$ is the vertical deflection of the spring, $G$ is the shear modulus, $d$ is the diameter of spring wire, $n$ is the effective number of spring circles.
3. Result and discussion
Simulation of the FEM approach with ANSYS 19.2 software is used to model the coil spring component to find the highest stress point. The stress analysis was carried out with a force limit of 6315 N applied from the bottom up [17,18]. Maximum stress analysis is required to predict the ductility of the material [19]. The maximum equivalent stress of the three coil spring types is shown in Figure 5.

![Image of coil spring types]

Figure 5. Maximum Equivalent Stress of. a) Constant pitch coil spring, b) Variable pitch coil spring, c) Barrel coil spring

| Type Coi Spring          | Stiffness (N m⁻¹)   |
|--------------------------|--------------------|
| Constant Pitch Coil Spring | 23.89 x 10⁶ N m⁻¹ |
| Variable Pitch Coil Spring | 23.89 x 10⁶ N m⁻¹ |
| Barrel Coil Spring      | 19.11 x 10⁶ N m⁻¹ |

The simulation results show that the maximum equivalent stress value of constant pitch is 714.47 MPa, variable pitch is 998.75 MPa, and barrel coil spring is 509.72 MPa. It shows that the largest maximum stress equivalent value is Variable pitch, followed by constant pitch, and the lowest is the barrel coil spring. In addition, by using equation (1) and the simulation results of the
maximum stress and shear strain, the stiffness values of the three types of coil springs can be obtained in Table 5. From the results of table 5, it shows that the constant pitch and variable pitch have a higher strength compared to the coil spring barrel, which is $23.89 \times 10^6$ N m$^{-1}$.

![Figure 6](image)

**Figure 6.** Maximum shear stress of a) Constant pitch coil spring, b) Variable pitch coil spring, c) Barrel coil spring

In Figure 6 the ANSYS 19.2 simulation of the maximum shear stress is specifically shown in red. The result of the maximum shear stress shows that the constant pitch has 411.08 MPa, a variable pitch has 570.09 MPa and the barrel coil spring is 293.41 MPa. The barrel coil spring model gets the best shear stress value with the lowest value of 32.601 and the highest value of 293.41 MPa. Basically, the maximum shear stress coefficient plays an important role in increasing the strength [20].
Figure 7. Equivalent elastic strain of a) Constant pitch coil spring, b) Variable pitch coil spring, and c) Barrel coil spring

The simulation results show that the value of the equivalent strain constant pitch is 0.0049%, variable pitch is 0.0064%, and the barrel coil spring is 0.0027%. Based on the stress strain diagram, when a ductile object has passed the yield strength limit, and the stress continues to increase, the strain will increase to achieve ultimate strength. The effect of strain on the material can cause unwanted cracking due to shifting of the structure (crystal lattice) of the material therein [21]. A reduction in stress indicates a higher strength [22]. In short, the barrel coil spring is considered to have the highest strength among the other three coil spring models, but has a higher level of stiffness compared to constant and variable pitch. In addition, the greater the value of the spring stiffness, the stronger the pull or push of the spring for a certain displacement.
4. Conclusion
Analysis using ANSYS on the three types shows that barrel coil spring is the most effective type. Among the other three types, barrel coil spring has the lowest equivalent stress and maximum shear stress of 509.72 and 293.41 MPa, respectively, so it has the highest strength. Besides, constant and variable pitch coil spring has the same value of spring stiffness 23.89 x 10^6 N m^-1 compared to barrel coil spring 19.11 x 10^6 N m^-1 which affects the level of comfort while driving.

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