Structural Analysis on the Coil Spring of Motorcycle Suspension System

W H Tan1,a, W C Lo1, C Y Teoh2, and E M Cheng3

1 Faculty of Mechanical Engineering Technology, Universiti Malaysia Perlis (UniMAP), Pauh Putra Campus, 02600 Arau, Perlis, Malaysia.
2 Department of Mechanical Engineering, Faculty of Engineering and Technology, Tunku Abdul Rahman University College, Kuala Lumpur, Malaysia.
3 Faculty of Electronic Engineering Technology, Universiti Malaysia Perlis (UniMAP), Pauh Putra Campus, 02600 Arau, Perlis, Malaysia.
a Corresponding Author: whtan@unimap.edu.my

Abstract. The motorcycle suspension system is one of the crucial components. It helps to support the motorcycle’s weight, isolate the vibration level caused by road imperfection, and keep the wheel in contact with the road surface. Therefore, the performance of suspension system needs to be enhanced to ensure the ride comfort and safety of riders. Coil spring is one of the essential parts of motorcycle suspension system. In this study, two different materials of coil spring are being focused include steel alloy and carbon fiber reinforced plastic (CFRP). The geometry of the coil spring is the existing design in the market. The static structural analyses are carried out to determine the directional deformation of y-axis, equivalent stress and equivalent elastic stress analysis of the corresponding coil spring material. The obtained results are discussed. It is found that the steel coil spring has better performance for the existing coil spring design. The directional deformation, equivalent stress and equivalent elastic strain of steel coil spring are considered at the lower side, which is 0.029357mm, 2003MPa and 0.010051mm/mm respectively. In this study, it is observed that the number of turns of coil spring should be increased to enhance the performance of CFRP coil spring.

1. Introduction
The suspension system plays a vital role for a motorcycle. A suspension system on the bike consists of a coil spring and hydraulic damper setup[1]. Coil spring allows a motorcycle wheel to move independently from its chassis. Hydraulic damper setup controls and manages the movement of the spring. The primary function of motorcycle suspension is to isolate the chassis and rider from road imperfection. With a proper suspension system, the vibration effect due to potholes, bumps, cornering and acceleration or deceleration force can be minimized. In contrast, tires would lose traction when a motorcycle runs into road imperfections. In addition, the suspension system also provides a comfortable riding experience for the rider and passenger[2]. It can reduce road-induced vibration and shock. Furthermore, a good suspension system can also prolong the lifespan of other components of a motorcycle as shock transmission to the components has been minimized. In short, the suspension system is a crucial part of a motorcycle, especially in the aspect of safety and ride comfort. Hence, the
control design problem of a suspension system is always a critical investigation topic. In this study, the performance comparison on the coil spring of motorcycle suspension system with different materials will be conducted according to the structural analysis results.

Material selection is considered one of the important stages for each of the components. The performance of the component closely related to the selected material. For a coil spring in the suspension system, several basic items need to be considered for the material selection stage[3]. There are include:

I. Quality of coil spring satisfies the performance requirement
II. Availability of selected material
III. Cost of material and its working processes
IV. Manufacturing process
V. Environmental-friendly material is encouraged

The standard material for coil spring fabrication in the market is steel. However, the composite material coil spring is an alternative for steel material. P.K. Mallick[4] suggested using fiber reinforced composite elliptic springs as a replacement for coil spring. In the study, it is observed that fiber reinforcement material has a higher strength-to-weight ratio. Besides that, approximate 50% of the weight is reduced compared to steel coil spring. According to J.C. Hendry and C. Probert[5], Carbon Fiber Reinforced Plastics (CFRP) is a better alternate material. By using CFRP as the coil spring fabrication material, the weight of spring is reduced more than 50% compared with the steel coil spring. On the other hand, the cost of CFRP is three times higher than steel. In this study, the material of CFRP will be considered for the structural analysis of coil spring.

2.Methodology
In this section, the existing design of coil spring is studied. Solidworks software is used as computer-aided software to draw the virtual model of coil spring. The parameters of existing coil spring are tabulated and shown in Table 1. The isometric view of the existing coil spring is modelled using Solidworks software and displayed in Figure 1. All the dimensions of this coil spring are according to the parameters stated in Table 1. After that, static structural analysis of coil spring will be carried out by using Ansys software.

Table 1. Parameters of Existing Coil Spring[6]

| Parameter                  | Value        |
|----------------------------|--------------|
| Wire Diameter, WD          | 6.7mm        |
| Mean Diameter, MD          | 33.3mm       |
| Outer Diameter, OD         | 40mm         |
| Inner Diameter, ID         | 26.6mm       |
| Total Number of Coils      | 17           |
| Total Number of Active Coils| 15           |
| Spring Index, C            | 4.97         |
| Solid Length, Ls           | 113.9mm      |
| Free Length, Lf            | 167.8mm      |
| Pitch diameter, P          | 9.87mm       |

Fig-1: Isometric View of Existing Coil Spring

2.1 Static Structural Analysis of Coil Spring
The static structural analysis is carried out using Ansys software. Table 2 shows the mechanical properties of coil springs which are inputted for simulation analysis in Ansys software. After setting up the mechanical properties, the model is imported from Solidworks to Ansys software using Finite
Element Analysis (FEA). Then, the meshing process is conducted on the model for the next step of simulation. The boundary conditions are applied to the model to continue the simulation. Firstly, one of the ends of coil spring is fixed support while the other end is compressed by force. Figure 2 shows the applied boundary conditions of steel coil spring. Based on Figure 2, point A is set as fixed support while 1412 N is applied on the other end of coil spring, which located at point B. The calculation of applied force, 1412N is shown as below:

Weight of bike = 120 kg
Let assume that 2 persons are sitting on the bike and each of them is 60 kg,
Weight of 2 person = 120 kg
Therefore, the total weight exerted to the bike is 240 kg.
Assume that 60% of the weight is supported by rear suspension,
240 kg \times 60\% = 144 kg = 1412 N

Table 2. Mechanical Properties of Steel Coil Spring[6]

| Property          | Value          |
|-------------------|----------------|
| Young’s Modulus   | 1.965 \times 10^5 N/mm\(^2\) |
| Poisson’s Ratio   | 0.25           |
| Density           | 7.876 \times 10^{-6} kg/mm\(^3\) |
| Shear Modulus, G  | 78600 N/mm\(^2\) |

3. Results and Discussions

In this section, the directional deformation of y-axis, equivalent stress and equivalent elastic stress analysis are selected for further investigation and discussion.

3.1 Directional Deformation

Figure 3 and Figure 4 show the directional deformation of y-axis of steel and CFRP. Directional deformation defined as the displacement of a system in a specific axis or user-defined direction. In this
study, y-axis of the coil spring is selected. This is because the force is applied in the y-direction. With the aid of Figure 3 and Figure 4, the deflection of the coil spring when a 1412N force applied on it can be determined. For steel coil spring, the directional deformation lies between -43.057mm and 0.029mm. For CFRP coil spring, the directional deformation lies between -106.81mm and 0.069693mm. The negative sign of deformation indicates that the deformation occurs in the negative y-axis.

3.2 Equivalent Stress

Figure 5 and Figure 6 show the equivalent stress of steel and CFRP coil springs. Equivalent stress also called von-mises stress. Equivalent stress takes account of different effects from multiaxial residual stress states. These effects include principal normal stresses, principal shear stresses and principal normal deformation. In most cases, Equivalent stress is used to determine whether the material will yield or fracture. For steel coil spring, the equivalent stress is lying between the range of $1.2907 \times 10^{-10}$ mm and 2003.4mm. For CFRP coil spring, the equivalent stress is lies between the range of $6.8313 \times 10^{-11}$ mm and 2080.1mm.

3.3 Equivalent Elastic Strain

Figure 7 and Figure 8 show the equivalent elastic strain of steel and CFRP coil spring. Equivalent elastic strain defined as the maximum value of strain which the object will rebound and return to its original shape when the load is removed. For steel coil spring, the equivalent elastic strain is lies between the range of $2.2547 \times 10^{-15}$ mm and 0.010051mm. For CFRP coil spring, the equivalent elastic strain is lies between the range of $2.2318 \times 10^{-15}$ mm and 0.029881mm. Based on the simulation analysis of coil spring, the results are obtained and tabulated in Table 3.
Table 3. Results from Ansys Static Structural Analysis

|                          | Steel spring | Carbon Fiber Reinforced Plastic |
|--------------------------|--------------|---------------------------------|
| Directional deformation (mm) | 0.029351     | 0.069693                        |
| Equivalent stress (MPa)    | 2003         | 2080                            |
| Equivalent Elastic Strain (mm/mm) | 0.010051     | 0.029881                        |

4. Conclusion
The results obtained from the Ansys workbench show that the steel coil spring undergoes less deflection compared to the CFRP coil spring. Besides that, the equivalent stress exerted by the steel coil spring also smaller than the CFPR coil spring when the same boundary conditions are set up. This is because steel has greater weight than CFRP. However, identical geometry of coil spring is used for two different materials in this study. This leads to the performance of CFRP is relatively poor than steel coil spring. The geometry of the coil spring for CFRP should be redesigned to increase the weight and enhance its performance. It can be achieved by increasing the number of turns of coil spring. In conclusion, an optimal geometry of CFRP coil spring is required to ensure the performance and safety of the motorcyclists.

References
[1] “How Do Motorcycle Suspension Systems Work?” https://www.uti.edu/blog/motorcycle/motorcycle-suspension-systems (accessed Nov. 09, 2020).
[2] J. Bryant, A. Grant, Z. Walsh, and R. Daniello, “Motorcycle Rear Suspension.” Accessed: May 10, 2021. [Online].
[3] Y. Yamada and T. Kuwabara, “A Guide to Spring Material Selection,” Materials for Springs, no. i, pp. 1–46, 2007, doi: 10.1007/978-3-540-73812-1_1.
[4] P. K. Mallick, “Static mechanical performance of composite elliptic springs,” Journal of Engineering Materials and Technology, Transactions of the ASME, vol. 109, no. 1, pp. 22–26, 1987, doi: 10.1115/1.3225927.
[5] J. C. Hendry and C. Probert, “Carbon fibre coil springs,” Materials and Design, vol. 7, no. 6, pp. 330–337, Nov. 1986, doi: 10.1016/0261-3069(86)90104-4.
[6] P. J. C. J and R. Pavendhan, “Design and Analysis of Two Wheeler Shock Absorber Coil Spring,” International Journal Of Modern Engineering Research (IJMER), pp. 133–140, 2011.