Study on Modal and Harmonic Response Analysis by Modifying Motorcycle Chassis using Finite Element Method

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Abstract. Motorcycle chassis is one of the most important structures in the design of a motorcycle. Excessive vibration occurs in chassis is undesirable as it may lead to structural failure and discomfort among riders. This study aims to model the motorcycle chassis and carry out dynamic analysis to understand the behaviour of the chassis under vibration. Modelling of chassis was conducted based on Seri Perlis motorcycle, which is characterised by double cradle frame. In dynamic analysis, the modal and harmonic response analysis were employed in this study of the motorcycle chassis and the material used is low carbon steel. Both modal and harmonic response analysis were conducted using Ansys. The results show natural frequencies for six mode shapes and the steady-state response of the chassis under the engine weight excitation revealed that the deformation under z-axis orientation was more prevalent. From this study, the dynamic behaviour of the chassis was understood and improvement of the chassis can be made in the future.

1. Introduction

A motorcycle chassis is one of the most important structures in the design of a motorcycle. It is a skeleton of a motorcycle that its strength and stiffness support all the payload that acted on it. According to T Foale [1], motorcycle chassis come in two different functions, which are statics and dynamics. In static term, the chassis must be able to withstand the weight of the rider, engine, transmission, and the required accessories such as fuel and oil tanks. In dynamic sense, the chassis should be able to deliver precise steering, good road-holding, vehicle manoeuvrability and riding comfort.

Motorcycle dynamics is an analysis of the motion of a motorcycle and its components due to the dynamic loading [2]. The dynamic interest normally includes the motorcycle balance, direction steering, acceleration and braking, suspension, and vibration. Therefore, dynamic behaviour is one of the key elements that need to be taken into consideration when designing a motorcycle chassis. It is a characteristic of how a chassis reacts to the dynamic load or vibration.

When a motorcycle travels along the road, the chassis is influenced by dynamic forces caused by the road roughness, engine, transmission, or any external factors. If there are any excitation frequencies...
that coincide with the natural frequency of the chassis, a phenomenon called resonance will occur which may lead to excessive deformation and vibration.

Thus, this study focuses on analysing the modal properties and steady-state response of the motorcycle chassis using the Finite Element Method (FEM). In addition, the effect of the chassis modifications on the behaviour of the chassis will be discussed.

2. Methodology

2.1. Material properties and boundary conditions
The model of the motorcycle chassis was generated by Catia V5 and imported to ANSYS software, the material properties and boundary conditions were defined. Table 1 describes the mechanical properties the material used.

| Material          | Mechanical Properties                                      |
|-------------------|------------------------------------------------------------|
| Low carbon steel  | Density: 7850 kg/m³                                       |
|                   | Young’s Modulus: $2 \times 10^{11}$ Pa                    |
|                   | Poisson’s ratio: 0.30                                     |

The fixed support boundary condition was applied on the suspension mounting point of the motorcycle chassis [4]–[7]. This is because the interaction of suspension and tyre were not considered in the analysis. As a result, the suspension and shock absorber ends were fixed by applying zero displacement at the swing arm pivot points as shown in Figure 1(a). These boundary conditions were utilized for both modal and harmonic analysis. The acting force points are shown in Figure 1(b).

![Figure 1](image)

**Figure 1.** (a) Fixed support at the motorcycle chassis, and (b) Engine weight excitation force acting at the engine mounting points

2.2. Modal analysis
In modal analysis, the dynamic characteristics of the motorcycle chassis were analysed. Free vibration with no pre-stress environment was simulated in modal analysis. The first six vibration modes are studied in this analysis. The value of maximum deformation was determined with respect to each natural frequency. Besides that, the nature of displacement of each mode shape also studied to determine whether the chassis experiences global or local vibration under the effect of twisting, bending, or a combination of twisting and bending. The chassis was further analysed for harmonic response analysis.
2.3. Harmonic analysis

The results from the modal analysis were served as a reference for harmonic analysis. In this part, the mass of 50 kg of motorcycle engine was considered [10]. The engine mounting points were subjected to a harmonic force equivalent to the engine weight (490.5 N) [3], [7], [8], [9]. The maximum response of the motorcycle chassis towards the harmonic force at frequency range from 65 Hz to 135 Hz was observed [10].

2.4. Structural modification

In the structural modification, the original chassis from the harmonic analysis was modified to study the changes in the overall vibration amplitude. The increment of the thickness of the cross member and the addition of the cross member were considered [3], [8], [11], [12]. The natural frequencies and the frequency response deformation plots of the modified chassis were evaluated.

![Figure 2. Motorcycle chassis (a) original, (b) modification 1, and (c) modification 2](image)

For modification 1, the thickness of the cross member was increased from 1.8 mm to 2.8 mm. Figure 2(b) shows the modified chassis with increased thickness of cross member highlighted at the seating frame of the chassis. For modification 2, a cross member with the same cross section and thickness at the seating frame was added where the deformation is critical. Figure 2(c) shows the modified chassis with additional cross member highlighted at the seating frame of the chassis.

3. Result and discussion

3.1. Modal analysis

Table 2 shows the natural frequency, maximum deformation, and nature of displacement of the motorcycle chassis in 6 modes. Figure 3 illustrates the mode shapes of the chassis corresponding to different natural frequencies. It is observed that the maximum deformation of 53.389 mm was obtained at the natural frequency of 215.12 Hz at the sixth mode for original chassis.

![Table 2. Natural frequency, maximum deformation, and nature of displacement of original chassis](table)

| Mode | Natural frequency (Hz) | Max deformation (mm) | Nature of displacement |
|------|------------------------|----------------------|------------------------|
| 1    | 70.777                 | 16.581               | Bend about y-axis      |
| 2    | 81.424                 | 18.654               | Bend about z-axis      |
| 3    | 129.650                | 35.064               | Bend about z-axis      |
| 4    | 141.910                | 35.354               | Twist and bend about y-axis |
| 5    | 183.050                | 24.484               | Twist about x-axis     |
| 6    | 215.120                | 53.389               | Bend about y-axis      |
Table 3 and Figure 4 show the comparison of natural frequency for original chassis, modified chassis 1 and modified chassis 2. The natural frequencies of the modified chassis 1 are higher than the original chassis. The effect of increasing the thickness of the cross member of the chassis will increase the natural frequency of the chassis. Besides, the modification increased the mass of the chassis from 10.922 kg to 11.001 kg, which increment of 0.079 kg. On the other hand, the natural frequencies of the modified chassis 2 were the highest among the three chassis. The modification of adding a cross member at the seating frame of the chassis has significantly increased the natural frequency of the chassis. Besides, the mass of the chassis increased from 10.922 kg to 11.085 kg, which increment of 0.163 kg.
Table 3. Comparison of natural frequency for original chassis and modified chassis 1

| Mode | Natural frequency (Original) (Hz) | Natural frequency (Modification 1) (Hz) | Natural frequency (Modification 2) (Hz) |
|------|----------------------------------|----------------------------------------|----------------------------------------|
| 1    | 70.777                           | 71.502                                 | 72.437                                 |
| 2    | 81.424                           | 81.724                                 | 82.504                                 |
| 3    | 129.65                           | 130.64                                 | 132.09                                 |
| 4    | 141.91                           | 143.8                                  | 149.54                                 |
| 5    | 183.05                           | 183.22                                 | 183.85                                 |
| 6    | 215.12                           | 218.43                                 | 281.65                                 |

Figure 4. Natural frequency versus mode number for original and modified chassis

3.2. Harmonic analysis

Figure 5 outlined the frequency response curves of original and modified chassis for z-axis deformation orientation. It can be observed that the original chassis produced a maximum amplitude of 21.045 mm at the frequency of 71 Hz. In addition, both modifications indicate a significant drop of deformation amplitude when compared to the original chassis.

Figure 5. Comparison of frequency response plot between original and modified chassis

A thorough consideration of the mass, natural frequency, frequency response, and the source of excitation should be emphasised when structural modification or optimisation takes place in designing chassis frame. When the mass of the chassis design comes into consideration, the modified chassis 1 can be the option as thickening the cross member of the chassis only increase the mass by 0.079 kg.
compared to the modified chassis 2 (0.163 kg). Besides that, if the natural frequency of the chassis is the main consideration, modification 2 can be implemented by introducing an additional cross member in the chassis where the deformation at a particular section is high. Finally, when the focus is the frequency response of the chassis, the vibration amplitude of modification 1 is slightly lower than modification 2 for z-axis orientations. Therefore, modification 1 is more preferred.

4. Conclusion
The dynamic analysis of the motorcycle chassis was performed through finite element method. The results outlined the difference between the response of the motorcycle chassis against harmonic loads, and how the structural modifications affect the chassis. From the modal analysis, the modification on the chassis indicates increment on the natural frequency as the chassis became stiffer. In harmonic analysis, the results revealed that the deformation under z-axis of orientation was more prevalent. The structural modification was implemented to reduce the amplitude of deformation of the chassis. The increment in the thickness of the cross member and the addition of the cross member in the critical area of the chassis were effectively reduced the vibration amplitude.

5. References
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