Static and Dynamics Analysis of Bicycle Frame

W H Tan¹, M Ashraf¹ and L E Ooi², and J Niresh³

¹ Faculty of Mechanical Engineering Technology, Universiti Malaysia Perlis (UniMAP), Pauh Putra Campus, 02600 Arau, Perlis, Malaysia.
² School of Mechanical Engineering, Universiti Sains Malaysia, 14300 Butterworth, Penang, Malaysia.
³ Department of Automobile Engineering, PsG College of Technology, Coimbatore, India.

Abstract. Leisure bike became a trend among the people in Malaysia as their method of exercise. The problem rises as the riders start to complain about their muscle fatigue after long cycling. This study aims to determine how the changing of material of the bicycle frame and the insertion of the suspension system can reduce vibration. This study was conducted using aluminium alloy as the material for bicycle frame to reduce the vibration and the weight of the bike. The suspension system has also been customized into the bicycle frame as the main vibration absorber. The CAD model was developed and been analysed using static and dynamic analysis based on the specific boundary condition. The result showed a small deformation occurs on the frame that causes the frame to deflect from the original shape as depicted in modal analysis. Overall, it is concluded that a suspension system adopted on the bicycle frame can have a significant enhancement in vibration reduction on the rider.

KEYWORDS: Bicycle Frame, Static Analysis, Dynamic Analysis, Modal Analysis

1. Introduction

Cycling is one of the most popular activities nowadays as a part of the exercise among the people in Malaysia. Bicycles are one of the green products that are environmentally friendly, safe, and currently used in the form of exercise. The customers desired their bike to be durable, compact, lightweight, attractive in design, and comfortable. The demand from the customers made the developers struggle since it is barely impossible to satisfy any of these specifications [1]. Over time, many researchers [2] have conducted the research and development of bicycles that contributed to a customizable design such as low weight chassis, increased rider performance, low-riding drive, and improved handling system satisfy customer requirements. A bicycle consists of several main parts: frame, wheel, pedal, saddle, brakes, and chain. Most of these parts undergo research and development based on customer requirements and engineering characteristics to improve the quality of bicycles.

This study would focus on the static and dynamic analysis of a bicycle frame since its plays a significant role in the consistency and efficiency of bicycles. Even if all other components like wheel and chain are top quality, they still cannot satisfy the need for the top quality of bicycles without the highest quality of the frame [3]. The quality design of the bicycle frame gives a better experience and comfort for the riders. If less vibration occurred by a quality-built frame, the rider could achieve a better
experience. The low-quality built frame cannot eliminate the vibration effectively, and the large amplitude of vibration acting on the riders will cause fatigue to the muscles.

The comfort point for a bicycle rider is influenced by the touchpoints between surface, such as hands, legs, and hips. When the riders ride through the rocky surfaces, the vibration causes the repeated movement on the handlebars where the human soft tissues are exposed by pressure [4]. This long period of exposure from the vibration will cause a state of fatigue in the human body [3]. The study on dynamic behaviour can lead to better frame quality and enhance performance [3]. This study aims to customize the frame with the suspension system and analyze the stress acting on the bicycle frame. Then the CAD model of a bicycle frame was designed to obtain the static and dynamic analysis using Finite Elements Analysis. The result will then be recorded and discussed in the result section.

2. Methodology

The material of leisure bike is replaced with advanced composite materials to maintain strength, low cost, reduce vibration and reduce weight. The replacement of the material used for manufacturing bicycle frames with aluminium alloy and the suspension system also be introduced into the system to reduce the vibration. The material properties of aluminium alloy are shown in Table 1. To analyze the model using the computer measurement; hence a CAD model needs to be designed. The CAD model is created using the software of CATIA V5 R21. The primary dimension of the bicycle frame and the suspension are shown in Table 2 and Table 3. The drawing of absorber and complete model of the bicycle frame can be seen in Figure 1 and Figure 2.

The basic requirements for a bicycle frame are top tube, head tube, down tube, chain stays, seat stay, and seat tube. The double triangle shape of bicycle frame is known as a diamond frame. Various loads are acting on the different parts of a bicycle frame. In this study, the rider with 76 kg was considered to analyze the static and dynamic analysis of the frame. The detail of the boundary condition is shown in Figure 3. Static and dynamic analyses are performed to observe the frame under the specific loading and various frequency modes. All the listed analyses are obtained using the Fusion 360 application.

| Property          | Value       |
|-------------------|-------------|
| Young’s Modulus, E| 69x10³ Mpa  |
| Poisson’s Ratio, v| 0.33        |
| Density, ρ        | 2700kg/m³   |
| Yield Strength    | 280 MPa     |

Table 1. Material properties of aluminium alloy [5].

| Part      | Length (mm) | Outer Diameter (mm) |
|-----------|-------------|----------------------|
| Top Tube  | 630         | 30                   |
| Head Tube | 201         | 30                   |
| Down Tube | 645         | 30                   |
| Chain Stays | 445      | 30                   |
| Seat Stays| 500         | 30                   |
| Seat Tube | 570         | 30                   |

Table 2. Main dimensions of the bicycle frame.
Table 3. Dimension of suspension.

| Part                      | Dimension (mm) |
|---------------------------|----------------|
| Coil diameter             | 30             |
| Wire diameter             | 8              |
| Spring length             | 100            |
| Nut diameter              | 8              |
| Bolt length               | 50             |
| Length of the suspension  | 140            |
| Suspension diameter       | 20             |

Figure 1. Absorber model

Figure 2. Full frame model

Figure 3. Boundary condition of bicycle frame [6]

For this study, the rider with the 76 kg (745.56 N) weight is considered and acting on point B in Figure 3. Fix boundary conditions are set at points A and D.
3. Result

3.1. Stress contour

3.2. Displacement plot

Figure 4. Stress contour for a bicycle frame. Figure 5. Displacement plot for bicycle frame

Based on Figure 4, the maximum stress occurs on the joint of down tube and seat tube, while the minimum stress occurs on the suspension system's location. However, the maximum displacement or deformation occurs on the seat tube area while the minimum displacement occurs on the joint of chain stays and seat stays, as shown in Figure 5.

3.3. Modal analysis

| Mode 1 = 0.188 Hz | Mode 2 = 0.1915 Hz |
|-------------------|--------------------|
| Max Min           | Max Min            |
|                   |                    |
| Mode 3 = 0.3603 Hz| Mode 4 = 37.15 Hz  |
| Max Min           | Max Min            |
|                   |                    |
Mode 5 = 63.73 Hz

Mode 6 = 87.47 Hz

Figure 6. Mode shape of bicycle frame

Figure 6 shows the mode shape of bicycle frame. The first six mode shapes will be considered and analyzed in this study. For mode 1, the natural frequency value is 0.1884 Hz, where the maximum deformation occurs on the suspension system. In contrast, the minimum deformation occurs on the joints of chain stays and seat stays. For mode 2, the natural frequency was increased to 0.1915 Hz, but there are no changes to the region of maximum and minimum deformation. The natural frequency keeps growing to 0.3603 Hz, but no changes occur for the maximum and minimum deformation region. When entering mode 4 of natural frequency (37.15 Hz), there are changes to the maximum deformation region where it starts to occur on the middle of seat tube. In contrast, the minimum deformation region remains the same.

For mode 5 (63.73 Hz), the maximum deformation region moves slightly upward to the top of the seat tube and still no changes to the minimum area. Lastly, when the natural frequency reached 87.47 Hz (mode 6), the maximum deformation shifts downward to the bottom part of seat tube while the minimum deformation region still the same. Table 4 summaries the result of modal analysis obtain in this study;

Table 4. Summary of modal analysis

| Mode  | Natural frequency | Maximum deformation       | Minimum deformation                        |
|-------|-------------------|----------------------------|--------------------------------------------|
| Mode 1 | 0.1884 Hz         | Suspension system          | Joints of chain stays and seat stays       |
| Mode 2 | 0.1915 Hz         | Suspension system          | Joints of chain stays and seat stays       |
| Mode 3 | 0.3603 Hz         | Suspension system          | Joints of chain stays and seat stays       |
| Mode 4 | 37.15 Hz          | Middle of seat tube        | Joints of chain stays and seat stays       |
| Mode 5 | 63.73 Hz          | Top of seat tube           | Joints of chain stays and seat stays       |
| Mode 6 | 87.47 Hz          | Bottom part of seat tube   | Joints of chain stays and seat stays       |
4. Conclusion

The static and dynamic analysis of bicycle frame was analyzed based on the specific boundary condition of adult's weight of 76 kg. Both static and dynamic analysis of bicycle frame using aluminium alloy as the material for the frame. The vibration analysis was conducted using dynamic analysis to obtain the six modes of frequency. The result of static and dynamic analysis is observed. The result shows the small deformation that occurs on the bicycle frame that causes it to deform from its original shape. Although the deformation occurs, the bicycle frame can still absorb the tested vibration without the large deformation on the frame structure. The results are still acceptable and can be improved by future researchers to increase the thickness of the frame. Hence, the objective for the project is achieved.

References
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