A Study on Multiple Load Conditions Analysis for a Bicycle Chassis

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***Received:** 8 November 2021; **Accepted:** 10 June 2022; **Published:** 25 July 2022*

Abstract: In Malaysia, mass utilization of bicycle as a "green approach" in ensuring environmental sustainability and minimizing over reliant on fossil fuel is indeed a great idea. One of the prominent components of a bicycle is its chassis. Chassis is the main part of a bicycle, where it absorbs all the load acting on it. The chassis plays important role in of safety as well as comfort. The aim of this study was to investigate on the multiple loading conditions on a bicycle chassis. For this study, an existing bicycle chassis design that was available in the market was selected to investigate. The specification details of the chassis were obtained from the manufacturer's website and then developed via the use of Computer Aided Design (CAD). The chassis was then analyzed via Finite Element Analysis (FEA) software for the following loading conditions: (i) Static start-up (ii) Steady pedaling (iii) Vertical loading (iv) Horizontal loading and (v) Rear wheel braking. The result of the analysis was shown the reading and position of maximum equivalent (von Mises) stress of the frame, reading of safety factor and weight for each design in normal and expandable mode under each load conditions. The highest of maximum stresses were found in the load condition 3 which was the vertical loading. The lowest maximum stress of the designs was found in the load conditions 4 which was rear wheel braking. The safety factors for certain loading condition were greater than 2.0. Hence, further design optimization could be made with this aspect. As a conclusion, the assessments were a success. The data attained from this assessment could now be utilized as a benchmark for future improvements on overall chassis design, engineering material or human factors.

Keywords: Bicycle, Chassis, Finite Element Analysis, Loading Conditions

1. Introduction

In Malaysia, mass utilization of bicycle as a "green approach" in ensuring environmental sustainability and minimizing over reliant on fossil fuel is indeed a great idea. One of the prominent components of a bicycle is its chassis. Chassis is the main part of a bicycle, where it absorbs all the load acting on it. The chassis plays important role in of safety as well as comfort. Thus, for the purpose of continuous improvement, the bicycle chassis is definitely one of the best points to initiate.

The aim of this study was to investigate the multiple loading conditions on a bicycle chassis. For this study, an existing chassis design which is available in the market was studied for continuous improvement. As the development of the VCL bicycle, the chassis is the body of the bicycle which helps to connect all the other components and support the rider and the cargo or luggage. The force that is applied on the chassis of the bicycle is the considered variable to prevent the chassis breaking or crashing. The applied force including the weight of the rider, the weight of the cargo or baggage and the force during cycling. Due to all the criteria, the chassis of the bicycle needs to undergo the structure strength test to determine the strength and the limit of the chassis (Muhammad Nasrul Faez, 2017). For this purpose, Finite Element Analysis (FEA) was selected as the primary research method.

FEA is one of the methods which is used to determine the distribution of stress on the complex body of a mechanism (Mills, N., 2007). As providing the trusty and accurate result, finite element method is widely being used in modelling the dynamics of some structures (Abdullah et al., 2015; Nor et al., 2019). It helps to make a simulation of the true physical situation by importing the 3D models to the FEA in the geometry and loading condition to analyse the position and the value of the maximum stress and strain on the imported 3D models. The range of the result will be classified by different colours which shows on the structure of the models. In the study of Akhyar, Husaini, Iskandar Hasanuddin, and Ahmad Farhan (2019), they have made structural simulations of the bicycle frame with different load conditions which refer the load conditions in the study of Miles Paul and Dr Mark Archibald (2013). They have added two additional load cases to the simulations. Therefore, there are total five load conditions to analyse the structural simulations of bicycle frame. The five (5) load conditions are static start up, steady state pedalling, vertical loading, horizontal loading and rear wheel breaking. The FEA assessments were conducted in reference to these load conditions.

From the FEA results, the stress locality could be clearly identified, thus, design improvement could be made. Henceforth, future bicycle chassis could be made better in term of strength and overall design. Furthermore, the use of material and more simplified design could be made to the region of the chassis which indicate the least amount of stress locality. Therefore, sustainability in term of raw material usage and production cost could also be minimized. In short, the bicycle chassis is a great point of which continuous improvement could be made.

Table 1: Properties of Material in comparison

Material Characteristic	Al 6061	Ti6-Al-4V	Carbon Fibre
Young Modulus ($N/m^2 \times 10^3$)	68.9	115	50-150
Yield Strength (N/m^2)	260-290	880-1100	Varies
Tensile Strength (N/m^2)	300-320	950-1170	250-400
Elongation (%)	17	10	2.50
Density (kg/m^3)	2.70	4.43	1.80
Weldability and Machinability	Excellent	Fair	Fair
Cost (€ per kg)	1.5	45	Varies

As aforementioned on material selection in Table 1, the Aluminium alloy Al6061 is one of the generally used type of alloy. This is because it has good machinability. The strength properties of the aluminium alloy AL6061 is able to increase by conducting thermal treatment and hardening (Rontescu et al, 2015). The selection of the material should be implemented in the additive manufacturing. This is because the generative design can only be produced by using the additive manufacturing technologies. The additive manufacturing process which used aluminium alloy as materials are powder bed fusion. There are some technologies in the process of the powder bed fusion.

2. Methodology

The specification details of the chassis were obtained from the manufacturer's website and then developed via the use of Computer Aided Design (CAD). The chassis was then analyzed via Finite Element Analysis (FEA) software for the following loading conditions: (i) Static start-up (ii) Steady pedaling (iii) Vertical loading (iv) Horizontal loading and (v) Rear wheel braking. The details of the five (5) scenarios of each load conditions are as below:

i. Static start-up

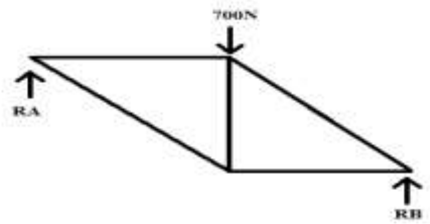

Figure 1: The free body diagram of the static start-up

Figure 1 shows the free body diagram of the static start-up. In this scenario is modelling the rider is riding the bicycle in the stationary position. The front wheel of the bicycle is pointed straight in the vertical equilibrium. There are some variables is negligible such as aerodynamics, rolling and gyroscopic force (Pawar, R. and Kolhe, K., 2016). The weight of the rider is 71.3kg which applied a load of 700N to the seat tube of the bicycle frame (Devaiah et al., 2018).

ii. Steady pedalling

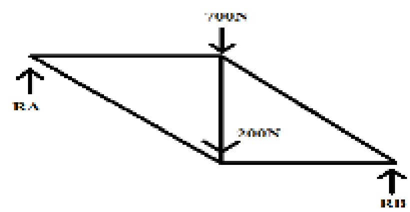

Figure 2: The free body diagram of steady pedaling

The free body diagram of steady pedalling is shown in Figure 2. This scenario is modelling the rider with the weight of 700N starts to apply a steady pedalling to the bicycle and maintains the power of pedalling at all times. The pedalling force is 200N due to leg dynamics (Devaiah et al., 2018). The load concentrate at the bottom bracket of the bicycle frame.

iii. Vertical loading

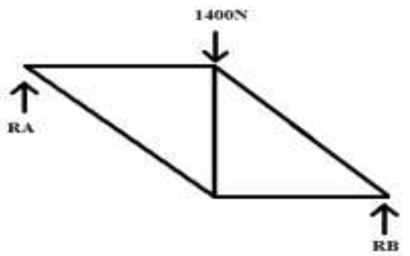

Figure 3: The free body diagram of vertical loading

The free body diagram of vertical loading is shown in Figure 3. In this scenario, the vertical loading will be double of the weight of the rider because of the present of the G factor. The double weight situation is representing the scenario of the bicycle cycling through a deep road hole which will make an impact. The impaction will transfer the energy to the whole structure body. Therefore, the load represents the weight of the rider is 1400N in this load condition.

iv. Horizontal loading

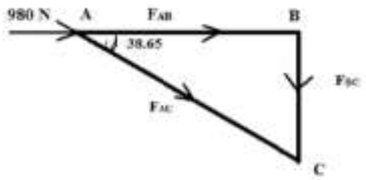

Figure 4: The free body diagram of horizontal loading

Figure 4 shows the free body diagram of horizontal loading. Horizontally applied a large amount of force which is 980N to the front head of the bicycle and the rear drop-out has no translation movement. This scenario is modelling the condition of the front of the bicycle hit to the hard obstacle. According to the standard of Bureau of National Affair (BNA). the bicycle should pass this condition with no cracks or deformation happen.

v. Rear wheel braking

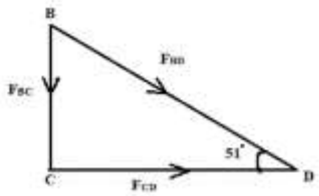

Figure 5: The free body diagram of rear wheel braking

The free body diagram of rear wheel braking is shown in Figure 5. The scenario is related to the brake on the rear wheel. Assumption is made that the obstruction has been given slowly to the wheels and the loads are focused on the rear wheel. The rider needs to decrease the speed to achieve steady speed. Then, the rider needs to brake the bicycle until it stops. In this condition, the load of 200N is given to the rear drop outs because of the consideration of brakes (Akhyar et al., 2019).

3. Result and Discussion

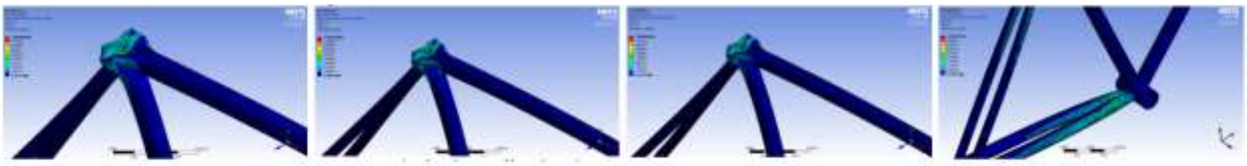

Figure 6: Load condition 1, 2, 3, 4

From the Finite Element Analysis, the Maximum Equivalent (von Mises) Stress (MPa) recorded for the loading conditions were as follow: (Condition 1) 126.69MPa, (Condition 2) 126.78MPa, (Condition 3) 249.64MPa, (Condition 4) 4.56MPa, and (Condition 5) 99.40MPa respectively. Adding to this, the safety factor for the aforementioned conditions were also obtained as follow: (Condition 1) 2.21, (Condition 2) 2.21, (Condition 3) 1.12, (Condition 4) 5.13 and, (Condition 5) 2.82. It could be noted that the safety factors for certain loading condition is greater than 2.0.

As the load condition 1 and 2 have the similar load applied, the maximum equivalent stress of normal mode and expandable mode have the similar reading. The highest maximum stress was found in the load condition 3 and lowest maximum stress in load condition 4. This is because the load applied on the seat tube of bicycle frame is 1400N which is double of the weight of rider. Besides, the force applied horizontally to the end of the chain stay in the load condition 4 has caused the lowest maximum stress result to the bicycle frame.

The position of maximum equivalent (Von Mises) stress in load condition 1, 2 and 3 were located at the top of the seat tube. This is because the load has applied on the top of the seat tube. However, the position of maximum equivalent (Von Mises) stress was located at the chain stays of the bicycle chassis due to the force applied was on the chain stays. These are all shown in the figure 6.

4. Conclusions

In short, the assessments were a success. For the purpose of continuous improvement and sustainability, further design optimization could be made with this aspect. The data attained from this assessment could now be utilized as a benchmark for future improvements. Improvement could be made with respect to the overall chassis design, engineering material or human factors. In addition, the use of new technology such as additive manufacturing and generative design could open-up greater possibilities of advancement in chassis design.

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