An Analysis of Vibration Reduction Design on the Bicycle Frame Based on Multi-Body Dynamics Simulation

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Abstract. In recent years, the awareness of environmental protection has risen, and modern people's quality of life has improved. Bicycles are no longer just general transportation and carrying tools, but evolved into the need to emphasize comfortable riding, energy-saving and carbon reduction, and physical fitness. In this study, the different vehicle-to-weight ratio and road bumpiness before and after designing the bicycle frame's damping and stiffness parameters were considered. The simulation results designate that the seat acceleration in both the y and z-axis is adequate constant, and the seat velocity gradually increases, whereas the vertical seat displacement of damped has significantly reduced compared with undamped.

1. Introduction

In terms of characterizing bicycle suspension components, shock absorbers are more challenging to achieve, but this is an essential factor in predicting the bicycle's dynamic behavior. There have been many studies on semi-active suspension system optimization; however, they are still limited to motorbikes or cars. Khadr et al. [1] studied the design and optimization of a semi-active suspension system called the continuous skyhook and the modified skyhook used in a fully dynamic model of a two-wheeled vehicle that is considered as a multibody system. The results show that the semi-active suspension system's control strategies give an improvement compared to the passive suspension system. Koulocheris et al. [2] presented a study of the semi-active suspension systems optimization used in a passenger car regarding ride comfort and road holding. A half-car model, equipped with controllable dampers, a seat, and a driver, was implemented and optimized using genetic algorithms to ride comfort and road holding. This study highlights how the optimization of the vehicle model could lead to the best compromise among ride comfort and road holding, overcoming their well-known trade-off. Lajqi and Pehan [3] introduced a design and optimization procedure for active and semi-active non-linear suspension systems regarding terrain vehicles to immediately investigate vehicles suspension accomplishments resulting from passive, active, or semi-active systems on the vehicle's body acceleration, velocity, displacement, and vertical tire force that directly affect driving comfort and safety.

The damping application in the suspension system is also an endeavor to diminish vibrations in the vehicle, which vibration present on various levels in many engineering fields and hence vibration mitigation has become a subject of intense study [4]. Dharankar et al. [5] presented an analysis of...
position-dependent damping (PDD) and a methodology for estimating its parameters for passive suspension of vehicles. The PDD concept can improve the performance of vehicle suspension by minimizing the well-known ride-handling conflict associated with passive suspensions. Yang et al. [6] studied a bioinspired damper enhanced with increased force capacity using a hydraulic damper on the small laboratory scale. The two disturbance of automotive suspensions over the sinusoidal road and a bump type road was applied as a theoretical damper on the numerical studies. An application in a mountain bicycle suspension over bump type road disturbance is presented. The theoretical damper shows improved vibration reduction performance over traditional passive systems and performed comparably to the active and semi-active suspension systems.

The bicycle frame is one of the main components that need to be analyzed for its vibrations resistance to estimate and prevent fatigue damage. Shelton et al. [7] presented an analysis of front shock failure on a mountain bike that occurred catastrophically. The fatigue cracks were initiated at a circumferential location in the tube commensurate with high tensile bending stress and the crown's stiffest region (highest stress concentration). The shock design, which facilitated high local stresses during use was suspected as the most probable cause of the bike shock fatigue failure.

This study proposed to find out and analyze shock absorbers on bicycles’ dynamic behavior using multi-body dynamics simulation software, particularly on the front fork and rear suspension shock absorber. In simulation analysis, the absorbent is explained by applying the spring coefficient and damping coefficient, besides cushion vibration simulating the road surface's bumpy state. The load is calculated from both the weight of the bicycle and the driver.

2. Bicycle Frame Model Establishment
2.1. The method on the study implementation
Multi-body dynamics simulation is an effective method to analyze forces and vibrations in a solid moving object, in this case, a bicycle being ridden. According to the previous study by Du Shihong [8] about the effects of the shock absorber on dynamic behaviors of bicycles by using ADAMS, the proposed method of this study as shown in Figure 1.

![Figure 1. The flowchart of proposed study.](image)

Figure 1 describes the study initiated with a literature study to obtain the fundamental intricacy; in this case, is vibration reduction using damping and stiffness parameters on the bicycle frame. Then determine the geometric model using Solidworks, which is then exported to multi-body dynamic software (ADAMS) to build a simulation model and determine the contact pair and solver setting. Finally, the results obtained were analyzed and verified.

2.2. Actual bicycle system architecture and the geometric model
According to the bicycle structure previously existed, as shown in Figure 2, the bicycle geometric frame model was formed. Next, using the SOLIDWORKS software, the bicycle model is divided into six parts: stay, tube, crown, fork, leg, and hub as simple geometric designs shown in Figure 3. This model is assumed to use Aluminum as the material. The detail parts are shown in Table 1.
This model is based on sketches of bicycle models in general that use spring as a shock absorber. The dimensions of each part refer to the prevailing standard measure because, in this study, more critical analysis of shock absorbers than the dimensions of the spare parts. The specified frame model is used for the suspension analysis model to dampen vibrations by using springs at two locations, the first on the front frame between the fork and leg and the second at the rear tube, connected to the stay.

Subsequently, the Solidworks models import into ADAMS software, using Import function with selection file type Parasolid.xt. Then, the contact pair setting among each part were constructed according to structure and linking method in Table 2.

### 2.3. Stiffness and dumping equations

A linear spring is applied in the two places as mentioned above to reduce the bicycle frame's vibration, then the stiffness and damping are analyzed. Stiffness in this study is the linear spring stiffness, which is the spring's ability to withstand the deformation of both the bicycle and driver and both dynamic loads due to rough road conditions, as illustrated in the following equations.

\[
W_{total} = W_{bike} + W_{driver}
\]

where \( W_{total} \) is the total load that works on the bicycles, \( W_{bike} \) is the weight of the bicycles and \( W_{driver} \) is the weight approximately of the driver who riding the bike.

\[
k = \frac{F}{x}; \quad F = m \cdot g; \quad k = \frac{m \cdot g}{x};
\]

where \( k \) is a constant factor characteristic of the spring (stiffness), \( F \) is the force/load that works on the bicycles and \( x \) is the displacement produced in the spring when the weight is suspended.
| Part name | Part name | Structure          | Link method      |
|-----------|-----------|-------------------|-----------------|
| Stay      | Ground    | 2 Bodies – 1 Location | Fixed joint     |
| Hub       | Ground    | 2 Bodies – 1 Location | Fixed joint     |
| Leg1      | Hub       | 2 Bodies – 1 Location | Fixed joint     |
| Leg2      | Hub       | 2 Bodies – 1 Location | Fixed joint     |
| Crown1    | Fork1     | 2 Bodies – 1 Location | Fixed joint     |
| Crown1    | Fork2     | 2 Bodies – 1 Location | Fixed joint     |
| Crown2    | Fork1     | 2 Bodies – 1 Location | Fixed joint     |
| Crown2    | Fork2     | 2 Bodies – 1 Location | Fixed joint     |
| Crown1    | Tube      | 2 Bodies – 1 Location | Fixed joint     |
| Crown2    | Tube      | 2 Bodies – 1 Location | Fixed joint     |
| Tube      | Stay      | 2 Bodies – 1 Location | Rotary joint    |
| Tube      | Stay      | 2 Location         | Spring element  |
| Fork1     | Leg1      | 2 Location         | Spring element  |
| Fork2     | Leg2      | 2 Location         | Spring element  |

Meanwhile, damping is meant more particularly as suspension damping, which is the method of managing or freezing the spring's oscillation, either when it compresses or rebounds, usually both. The position-dependent damping (PDD) curve is such that it has a low damping coefficient at the average position and gradually increases the maximum towards the step end, as shown in Figure 5. When the vehicle suspension experiences high-frequency vibrations (low amplitude), PDD works like a conventional software damper for providing driving comfort. The PDD length can be divided into three zones: a) constant minimum attenuation coefficients (soft damping zone), b) the constant maximum attenuation coefficient (high damping zone), and c) intermediate transition zone [5].

![Figure 4. Frame geometric model and Contact pair setting by ADAMS.](image)

![Figure 5. Variation of damping coefficient.](image)

3. Vibration Absorber Design Simulation

3.1. Simulation parameter setting
This research model simulates the shock absorber by applying springs installed on the front legs and in the middle of the mainframe. The simulation process considers both the spring parameter, stiffness, and damping coefficient. The equation solved the calculation of stiffness and damping coefficient explained in the previous section. Furthermore, simulation conducted using ADAMS View with an end time and steps is 5.0 seconds and 100 steps, respectively, as shown in Figure 6.

3.2. Initial parameter definition
The load is calculated from the cumulative weight of the bicycle and the driver's weight. The load assumed that the bike's total weight is 12.5 kg, and the person is 60 kg. The force acting on a bicycle is
assumed to occur at three different points: at x, y, z, with force, as explained by the function written in the following equations.

\[ f_1 = -(122.5 \times \sin(2\pi \times time) + 98.1) \text{ (Newton)} \]  
\[ f_2 = -(122.5 \times \sin(2\pi \times time) + 490.5) \text{ (Newton)} \]  
\[ f_3 = 122.5 \times \sin(2\pi \times time) + 490.5 \text{ (Newton)} \]

The shock absorber is composed of three springs that are installed on the bicycles. The two springs are located on the front legs, and another is located in the middle connection between the tube and stay, the model-free body diagram shown in Figure 7.

4. Results Analysis and Discussion
The measurement point is defined on the saddle for displacement, velocity, and acceleration. Measurements are calculated in the direction of the y and z axis. The simulation results graph in the y-direction is shown in Figure 8, while the z-direction graph results is shown in Figure 9.

Seat acceleration in both the y and z-axis is quite similar during simulation time. It means that the seat has a constant acceleration. Because of the constant acceleration, the seat velocity gradually increases during simulation time, and seat velocity in the y-axis greater than the z-axis since the initial velocity of the z-axis less than the y-axis. The other significant result is concerning seat displacement. The displacement in the y-axis is around 0.02 meters, while on the z-axis is around 0.006 meters.

Figure 6. Simulation parameter setting.

Figure 7. Free body diagram.

Figure 8. Simulation result graph for y-axis.
5. Conclusion
This study constructs a frame model and proposes a simulation result close to the real road. According to different loads, suitable damping can be selected. This method can be applied to develop an air suspension design with a damping variable. The evaluation considers the various vehicle-to-weight ratio and road bumpiness before and after designing the bicycle frame's damping and stiffness parameters. The frame model is linked with the seat cushion as the center. The simulation results designate that the seat acceleration in both the y and z-axis is adequate constant, and the seat velocity gradually increases, whereas the vertical seat displacement of damped has significantly reduced compared with undamped.

6. References
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