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Simulation of riding a full suspension bicycle for analyzing comfort and pedaling force

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Abstract

Recently, there is an increasing interest on bicycle riding for recreation or fitness purpose. Bicycles are also accepted as urban transportation due to the consciousness of environmental protection. For a more comfortable riding experience, many bicycles are equipped with a suspension system including a front suspension fork and/or rear suspension. However, when a suspension system is added to a bicycle, it makes riding a little heavier since suspension dissipates some pedalling energy. This paper discusses front and rear suspensions corresponding to rider comfort and pedalling effort when riding on a rough road and smooth road. A human body computer model LifeMOD® is employed to model the cyclist. Dynamic analysis software ADAMS® is employed to analyze human body vibration and leg muscle forces of bicycle riding. Human body acceleration vs. vibration frequencies are used as the comfort criteria. The results show that a suspension system may effectively reduce high frequency vibration of the human body when riding on a rough road. Pedalling forces are mostly contributed by the biceps femoris and semitendinosus. The suspension system would increase the pedaling forces of femoris and semitendinosus. Other leg muscles have a minor effect on pedaling forces. Results obtained from this research are useful for the design of bicycle suspension systems with better comfort and less loss of pedalling efficiency.

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Keywords: Bicycle suspension system; LifeMOD; ADAMS

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1. Introduction

Recently, there is an increasing interest on bicycle riding for recreation or fitness purpose. Bicycle is also accepted as urban transportation due to the conscious of environmental protection. For more comfortable riding experience, many bicycles are equipped with suspension system including front suspension fork and/or rear suspension. Many studies have been done to investigate bicycle suspension system either by mathematical modelling or experiment. Wang et al. [1] developed a 2-D lumped-masses dynamic system model to simulate an off-road cyclist. Waechter et al. [2] developed a 2-D multibody dynamic model to simulate both cyclist and bicycle suspension system. A more sophisticated 3-D human body computer model called LifeMOD was conducted by Lifemodeler Inc. LifeMOD has been proved as an effective biomechanical simulation software [3] - [5]. This research is to build a cyclist model by using LifeMOD. The cyclist model is then integrated with a bicycle model built by virtual machine software ADAMS to simulate bicycle riding. The objective of this research is to investigate the effectiveness of suspension system and influence on pedalling effort.

2. Methods

LifeMOD consists of 19 segments which are connected by 18 joints on modelling skeleton (Fig. 1(a)). Muscles are modelled by spring-damper complexes (Fig. 1(b)). LifeMOD contains a database for the spring stiffness and damping coefficient based on input parameters (height, weight, etc.). ADAMS is a multibody dynamics software developed by MDI (Mechanical Dynamics, Inc.). It can be used to model a complicated mechanical system just like creating a "virtual machine." ADAMS can adopt LifeMOD model as a multibody system to analyze motions and forces of human body.

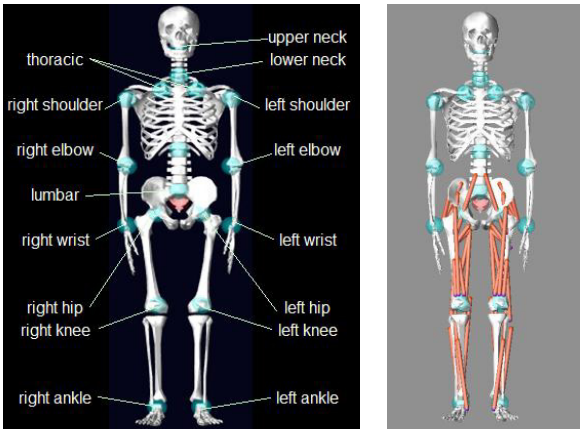

Fig. 1. (a) Segments and joints; (b) Muscles of lower torso and legs

In this research, a male subject with 175 cm height and 70 kg weight is modelled for riding bicycle on smooth road and rough road. A three-dimensional bicycle model equipped with both front suspension fork and rear suspension is shown as Fig. 2(a)-(c). Human body model is then adjusted by bring up LifeMOD posture panel and inputting relative joint angles so that the model would fit the bicycle riding posture (Fig. 2(d)). Hands, hip and feet are linked with handles, saddle and pedals respectively by using bushing joints. Bushing joints have the same stiffness and damping properties as muscles.

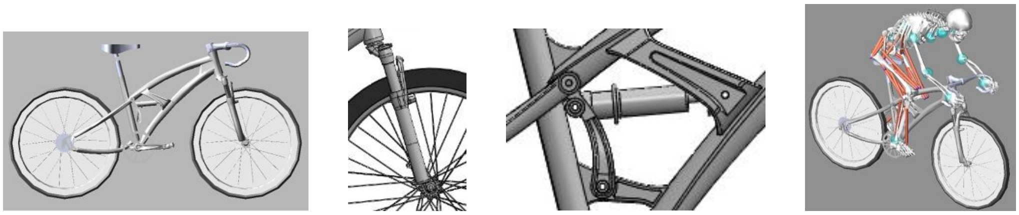

Fig. 2. (a) Bicycle model; (b) Front suspension fork; (c) Rear suspension; (d) Riding posture

After setting up the human model with LifeMOD, an inverse dynamic simulation of bicycle riding was performed by ADAMS. During inverse dynamic simulation, a motion driver is equipped at the bicycle crank and makes the bicycle pedalling itself. The legs of human body are therefore driven by the crank through pedals. The spring-damper complexes (muscles) contraction histories will be recorded in inverse dynamic simulation. Then the motion driver will be removed and the muscle contraction histories are employed to perform a forward dynamic simulation. During forward dynamic simulation, the bicycle will be pedalled by human model to reproduce the motion history and therefore the human body motion and muscle force would be analyzed by ADAMS.

A section of rough road is modelled by a sinusoidal curve with wavelength 500 mm and amplitude 10 mm. Suspension systems are modelled by spring-damper complex. Spring stiffness of front fork is 17.2 N/m and damping coefficient is 1.15 N-s/m. Rear suspension has spring stiffness 97.5 N/m and damping coefficient 2.05 N-s/m. Both front fork suspension and rear suspension may set to deactivated in ADAMS to make the bicycle model rigid. Cyclist travelling on rough road at the speed of 12 km/h is simulated either riding a full suspension bicycle or a rigid bicycle to investigate the effectiveness of the suspension system. Bicycle equipped with suspension system would make riding a little heavier since dampers dissipate some pedaling energy. Simulation of riding bicycle on smooth road is also accomplished to investigate the pedalling forces of some muscles. Comparison of pedalling forces between riding rigid bicycle and full suspension bicycle is done to show the influence of suspension system on pedalling effort.

3. Results and discussion

The effectiveness of suspension systems is shown by the vibration accelerations of human body in vertical direction. ADAMS can analyze the vibration acceleration of specific points just like putting accelerometers onto the points. Fast Fourier Transformation (FFT) is employed to transform accelerations as functions of time into the frequency domain. Therefore comparison of the vibration accelerations between riding full suspension bicycle and rigid bicycle under some specific frequency may be accomplished. Fig. 3 (a) and (b) show the vibration accelerations of lower torso for riding rigid bicycle and full suspension bicycle respectively.

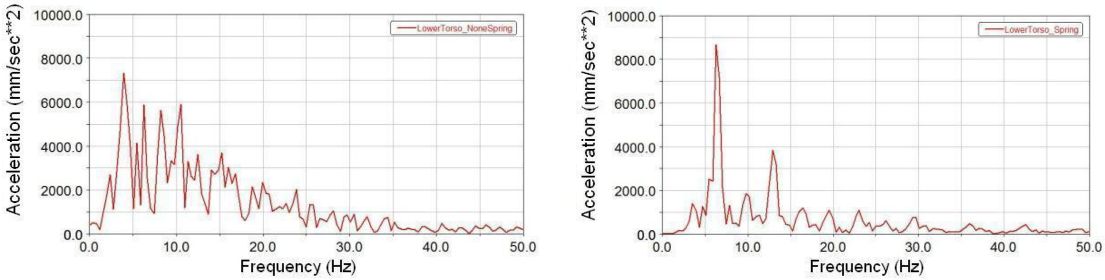

Fig. 3 (a) Vibration accelerations of lower torso for riding rigid bicycle; (b) For riding full suspension bicycle

Fig. 4 (a) and (b) show the vibration accelerations of hands for riding rigid bicycle and full suspension bicycle respectively.

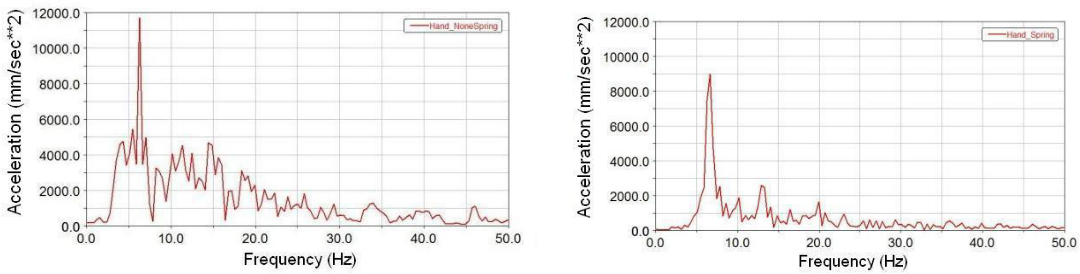

Fig. 4 (a) Vibration accelerations of hands for riding rigid bicycle; (b) For riding full suspension bicycle

Fig. 5 (a) and (b) show the vibration accelerations of scapula for riding rigid bicycle and full suspension bicycle respectively.

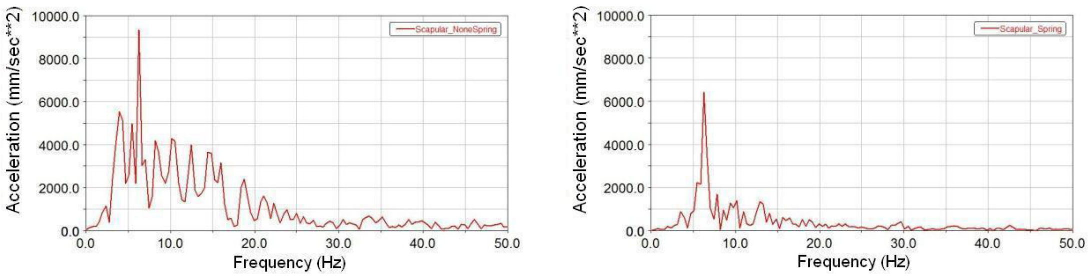

Fig. 5 (a) Vibration accelerations of scapula for riding rigid bicycle; (b) For riding full suspension bicycle

Fig. 6 (a) and (b) show the vibration accelerations of neck for riding rigid bicycle and full suspension bicycle respectively.

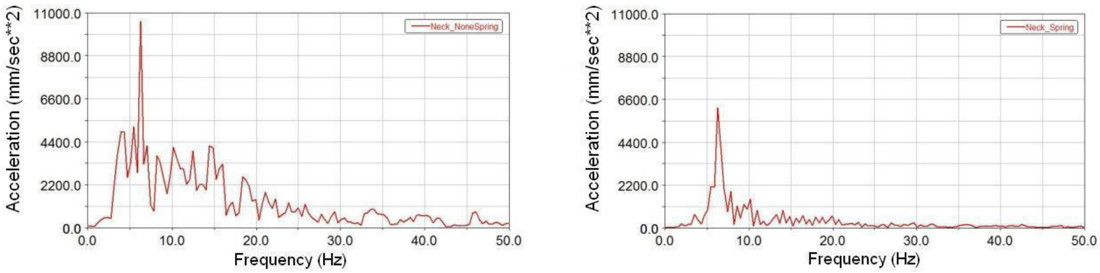

Fig. 6 (a) Vibration accelerations of neck for riding rigid bicycle; (b) For riding full suspension bicycle

Then some muscle forces are analyzed by ADAMS for simulation of riding bicycle on smooth road. Muscles examined include biceps femoris, vastus lateralis, rectus femoris, semitendinosus, and soleus. Fig. 7 (a) and (b) show the muscle force of biceps femoris for riding rigid bicycle and full suspension bicycle respectively.

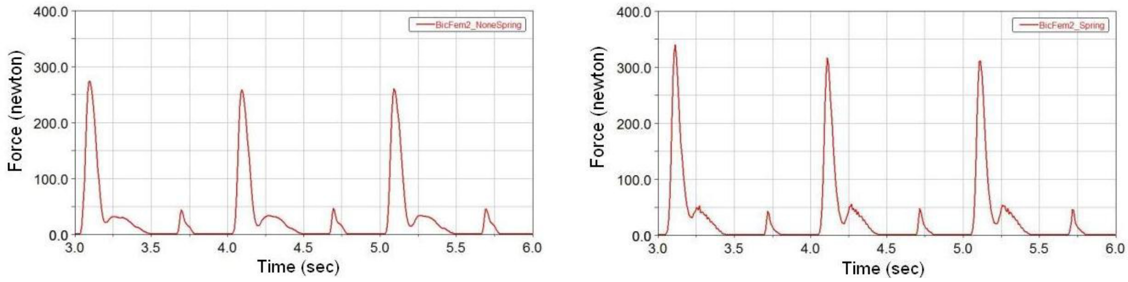

Fig. 7 (a) Muscle force of biceps femoris for riding rigid bicycle; (b) For riding full suspension bicycle

Fig. 8 (a) and (b) show the muscle force of vastus lateralis for riding rigid bicycle and full suspension bicycle respectively.

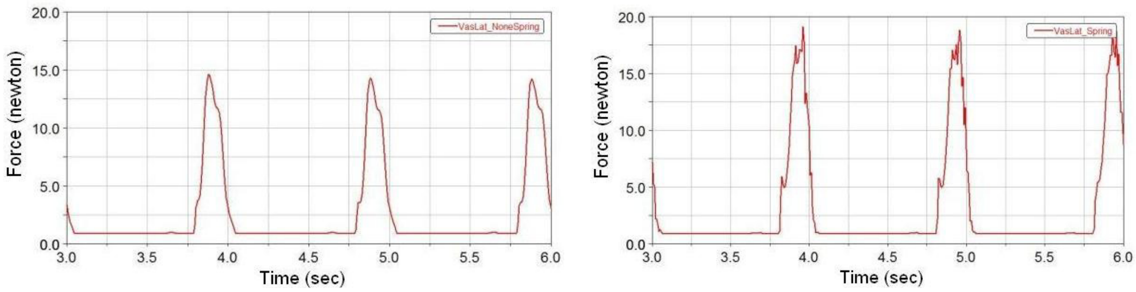

Fig. 8 (a) Muscle force of vastus lateralis for riding rigid bicycle; (b) For riding full suspension bicycle

Fig. 9 (a) and (b) show the muscle force of rectus femoris for riding rigid bicycle and full suspension bicycle respectively.

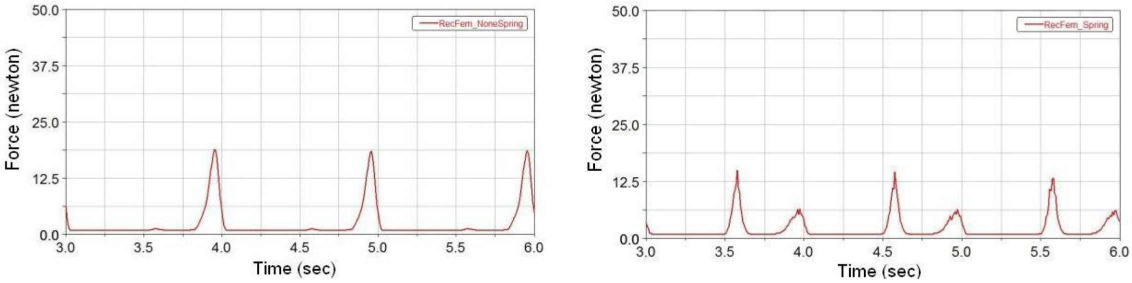

Fig. 9 (a) Muscle force of rectus femoris for riding rigid bicycle; (b) For riding full suspension bicycle

Fig. 10 (a) and (b) show the muscle force of semitendinosus for riding rigid bicycle and full suspension bicycle respectively.

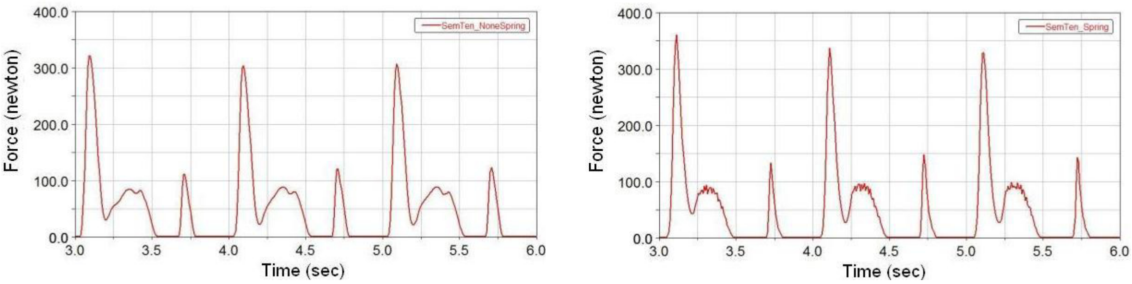

Fig. 10 (a) Muscle force of semitendinosus for riding rigid bicycle; (b) For riding full suspension bicycle

Fig. 11 (a) and (b) show the muscle force of soleus for riding rigid bicycle and full suspension bicycle respectively.

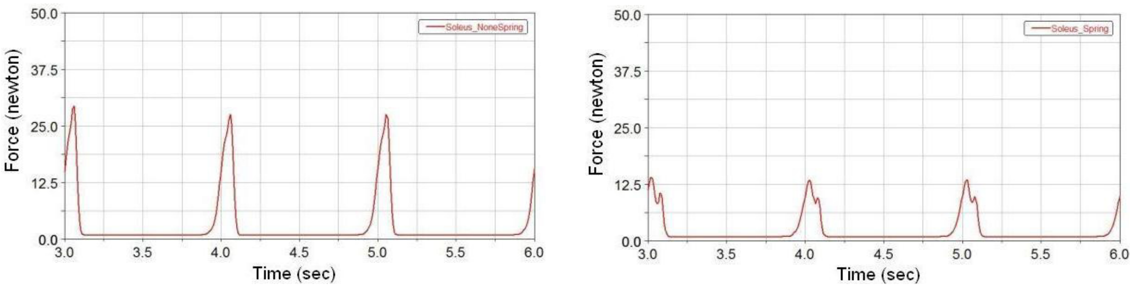

Fig. 11 (a) Muscle force of soleus for riding rigid bicycle; (b) For riding full suspension bicycle

4. Conclusion

The results shown above indicate that suspension systems can effectively reduce the vertical vibration of human body especially at the frequencies over 10 Hz. So cyclist may not experience high frequency vibration on rough road and would have more comfortable riding experience. The muscle force analysis shows that biceps femoris and semitendinosus give the major contribution on bicycle pedaling. Suspension systems would cause biceps femoris, vastus lateralis, and semitendinosus pedaling a little heavier when riding on smooth road. Although suspension lighten the rectus femoris and soleus, but these two muscles are minor on pedaling. Since bicycle riding is under unstable equilibrium state, it is hard to use a dummy and sensors to verify the computer human body model. However, the modeling technique introduced in this paper may be adopted to provide relative comparisons between different suspension systems and promote bicycle suspension performance.

Acknowledgements

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