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Research for Motorcycle Dynamic Simulation Based on Actual Road Loading Spectrum

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Abstract. The vibration performance of motorcycle is regarded as an important indicator of its quality level. This paper studies the dynamic characteristics of motorcycle by the combined methods of finite element technique, multi-body dynamics simulation technique and experimental technique, with a goal to improve the vibration performance. The rigid-flexible coupled multi-body dynamics model of complete motorcycle is set up using ADAMS software in order to research the dynamic responses characteristics of motorcycle under the actual road excitation and engine excitation. Meanwhile, it also explores the effective combination of simulation technique and experimental technique, as a new technical approach to analyze dynamic characteristics and ride performance of complete motorcycle. As shown from the conclusion, this approach exerts high guiding significance on the development and dynamic performance optimization of motorcycle.

Introduction

Since China is the largest producer of motorcycles, the expectation for motorcycle quality from the user is in gradual rise. The vibration performance of motorcycle is regarded as an important indicator of its quality level. So, it is very important for product competitiveness to improve the vibration performance through combined methods of finite element technique, multi-body dynamics simulation technique and experimental technique. The analysis of dynamic characteristics and ride performance of complete motorcycle under the combination of simulation technique and experimental technique remains as a trend for motorcycle development [1].

A motorcycle can be influenced by engine excitation and road irregularities excitation under working condition. The phenomenon of resonance emerges as the external excitation frequency matches with natural frequency of certain structure of motorcycle, which not only seriously impacts the riding comfort and handling stability, but also shortens the lifetime of parts including the reliability of various electrical apparatus elements. The motorcycle has a relatively intensive distribution of natural frequency due to the complicate complete vehicle model. Therefore, the response of motorcycle to engine excitation and road excitation is a very important part for analyzing dynamic characteristics of motorcycle.

Theoretical Basis of Multi-Body Dynamics Simulation

ADAMS can be used to analyze the property, motion trail, and collision detection, peak load of mechanical system and load-carrying capacity of each part, with an open architecture to allow users to integrate their own subroutines and develop specific modules based on different product features [2]. The ADAMS simulation analysis adopted in this paper is arranged as follows:

(1)System modeling: set up parts, add constraints and apply load, etc;

(2)Simulation analysis: set test objective and resolving parameter, and observe and analyze simulation result;

(3)Verification model: import experimental data and analyze data regarding experiment and simulation, and modify model;

(4)Optimization model: add friction, substitute flexible body and control definition, etc;

(5)Virtual experiment: design research and optimized analysis.

Option of Generalized Coordinates. ADAMS has such three coordinate systems as absolute coordinate system which is the ground-fixed inertial coordinate system; local part reference coordinate which is the only one fixed to the part and has a position to absolute coordinate as used to signify the direction of part; labeled coordinate system which is the internal coordinate system, including one called a fixed coordinate system, fixed on parts and used for defining graphic limits, barycenter, acting force and constraints, etc., with position and direction determined by local reference coordinate, and the other one called floating coordinate system, time-varying and easy to define the position and direction of forces and constraints [3].

The velocity of solving dynamics equation largely depends on the choice of generalized coordinates. The ADAMS software takes Cartesian coordinates and Euler angle of the barycenter local reference coordinate system of rigid body in absolute reference coordinate system as the generalized coordinate:

$$q_i = [x, y, z, \psi, \theta, \phi]_i^T, \quad q = [q_1^T, q_2^T, \cdots, q_n^T]^T \tag{1}$$

Establishment of Dynamics Equation. The ADAMS takes the Cartesian coordinates and Euler angle that respectively shows the position and direction of rigid body as the generalized coordinate, and establishes the systematic motion equation by utilizing Lagrangian Multiplier Method [3]:

$$\frac{d}{dt}\left(\frac{\partial T}{\partial \dot{q}}\right)^T - \left(\frac{\partial T}{\partial q}\right)^T + \phi_q^T \rho + \theta_{\dot{q}}^T \mu = Q \tag{2}$$

Integrity Constraint Equation:

$$\phi(q,t) = 0 \tag{3}$$

Non-Integrity Constraint Equation:

$$\theta(q,\dot{q},t) = 0 \tag{4}$$

Among which, T: System Function;

q: System generalized coordinate matrix;

Q: Generalized force matrix;

ρ: Lagrangian Multiplier matrix of Integrity constraint;

μ: Lagrangian Multiplier matrix of Non-Integrity constraint.

Solution of Dynamics Equation. Prior to the analysis of Dynamics, Kinematics and Statics, ADAMS carries out the assembly calculation as an initial condition analysis to coordinate the kinematic constrains and coordinate system of each object in the system and thus satisfy all constraint condition. The initial condition analysis can be obtained by solving the minimum value of objective function regarding position, velocity and accelerated velocity, etc [3].

Statics analysis: assume that the velocity and accelerated velocity are both zero, and then the statics equation is described as follows:

$$\begin{bmatrix} \frac{\partial F}{\partial q} & (\frac{\partial \Phi}{\partial q})^T \\ \frac{\partial \Phi}{\partial q} & 0 \end{bmatrix}_j \begin{Bmatrix} \Delta q \\ \Delta \lambda \end{Bmatrix}_j = \begin{Bmatrix} -F \\ -\Phi \end{Bmatrix}_j \tag{5}$$

Kinematics analysis: analyze the position, velocity, accelerated velocity and constraint reaction of zero degree of freedom, and resolve the constraint equation of system:

$$\Phi(q,t_n) = 0 \tag{6}$$

The position of t_n at any moment can be calculated and determined by Newton-Raphson

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iteration method:

$$\left.\frac{\partial \Phi}{\partial q}\right|_{j} \Delta q_{j}=-\Phi(q_{j}, t_{n}) \tag{7}$$

Among which, $\Delta q_{j}=q_{j+1}-q_{j}$, j represents the j iteration.

The constraint equation can get the velocity and accelerated velocity by resolving the first and second time derivatives:

$$(\frac{\partial \Phi}{\partial q})\dot{q}=-\frac{\partial \Phi}{\partial t} \tag{8}$$

$$(\frac{\partial \Phi}{\partial q})\ddot{q}=-\left\{\frac{\partial^{2} \Phi}{\partial t^{2}}+\sum_{k=1}^{n} \sum_{l=1}^{n} \frac{\partial^{2} \Phi}{\partial q_{k} \partial q_{l}} \dot{q}_{k} \dot{q}_{l}+\frac{\partial}{\partial t}(\frac{\partial \Phi}{\partial q}) \dot{q}+\frac{\partial}{\partial q}(\frac{\partial \Phi}{\partial t}) \dot{q}\right\} \tag{9}$$

Constraint reaction:

$$(\frac{\partial \Phi}{\partial q})^{T} \lambda=\left\{-\frac{d}{dt}(\frac{\partial T}{\partial \dot{q}})^{T}+(\frac{\partial T}{\partial q})^{T}+Q\right\} \tag{10}$$

Buildup of Multi-Body Dynamics Model

The buildup of dynamics model is a process of retrieving structural mechanics characteristics, and needs to be simplified properly. The model should reflect the real characteristics as much as possible so as to ensure the accuracy. Therefore, it is required to complete the structural parameter when building the dynamics model, such as geometrical parameter and physical parameter of structure, and reciprocal constraints among structures and characteristic parameter of critical parts [4].

This process should set up geometrical model of parts as per drawings and establish constraints among parts in accordance with actual constrained relationship, for the purpose of an integrated dynamics model. The dynamics model for complete vehicle includes the critical parts as human body, frame, rear-wheel fork, handlebar, engine, fuel tank, front and rear hanger brackets, tires, and etc., with the established multi-body dynamics model shown as Fig. 1.

Fig. 1 Multi-body Dynamics Model for Motorcycle

This model is mainly applied to the virtual riding test of motorcycle, on which the following assumptions and simplifications are based:

(1)Motorcycle frame is the research object with high rigidity for other parts including front and rear forks etc [5]. So only the frame is replaced by flexible body and other part by rigid body;

(2)Constrained frame only moves within the vertical plane of driving coordinate of motorcycle;

(3)The handlebar is fixed together with frame regardless of its relative rotation;

(4)The engine, fuel tank, cushion, goods, accessories and etc. are fixed together with frame regardless of relative movement as concerned;

(5) The shock absorbers in front and back are simplified to a spring with equivalent rigidity and damp;

(6)Take no consideration of contact and friction among the constraints.

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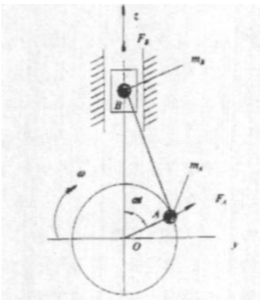
Simulation of Engine Excitation. The vibration of engine is mainly caused by the working pressure of atmosphere and inertia force of piston rod unit [6]. The schematic diagram of crank-link rod is as shown in Fig. 2. Classical Dynamics defines that the engine is influenced by the applied force of atmosphere, reciprocating inertial force, rotating inertial force and the relevant force moments [7]. This paper tries to establish the entity model of engine and define the constraint conditions of actual crank, connecting rod, piston and engine block in MSC. Adams. The dynamics model of crank-link rod is as shown in Fig. 3.



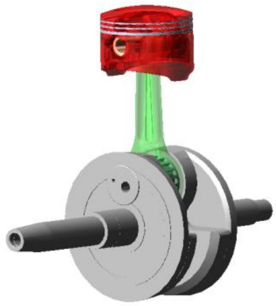
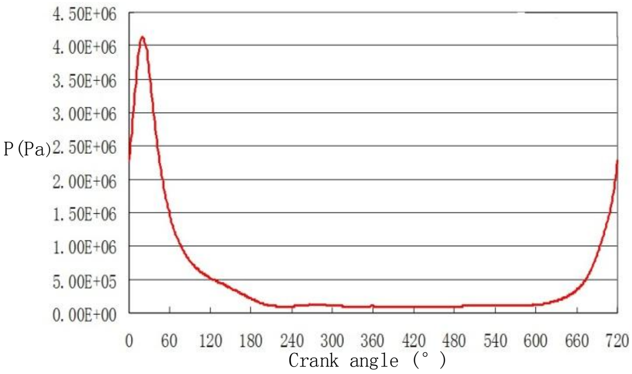


Fig. 2 The Schematic Diagram of Crank-link Rod Fig. 3 The dynamics model of crank-link rod

It is necessary to impose gas acting force in order to simulate the real operation of engine. The combustion analyzer is used to measure the in-cylinder pressure curve as the capsizing moment produced by the gas acting force. The pressure curve of engine under 3000rpm is as shown in Fig 4. The procedure of exerting a crank angle on crank and the corresponding capsizing moment as shown in Fig. 5 can be applied to simulate the real movement of engine as well as its acting force on frame.



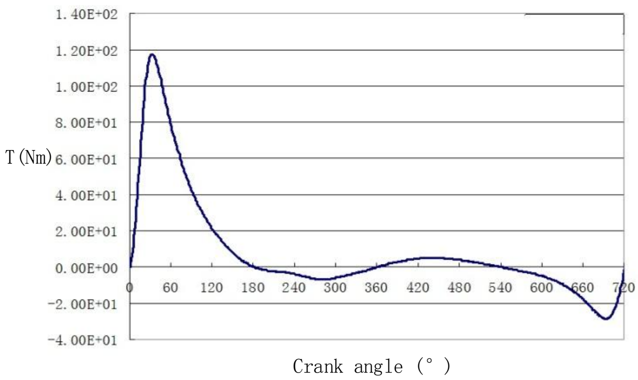


Fig. 4 The Pressure Curve of Engine Fig. 5 Capsizing Moment of Engine

Confirmation of Road Excitation. The road loading spectrum is the foundation not only for the road simulation test of the whole vehicle and its parts, but also for the fatigue analysis, service life calculation, lightweight design of vehicle and its parts. Concerning the extreme complication of contact between road and tires, as well as the uncertainty of tire parameters, this paper adopts the wheel axle accelerated velocity obtained from actual road test as road excitation.

Fig. 6 The Test System

After installing various sensors and inspecting of instrument setup, a piece of road applicable for riding test shall be chosen to conduct the collection of road loading spectrum. Meanwhile, keep regular record of weather, road condition, tire pressure, driver weight and the load of axles in front and back; the collection of road loading spectrum shall be conducted soon after the preparation work. The test system is laid out as shown in Fig. 6. The time tendency of accelerated velocity of wheel axles in front and rare can be obtained after smoothing and examining the collected data, as shown in Fig. 7.

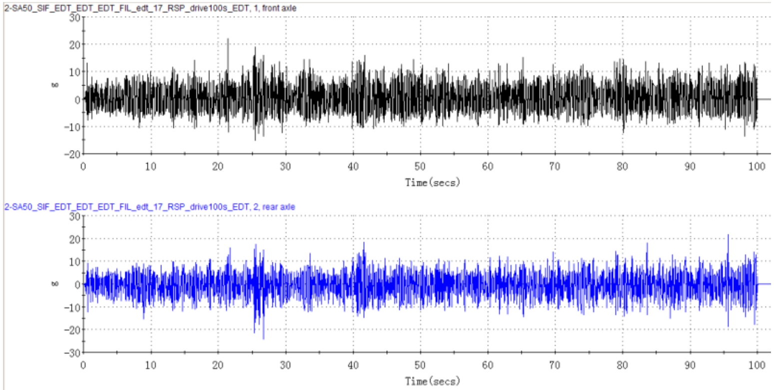


Fig. 7.The Time Tendency of Accelerated Velocity of Wheel Axles in Front and Rare

Simulation of Driving Cycle of Motorcycle

The motorcycle under straight running is mainly influenced by the road irregularities excitation and engine excitation. And the engine excitation contains inertia force of moving parts and trimming moment of output torque, etc. Therefore, we take above-stated factors into consideration in the simulation so that the result conforms to the actual circumstance [8]. This paper carries out three kinds of driving simulation to study the influence of each excitation on entire motorcycle, including the road driving simulation shielding engine excitation; engine excitation simulation with static vehicle; complete driving model simulation by engine excitation coexisted with road excitation.

Simulation of Single Road Excitation. Considered only the road excitation, the power spectrum density of vertical vibration acceleration of cushion is as shown in Fig. 8. The vibration energy of measuring point under single road excitation mainly focuses on the low frequency part, indicating that the road excitation produces LF vibration on vehicle body through hanger brackets in front and back. As per <Guideline of Bearing Whole-body Vibration>, the most sensitive frequency domain for human body centers on LF of below 10Hz, so sufficient attention shall be given to the selection and matching of hanger bracket parameter during design of motorcycle.

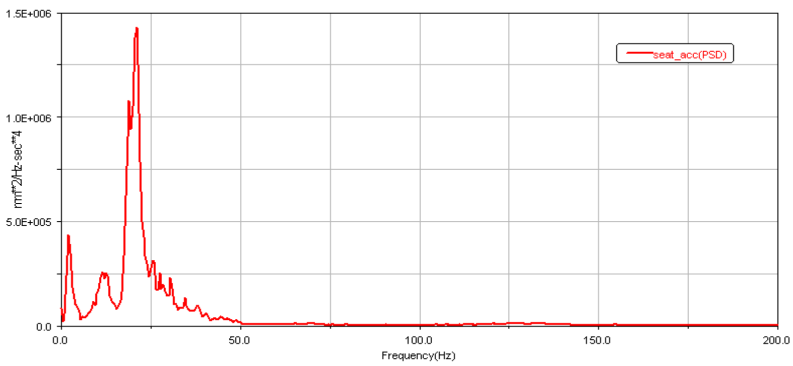


Fig. 8 The Power Spectrum Density of Vertical Vibration Acceleration of Cushion (road)

Simulation of Static Engine Excitation. This paper sets an engine speed of 3000rpm to solely investigate the vibration response of each part attributable to engine inertia force and trimming moment, and the power spectrum density of vertical vibration acceleration of cushion is as shown in

Fig. 9. Due to the engine speed of 3000rpm and axle frequency of 50Hz, it is found that the measuring point under single engine excitation shows a strong harmonic characteristic on HF part and conforms to the axle frequency of engine and the second harmonic generation frequency, illustrating that the engine excitation mainly leads to vibration on HF parts.

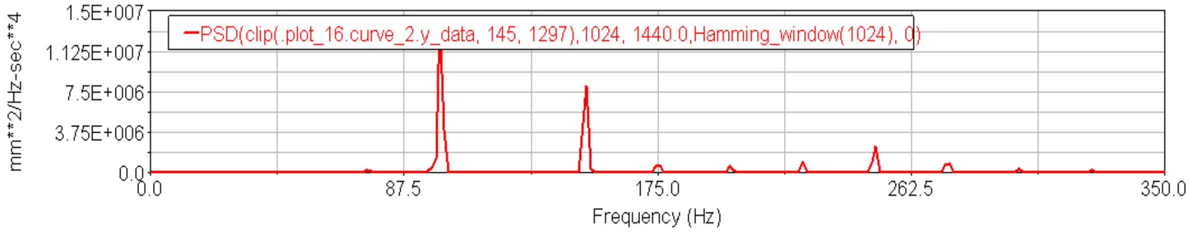


Fig. 9 The Power Spectrum Density of Vertical Vibration Acceleration of Cushion (engine)

Simulation of Road Excitation and Engine Excitation Coupling. Under the simultaneous function of road irregularities excitation and engine excitation, the motorcycle will receive a more complicate excitation. In this regard, this paper tries to conduct a further simulation on the coupling of both road excitation and engine excitation after finishing the simulation on single action of each excitation on motorcycle. With an engine speed of 3000rpm, the power spectrum density of vertical vibration acceleration of cushion is as shown in Fig. 10. It is observed that under the simultaneous function of road irregularities excitation and engine excitation, the vibration performance of each measuring point basically shows an overlaying response of road excitation and engine excitation, with nearly no difference between the indicating frequency of its peak value & amplitude and the corresponding single excitation.

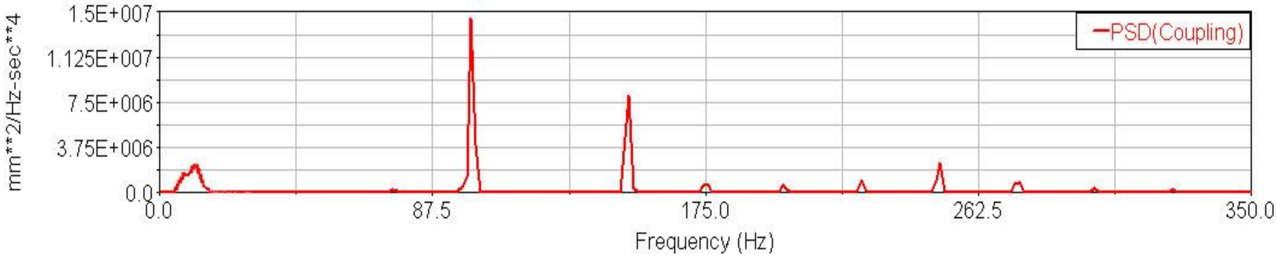


Fig. 10 The Power Spectrum Density of Vertical Vibration Acceleration of Cushion (Coupling)

Summary

This paper gives a brief introduction of the function and analytic method of ADAMS software in use, describes the riding simulation test of complete vehicle and its parts and discusses respectively the influence exerted by road excitation, engine excitation and the coupling effect of engine and road on motorcycle. The result shows that road excitation only leads to vibration of LF part of frame while engine excitation causes vibration of HF part of frame and remains as the major reason of frame vibration.

It is both convenient and accurate to conduct dynamics simulation on motorcycle by ADAMS software, which should be more extensively applied and popularized in practice. The virtual prototype technique, used to establish dynamics simulation model of motorcycle, is not only convenient but also allows obtaining the response message from the excitation. Meanwhile, it’s also a good way to change the road excitation and other parameters to reach the influence of each changing parameter on riding comfort of motorcycle, which not only saves a large number of costs required for entity measurement but also shortens the time for design and examination.

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