

Development of HEV Engine Start-Shock Prediction Technique Combining Motor Generator System Control and Multi-Body Dynamics (MBD) Models

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ABSTRACT

Previous reports have already described the details of engine start-shock and the mechanism of vibration mechanism in a stationary vehicle. This vibration can be reduced by optimized engine and motor generator vibration-reduction controls. A prediction method using a full-vehicle MBD model has also been developed and applied in actual vehicle development.

This paper describes the outline of a new method for the hybrid system of mechanical power split device with two motors that predicts engine start-shock when the vehicle is accelerating while the engine is stopped. It also describes the results of mechanism analysis and component contribution analysis. This method targets engine start-shock caused by driving torque demand during acceleration after vehicle take-off.

The hybrid control system is modeled by MATLAB/Simulink. A power management and motor generator control program used in actual vehicles is installed into the main part of the control system model. The voltage of the inverter and converter, and the capacity of the battery are expressed by simple mathematical models.

The motor generator torque and floor acceleration predicted using this method correlated closely with test results.

Mechanism analysis using this simulation revealed that the main factor in engine start-shock during acceleration after vehicle take-off is the longitudinal vibration mode of the suspension generated by driving torque. Contribution analysis of the suspension bushing and driveline torsional characteristics showed that increasing the hysteresis of the torsional damper and reducing the torsional stiffness of the driveshaft can reduce engine start-shock.

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1. INTRODUCTION

Hybrid systems, which combine an internal combustion engine with a motor/generator (MG), are being adopted in a growing range of models as efforts to improve efficiency have further enhanced their environmental performance. However, one issue with hybrid systems is driver discomfort caused by shock and vibration generated by frequent engine starts.

The mechanism of vibration caused by engine start when the vehicle is stationary has been investigated by experiments and analyses, leading to the development of vibration prediction techniques using a full-vehicle multi-body dynamics (MBD) model. This model has been successfully used to reduce vibration [1,2,3,4,5]. In contrast, engine start

during acceleration results in the sudden application of larger driving torque than when the vehicle is stationary. This increases the effects of non-linear characteristics, such as those of load-dependent components including engine mountings, suspension bushings, and driving torque transfer elements. The mechanism of transfer paths and the like that include these items is yet to be identified. In addition to this existing technique for predicting vibration caused by engine start-shock and the driveline when the vehicle is stationary [5,6,7], engine start-shock prediction during acceleration also requires the development of modeling techniques to express the non-linear characteristics of transfer elements, as well as a control model to calculate the motor torque in accordance with driver accelerator pedal operation, the vehicle driving state, and battery state of charge (SOC).

Consequently, a technique has been developed for accurately predicting engine start-shock during acceleration. This paper presents an outline of this technique and the results of verification tests to confirm its accuracy. It also describes the engine start-shock mechanism analyzed using this technique.

2. ENGINE START UNDER ACCELERATION BY HYBRID SYSTEM

2.1. System Outline

This research focused on the hybrid system shown in Fig. 1. This is a parallel-series type hybrid system with two MGs and is composed of an engine, a power split device that controls inputs and outputs to and from the engine and MG1, a motor speed reduction device that controls inputs and outputs to and from MG2, a speed reduction device comprising a pair of counter gears and a pair of differential gears, a differential mechanism, and so on.

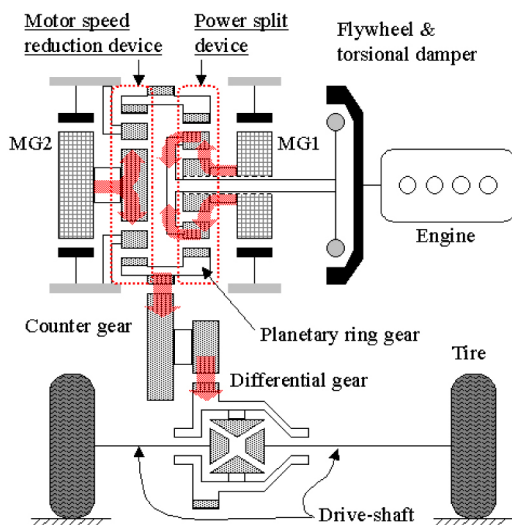


Figure 1. Hybrid system configuration

2.2. Engine Start Requirements

With this hybrid system, factors requiring the engine to start include battery charge demand, driving force demand when the driver depresses the accelerator, engine warm-up demand, and so on. This research mainly focused on engine start caused by driving force demand during acceleration after take-off while the vehicle is being driven by the motor.

2.3. Input and Shock Characteristics during Acceleration after Take-Off

Figure 2 shows examples of speed of rotation (i.e., engine speed and MG rotational speed), in-cylinder pressure, MG torque, and floor acceleration during acceleration after take-off. MG2 accelerates the vehicle from a stationery condition.

MG1 then starts the engine in accordance with the accelerator angle and vehicle speed, and the vehicle is accelerated by the motor and engine together. The graphs show fluctuation in the torque of MG1 and MG2 due to the vibration-reduction control that is performed by the MGs after engine start. It also indicates that engine start-shock coincides with the generation of in-cylinder pressure and that longitudinal acceleration is greater than vertical acceleration.

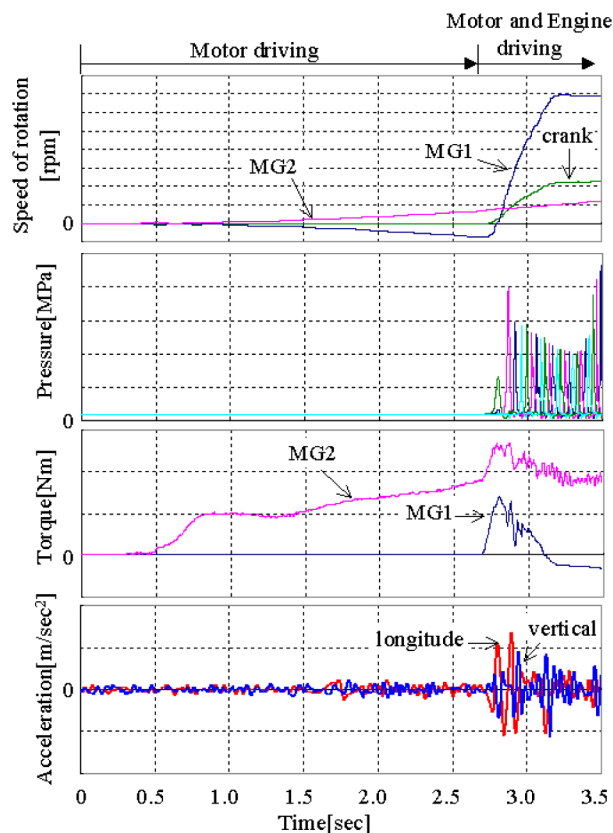


Figure 2. MG torque, in-cylinder pressure, and floor acceleration during acceleration after take-off

3. SIMULATION MODEL

3.1. Model Outline

Figure 3 shows the full-vehicle model, which was constructed using MBD software. Since the target phenomenon is low-frequency vibration of 20 Hz or less, structural parts such as the body, suspension, and the like were modeled from rigid elements considering mass and the moment of inertia. The characteristics of the engine mountings, suspension bushings, and driveline torsional element models were set in accordance with the amplitude and frequency. Actually measured values were adopted for in-cylinder pressure, which is one of the inputs to the MBD model. MG torque was determined by a coupled calculation integrated with a hybrid system control model that incorporates software installed in actual vehicles.

The following sections describe the details of the main changes to the existing model [6-7].

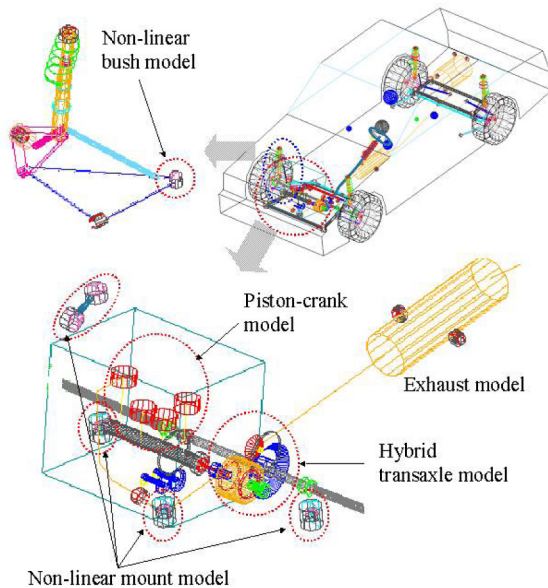


Figure 3. Full-vehicle MBD model

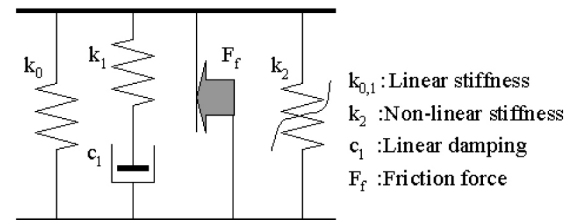


Figure 4. Mounting and bushing model

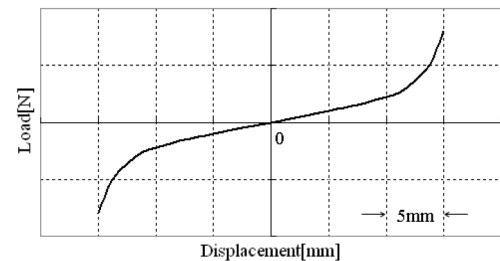


Figure 5. Engine mounting model static characteristics

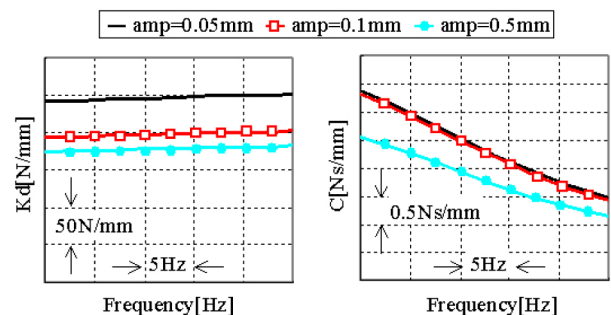


Figure 6. Engine mounting model dynamic characteristics

3.2. Modeling of Non-Linear Elements

1. Viscoelastic elements

Engine mountings and suspension bushings have viscoelastic properties with transfer characteristics that change in accordance with the excitation frequency and amplitude. In addition, engine mountings and suspension bushings are also pre-loaded during acceleration after take-off. This is caused by the MG2 torque as the vehicle is accelerated by the motor, and by the inertial force of each component. This pre-load generates shock when contact occurs with the mountings and bushing stoppers. For this reason, the excitation frequency and amplitude dependence are expressed using the physics model in Fig. 4 that combines spring, dash pot, and frictional elements [6]. In addition, a bushing stopper model with nonlinear spring characteristics was provided in parallel with a mounting and bushing model to simulate changes in rigidity due to contact with the bushing stoppers. The parameters of each element were optimized and identified using the results of a stand-alone mounting excitation test so that the storage spring constant and loss factor were consistent with the test results. Figures 5 and 6 show examples of the engine mounting model characteristics.

2. Driveline torsional damper model

A driveline torsional damper functions to transfer driving torque between the engine and transmission. It also includes a torque fluctuation absorption device that uses non-linear spring characteristics and hysteresis to vary the torque fluctuation transfer characteristics in accordance with the driving torque. These non-linear spring characteristics and hysteretic characteristics are modeled using the physics model shown in Fig. 7. Figure 8 shows the driveline torsional damper characteristics.

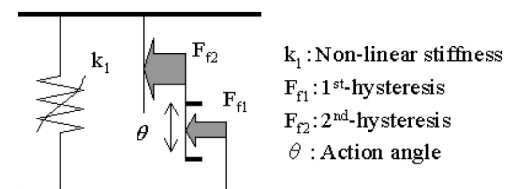


Figure 7. Driveline torsional damper model