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SUV - EPS 차량의 동시 시뮬레이션 기술 개발 및 시뮬레이션 통합 기술 개발

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Co-Simulation and Simulation Integration Technology Development for SUV Vehicle Equipped with Electric Power Steering (EPS)

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ABSTRACT

Electric Power Steering (EPS) mechanism has become widely equipped in passenger vehicle due to the environmental consciousness and higher fuel efficiency. This paper describes the development of co-simulation technique and simulation integration technique of EPS control system with dynamic vehicle model. A full vehicle model interacted with EPS control algorithm is concurrently simulated on a single bump road condition. Dynamic responses of vehicle chassis and steering system resulting from road surface impact are evaluated and compared with proving ground experimental data. The comparisons will show reasonable agreement on tie-rod load, rack displacement, handle-wheel torque and tire center acceleration. This developed simulation capability can be used for EPS performance evaluation and calibration as well as for vehicle handling performance integration and synthesis.

Key Words : electric power steering (전동조향), co-simulation (동시시뮬레이션), integrated simulation (통합시뮬레이션), vehicle dynamics (차량역학), rack displacement (랙 변위)

1. INTRODUCTION

Power-assisted steering is designed to reduce the effort exerted by driver on handle-wheel and to reduce the handle-wheel movement for a given swivel-pin angular turn, that is, to make the input (handle-wheel movement) to output (swivel-pin movement) more direct. Most passenger vehicles equipped with power steering systems are hydraulic power assisted. Vehicle equipped with hydraulic power steering system consumes more fuel than vehicle with manual steering system, because oil pressure must be continuously boosted.

Electric power steering (EPS) is an advanced steering system that uses an electric motor to provide steering assist. It eliminates the need for a hydraulic power steering pump, hoses, hydraulic fluid, drive belt and pulley on the engine, therefore the total system is lighter than a comparable hydraulic system through the use of compact system units. Also, since EPS is an on-demand system that operates only when the handle-wheel is turned, the fuel efficiency of vehicle equipped with such system is 3% better than that of vehicles equipped with an equivalent-output hydraulic system. As a result, electric power steering is more energy efficient and environmentally compatible. This motivates the great increase of EPS equipped vehicles recently.

The debugging and refining a control algorithm is becoming more difficult with the increasing complexity of automotive mechanisms and other critical vehicle chassis structures. While Olson and Milacic[1] utilized computer code to simulate a quarter vehicle model interaction with several control systems (steering, brake and traction), most of the previous research did not account for the interaction of all chassis variables involved in monitoring the vehicle

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and generating control signals. The dynamic responses of vehicle chassis system equipped with EPS have not been analytically investigated yet. This paper develops two techniques, co-simulation and simulation integration, of EPS control system with dynamic vehicle model. A full vehicle model interacted with EPS control algorithm is concurrently simulated on a single bump road condition. Dynamic responses of vehicle chassis and steering system resulting from road surface impact are evaluated and compared to proving ground experimental data. This integrated method allows engineers to determine if the overall design of the vehicle and EPS meets design targets without going through extensive prototype testing which is expensive and time-consuming.

2. MODEL DEVELOPMENT

2.1 EPS Overview

EPS incorporates a steering gear, assist mechanism, brushless motor and electronic controller to provide responsive steering assist. Two primary inputs, driver torque on the handle-wheel and vehicle speed signal, along with other system variables are continuously fed into an electronic control module which determines the direction and amount of steering assist. As a driver makes a turn of the handle-wheel, a certain torque/angle exerted on the handle-wheel, representing the intention of the driver to move the vehicle. Based on the road conditions and the desire of the driver to turn the vehicle, a torque sensor located between handle-wheel and motor detects the steering torque, if there is a discrepancy between the intended angle at the handle-wheel and the actual angle at the front tire. Then the motor current is determined based on this torque sensor signal. Assistant torque, an input to steering shaft, is obtained by multiply the motor torque and gear ration. This assistant torque together with the driver handle-wheel torque rotates the steering shaft against the reaction torque of tires and frictional loss of the steering mechanism. This assistant torque eases the stress in steering column and the effort exerted by the driver. The typical EPS mechanism and block diagram is shown by Jang [2].

2.2 A Full Vehicle Model

A full vehicle model was created from ADAMS[3,4]. This multi-body dynamic model comprises of non-linear elastic front and rear suspension. steering system including the rack and its joints with tie rods, and a tire model with combined longitudinal and lateral force calculation, originally built for vehicle dynamic simulations. The vehicle model is driven by speed applied on the vehicle center of gravity. The driven path of vehicle is controlled by the displacement of rack. Overall, this full vehicle model processes 347 kinematic degrees of freedom. A single bump road profile is created to study the chassis dynamic responses resulting from road surface impact force. To simulate the higher unbalanced impact force on the chassis, only tires (front and rear) on the driver side hit the bump. The dimension of bump is 50.8 mm in height and 457 mm in width corresponding to road test condition in proving ground. Refer to Reference 4.

3. INTEGRATED ANALYSIS PROCESS

3.1 Co-Simulation & Simulation Integration Method Overview

In co-simulation, the input and output parameters of both softwares need be defined. The whole coupling is controlled by a subroutine in Matlab[5,6]. This subroutine opens the pipes for the data exchange and starts ADAMS at every time step. During the simulation, both packages take simultaneous time steps. Each package independently computes the solution for their respective models. At the beginning and end of each step, the two packages exchange input/output signal data. The co-simulation method is suitable for full vehicle model that is numerically very stiff and cannot be integrated by control application.

In simulation integration, DADS[7] and MATLAB are utilized to model a full vehicle equipped with EPS control system. DADS model is prepared as a MATLAB subroutine and MATLAB takes over the integration. DADS calculates the interested outputs from the dynamic vehicle model and MATLAB executes the control integration of the EPS system. DADS with a full vehicle model is represented as a MATLAB subroutine 'S-function.'

3.2 Interface Variables

The translational force applied on the rack resulting in rack displacement that determines the turn of vehicle. Therefore rack force is denoted as external input of the vehicle model. The responded displacement and velocity of rack are the external outputs to the control laws.

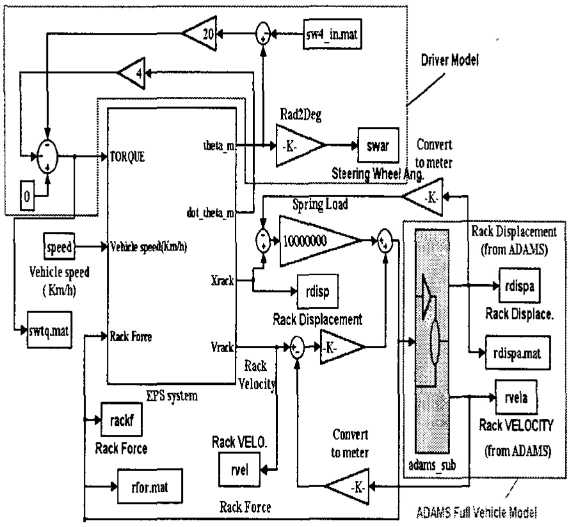

Fig. 1 **Co-Simulation** technique executing two softwares MATLAB EPS and ADAMS model

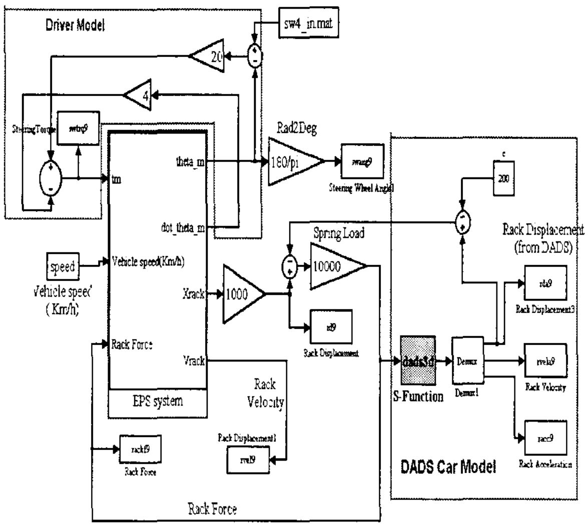

Fig. 2 **Simulation Integration** technique executing MATLAB only with DADS subroutine

Figures 1 and 2 illustrate the block diagram of the integrated model. They also show the interface for co-simulation and simulation integration between full vehicle model and EPS control module, respectively. The inputs to the EPS system are handle-wheel torque, vehicle speed and rack force. The outputs of EPS system are resultant angular position and velocity of handle-wheel, as well as the displacement and velocity of rack. A simplified driver model who is just holding handle-wheel to create a constant step input is also integrated with the EPS system. This driver model consists of the stiffness of driver (20 N-m/radial) and the damping of human body (4 N-m * second/radial). An input file (sw4_in.mat) to the driver model is the historical experimental data of handle-wheel angular position. This driver model produces a resultantly constant angular position of handle-wheel that turns the vehicle in a desired circular path corresponding to the road curve on providing ground. The shade block denoted as adams_sub in Fig. 1 is a subsystem that consists of the full vehicle model created from ADAMS. The shade block denoted as 'S-Function' in Fig. 2 is a subsystem that consists of the full vehicle model created from DADS.

4. SIMULATION RESULTS AND COMPARSION WITH EXPERIMENTS

The simulation result and its correlation with experimental data are discussed in this section. A prototype vehicle was tested three times on the proving ground. This vehicle was driven at speed of 32 km/hour on a circular path with diameter of 65.8 meter. As vehicle lateral acceleration reached 0.25 g, the vehicle was driven over a single bump with tires on driver side (front and rear). The dimension of this single bump was illustrated previously. For vehicle performance evaluation, only the left side tires were driven over this single bump that generated the larger unbalanced load on the vehicle chassis from road surface impact. Accelerometers mounted on several locations inside the vehicle acquired the dynamic characteristic of vehicle chassis under these driving and road conditions.

The vehicle hits the bump at 2.25 seconds on the left-front tire and then on the left-rear tire. The entire simulation time is 3 seconds and the sampling rate is 0.005 second that is about five times as fast as the required controller bandwidth. The comparisons between simulation results and test data are focused on the time period where vehicle impacts on single bump.

Figure 3 shows the predicted and test results of the left-front tire center accelerations in the directions of vertical. Overall the simulation results correlate quite well to the experimental data in terms of the occurrences of spikes and their magnitudes. Figures 4 and 5 show the compared results from co-simulation and simulation integration.

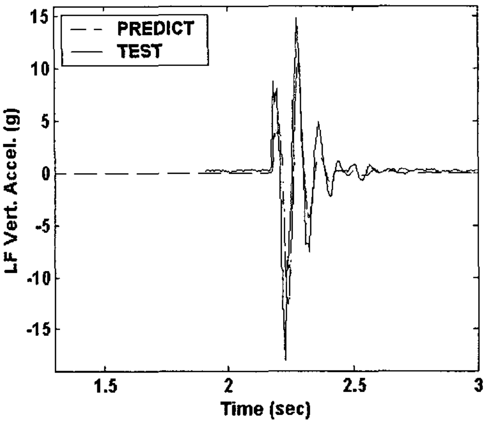

Fig. 3 Comparison of the left-front tire center vertical accelerations

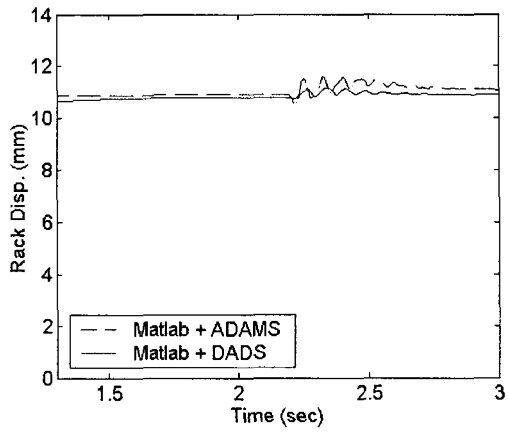

Fig. 4 Comparison of rack displacements from 'Co-Simulation' and Simulation Integration Methods

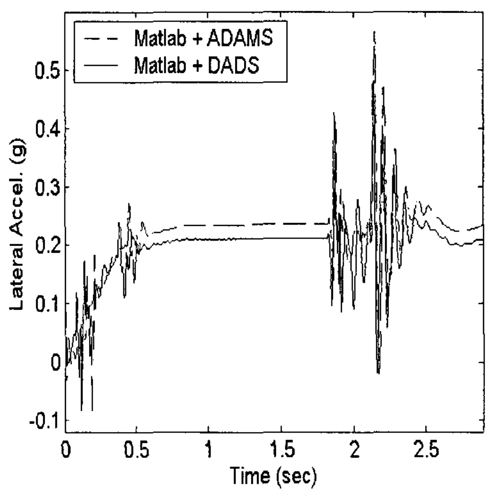

Fig. 5 Comparison of lateral accelerations from 'Co-Simulation' and Simulation Integration Methods

Figure 4 shows a tiny difference and Fig. 5 show a little error which might be caused by different integrators. In co-simulation two integrators were executed but in simulation integration only MATLAB was executed.

5. CONCLUSIONS

A full vehicle model integrated with EPS control algorithm has been developed that predicts the dynamic characteristics of vehicle chassis and steering system subjected to road surface condition. Using co-simulation technique and simulation integration, the integrated vehicle model is simulated on a circular path with single bump road condition. Through this research the dynamic responses of vehicle chassis and steering system resulting from road surface impact would be evaluated and compared with proving ground experimental data.

The integrated method allows engineers to determine if the overall design of the vehicle and EPS meets design targets without going through extensive prototype testing which is expensive and time-consuming. This developed simulation capability can be used for EPS performance evaluation and calibration as well as for vehicle handling performance integration and synthesis.

후 기

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