Supporting System for Model Based Development (MBD)

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Abstract

As a result of rapid advancement of car electrification and autopilot technologies, evaluation items in automotive development have increased as are the costs for evaluation reliability. In order to resolve this issue, Model Based Development (MBD) is used to cut development man-hours and improve quality. Processes of development have been shifted to MBD. In order to acquire highly accurate test results from bench tests, it is necessary to operate a dynamometer system ("dynamometer" hereafter) at a high accuracy and speed in combination with various systems, while executing large-scale simulation models in real time. We have developed a Hardware-In-the-Loop Simulation (HILS) system for virtual vehicle testing (systems validation and verification). This combines our conventional dynamometer test system with simulation models to improve measuring accuracy and reliability.

1 Preface

As automotive systems get higher functioning and more complicated, the cost for reliability evaluation in development increases continues to grow exponentially.

To address this issue, a technique called Model Based Development (MBD) is expanding. With MBD, a detailed simulation of the actual driving conditions and such investigation improves the design accuracy. Regarding the validation and verification of parts, MBD enables the simulated tests under the same virtual conditions from a simple endurance test to actual driving conditions. It reduces development man-hours and improves the quality.

In the last stage of MBD, when testing the actual products with the simulation, a test similar to an actual running vehicle is performed by applying a load equivalent to an actual vehicle using simulation models of parts around the actual products under test. If the actual product under test is a complete vehicle, the model reproduces the road surface conditions and if the product under test is an engine, the model reproduces the simulated testing environmental conditions from the transmission to the vehicle body and road surface conditions.

In order to achieve this test environment, our products include a control system linked to the customer's simulation machine and our dynamometer system ("dynamometer" hereafter) that reproduces model commands with high accuracy. We develop and provide MBD support systems. This paper introduces our recent initiatives on our MBD support system.

2 MBD Processes

Fig. 1 shows recent changes in development processes of automotive companies and Fig. 2 shows MBD processes. Although MBD processes achieved a great reform in development processes, these processes come in a variety of styles and each step is by the name of "'X' In The Loop Simulation." The acronym Model-In-the-Loop Simulation (MILS) takes the development processes in a V-Cycle. In preparation for the final complete vehicle verification and in the early MBD processes, we can perform simulations on a PC by using the modeling framework without any physical hardware components in order to study the orientation of the final car specifications. The next stage is Software-In-the-Loop Simulation (SILS). SILS verifies the embedded software in the controller. The controller's environment is simulated as models. In the case of Hardware-In-the-Loop Simulation (HILS), HILS performs the verification of each part. All prod-

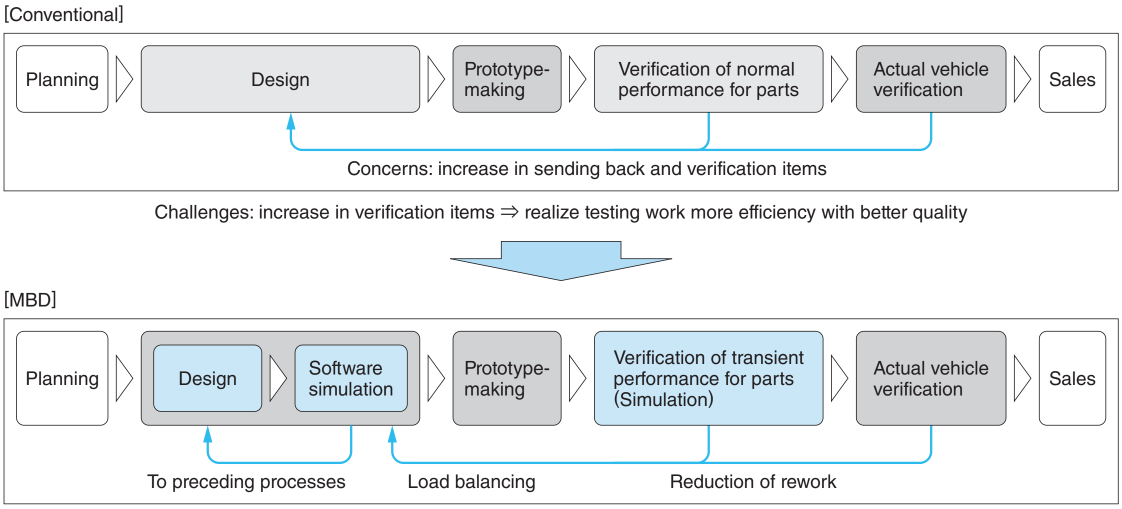

Fig. 1 Recent Changes in Development Processes of Automotive Companies

An example of recent changes in the development process of automotive companies is shown. Currently, MBD is popular in reducing the workload in the preceding process or to reduce time spent on modifications.

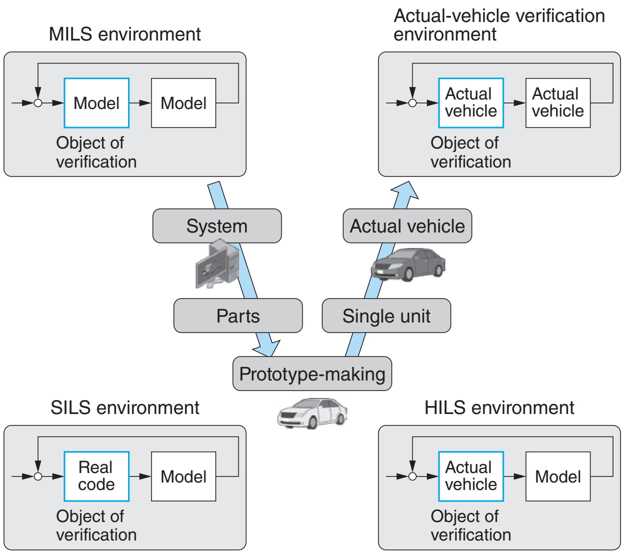

Fig. 2 MBD Processes

Each verification stage is shown in the respective development processes in a form of V-Cycle.

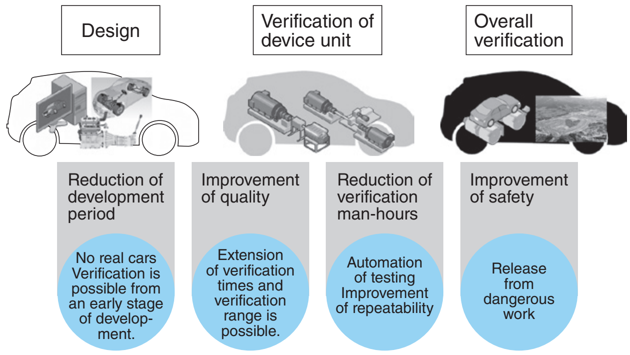

Fig. 3 Effect of HILS Test System Introduction

An example of the effect of HILS test system introduction is shown together with its contents.

ucts for which the virtual load against the vehicle under test is produced by the dynamometer can be called the HILS-related items. Recently, reproduction with simulation models has been extremely advanced and reproduction of actual conditions has been rapidly improved.

Fig. 3 shows the effect of HILS test system introduction. When the HILS test system is introduced, the following effects can be expected. At the early design stage, the period for development can be shortened because testing equivalent to the tests by an actual vehicle is possible even at an early stage of development without any actual vehicle. In the component validation and verification stage, changes in the environmental conditions can be reproduced only by modifying the simulation models. The number of validation and verification or its range can be easily increased. We can expect quality improvement of each component.

In the case of validation and verification of a complete vehicle, the repeatability is high and the test itself can be easily automated. Various tests can be performed unattended and automatically overnight. This reduces the number of validation and verification steps. At the stage of validation and verification of a complete vehicle, there is no need for a test driver to get into the actual vehicle and drive near or beyond the limit. This enables highly safe tests.

3 HILS Test System Technologies

Fig. 4 shows the outline of the HILS test system. There are a dynamometer, an inverter panel, relay panels, a temperature control system, and mechanical control units based on inputs from various measuring devices installed in such panels or systems. These are connected with high-speed communication networks and high-speed controllers. For torque and speed, the system generates vibration, vibration suppression and gives inertia control. By connecting with an operation measurement device, it performs various data measurement, safety monitoring, driving operation, etc. Essential element of HILS is simulation model. We build various models by using Computer Aided Engineering (CAE) tools and modeling software of an external arithmetic machine, high-speed controllers for operation devices. Such simulation models are in sync with test system in real-time.

Fig. 5 shows the vehicle model and evaluation items. In a motor vehicle, the powertrain comprises

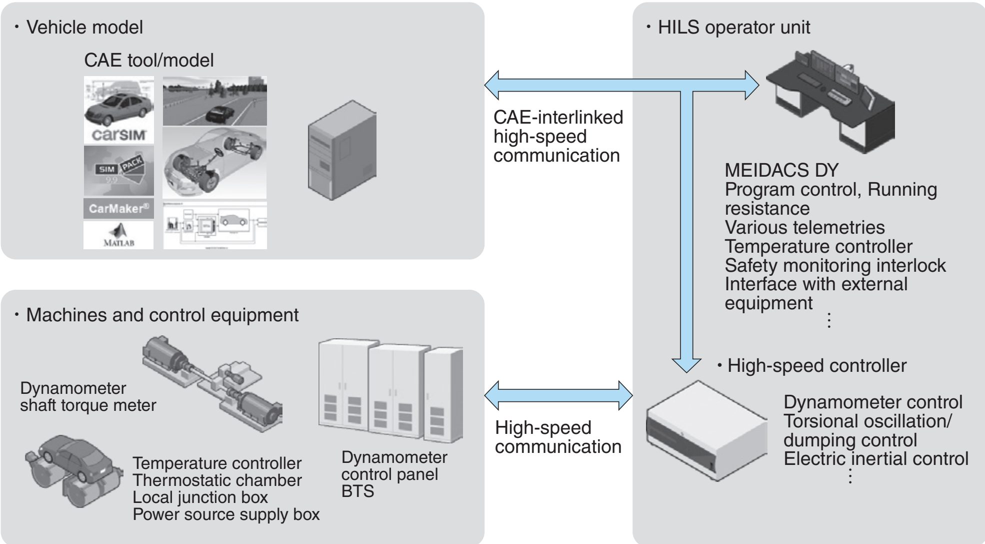

Fig. 4 Outline of HILS Test System

Major equipment and units are shown. These items are necessary in building a HILS test system.

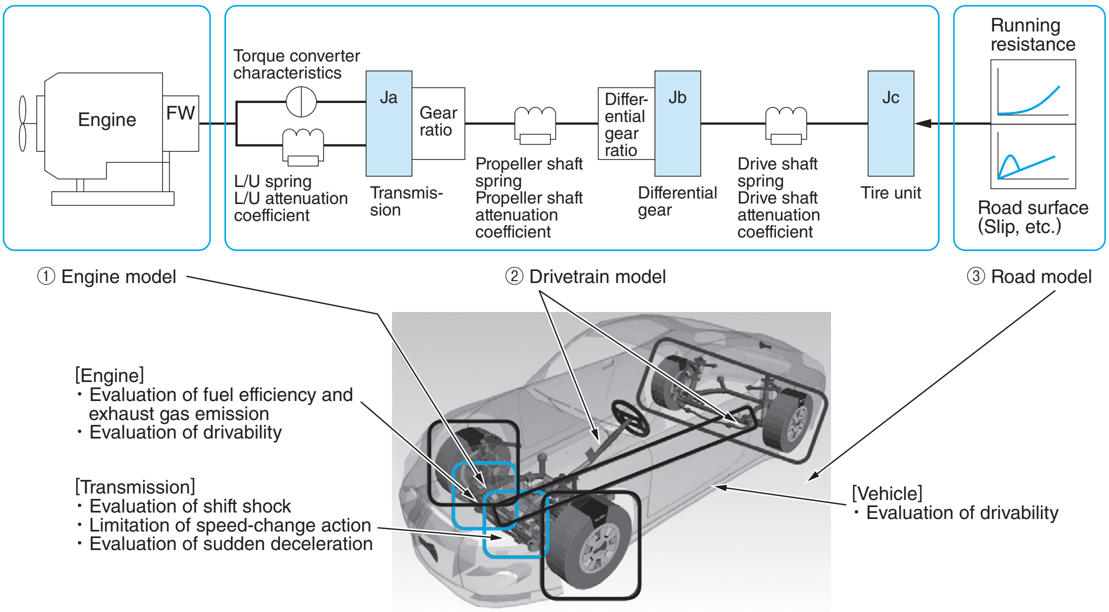

Fig. 5 Vehicle Model and Evaluation Items

An example of simulation model elements and possible evaluation items on the model is shown.

the main components that generate power and deliver that power to the road surface. This includes the engine, torque converter, transmission, drive shafts, differential gears, and the final drive (drive wheels). In the powertrain simulation models, by changing engine characteristics and the gear ratio of the transmission, the vehicle characteristics can be adjusted and fuel consumption and exhaust gas emission can be evaluated. The driving conditions can be changed by setting the road surface to a slope, snowy road, off-road, or other condition. Furthermore, if the simulation models are used to reproduce the mounting mechanism of the main body and parts, or reproduce the test driver, certain micro level part change may impact on the macro level in the overall complete car design. When the vehicle starts or changes its gear, it is possible to evaluate the riding comfort felt by the test driver on a bumpy road.

Table 1 shows technical issues of the HILS test system. In the HILS test system, the simulation models and the test system need to cooperate in real time to reliably reproduce movement. It is for this reason, that individual systems need to be connected at a high speed and improving the response speed of each device is a priority. To address such issues, direct connection was made with in-vehicle electronic devices by a high-speed communication network exceeding 1 kHz. A control system to achieve high response speed while suppressing resonance was made. As the dynamometer is an essential element of HILS test system, we realized a lower inertia model at 1/10 of our old model.

Table 1 Technical Issues for HILS Test System

Technical issues to realize the HILS test system and possible measures to be taken are shown.

System configuration	Technical challenges	Measures taken
Vehicle model	Real-time reproduction of real-car behavior	Real-time interlinkage with a model (SIMPACK/ CarSim/MATLAB/ dSPACE···)
Operation measuring unit for HILS	Interlinkage with other equipment Communication rate (500Hz) High responsive shift control	High-speed mutual communication (1kHz) Reproduction of inertia (100Hz) Model-interlinked control
	High-speed connection with peripheral equipment of specimen (CAN communication 10Hz)	Connection by high-speed communication with Engine Control Unit (ECU) (>1kHz)
Mechanical control unit	Realization of inertia equivalent to real engine and real tires (DY inertia: 0.95kg·m²/14.6kg·m²)	Attainment of low dynamometer inertia (DY inertia: 0.12kg·m²/1.6kg·m²)

4 A Case Study and Advantages of the HILS Test System

Table 2 shows a case study of the HILS test system. For the validation and verification of transmission gear and hybrid system, our HILS test systems have been developed. It is in sync with 1D/3D vehicle simulation models and the power transmission system simulation model. It has contributed to the reduction of man-hour time for validation and verification processes, an improvement of safety, a shorter development period, and an improvement of quality.

For Firm A, we supplied a test bench in which the vehicle simulation model involved with the actual ECU changes the transmission. This test bench reproduces the transmission shift behavior. Vehicle measurement data and test bench simulated data match in terms of transient torque/speed changes. The on-road operation conditions were reproduced by the test bench up to the detailed behavior points. Speed gear shifting depends on various conditions such as torque, speed, and oil pressure, so, there are various adjustment factors. These adjustments can be performed on the test bench without having to drive the actual vehicle.

For Firm B, we supplied a test bench in which

Table 2 Case Study of HILS Test System

Typical examples of supplied HILS test system is shown.

Supply Cases	Actual unit	Model	Evaluation points	Impact
Firm A	Transmission	Vehicle behavior model	Reproduction of torque during shift change	●Reduction of verification man-hours: Realization of evaluation results (equivalent to a real vehicle) by using only an actual transmission unit
Firm B	Transmission	Snowy-road vehicle behavior model Vehicle behavior model	Reproduction of tire lock Strength of transmission	●Improvement of safety: Realization of dangerous testing on the bench equivalent to testing on rear road
Firm C	HEV system	Power Transmission System (PTS) model	Modification of PTS model	●Reduction of development period: Attainment of fuel efficiency evaluation among different PTSs without making prototypes
Firm D	Transmission	3D vehicle model	Reproduction of real-car riding comfortability	●Improvement of quality: Improvement of riding comfort attained by the test bench

it can reproduce a snowy road driving conditions called a “low μ (friction coefficient) road driving.” We built a HILS test system similar to the one at Firm A which reproduces the car behavior when braking is applied while driving in a snowy road condition. It can reproduce the state of locked tires by a control adjustment on Anti-lock Braking System (ABS). For this type of test, we needed to have dedicated test facilities or test drive at specific cold climate areas. This test bench can shorten the required time and efforts for such a test.

For Firm C, we supplied a test bench in which the fuel efficiency of the Hybrid Electric Vehicle (HEV) under test can be evaluated. HEV has multiple power sources and power devices. The fuel efficiency changes greatly depending on how power sources and power devices work together. This power balance design is the key in HEV development. This test bench consists of individual test benches, respectively for each engine, motor and battery device. Such actual components are connected to the simulation environment of the vehicle simulation model and power transmission system simulation model. This test system has a very complicated configuration. Since the interconnection between this power transmission system and the test system is complicated, the process of prototype-making and testing must be repeated, which is an enormous cost. Since the power mechanism and system cooperation are also complicated, the repetition of prototype-making and testing (validation & verification) require enormous costs as well. In this test bench, we use a simulation model only for the key element, the power transmission system. The model is connected to a dynamometer via an information network system. Through such configuration, we reduce the time for development and contribute to the HEV development.

For Firm D, we supplied a test bench in which a 3D vehicle simulation model is connected to a dynamometer via an information network system. It is used for evaluating ride comfortability. Just like Firm A, it evaluates gear shifting behavior. The main difference is that this simulation model is 3D. The 3D model used in this test bench can reproduce the detailed internal mechanisms such as the suspension system or inter-parts-connections. The factor evaluated at this stage is how the driver feels with the quality of gear-shifting. This test bench observes the effort of gear-shifting on the vehicle body and driver and incorporates it in the quality evaluation. It can perform a different level evaluation one-step-further than before.

5 Postscript

This paper introduced our MBD support system. We have been providing in advanced car development and test systems. We help the auto industry speed up the new vehicles time to market and improve reliability during the development stage. In recent years, the MBD including HILS test system has become mainstream as a product development process. Going forward, we will continue to provide excellent HILS testing systems.

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