Improvement of development quality by applying MBD to experiments
–Application of a HILS system to AT development–

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Summary

Development costs have tended to increase in recent years owing to longer lead time and greater expenses because of the diversified and higher functionality required of vehicles. The cost burden of experiments using actual vehicles is especially large, and increased efficiency is required in addition to ensuring quality. This article describes the use of a new hardware-in-the-loop simulation (HILS) system that has been improved so as to enable coordinated engine control, making it possible to substitute theoretical experiments for evaluations that previously could only be made with actual vehicles. This improved system achieves solid quality while holding down the cost of developing automatic transmissions by enabling advance evaluations to be conducted efficiently.

1. Introduction

Development lead time and costs have tended to increase enormously in recent years owing to the diversified and higher functionality demanded of vehicles. Issues that occur in actual vehicle evaluations conducted on real-world road surfaces in the later phase of the development period are an especially large cause of rework that puts pressure on development costs.

In order to deal with this issue, JATCO has promoted the use of model-based development (MBD) technology for substituting test bench experiments and theoretical experiments in place of actual vehicle experiments. The following benefits can be expected from this approach.

1) Advance evaluation of conditions simulating real-world road surfaces by using simulation functions.
2) Efficient evaluation of a huge number of conditions by using an automatic experiment system.

This article describes an example of the application of a hardware-in-the-loop simulator (HILS) embodying MBD technology to substitute theoretical experiments for vehicle experiments in developing automatic transmissions (ATs). This approach both reduces development costs and improves quality.

2. Issue

More speed ranges have been added to ATs in recent years to meet demands for better fuel economy among other requirements. Like other companies, JATCO has added more speed ranges to 7-speed ATs to create 9-speed ATs for use on rear-wheel-drive vehicles. As a result, the number of shift patterns has increased 1.6 times as shown in Fig. 1. Moreover, owing to the greater complexity of shift control, conditions with finer throttle valve openings have been added along with various driving environment conditions, including high elevations and road gradients. Automatic transmissions must always provide satisfactory smoothness, response and other shift performance qualities under this vast number of evaluation conditions. However, it is difficult to ensure such performance on the basis of actual vehicle experiments.

As one measure for coping with this issue, for some time now we have been using a HILS-based experiment

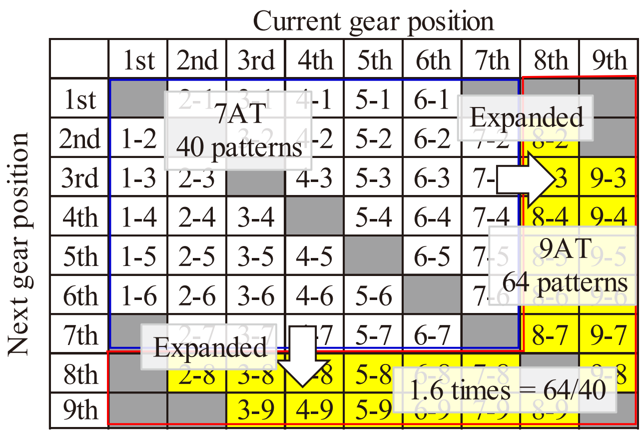

Fig. 1 The number of shift patterns

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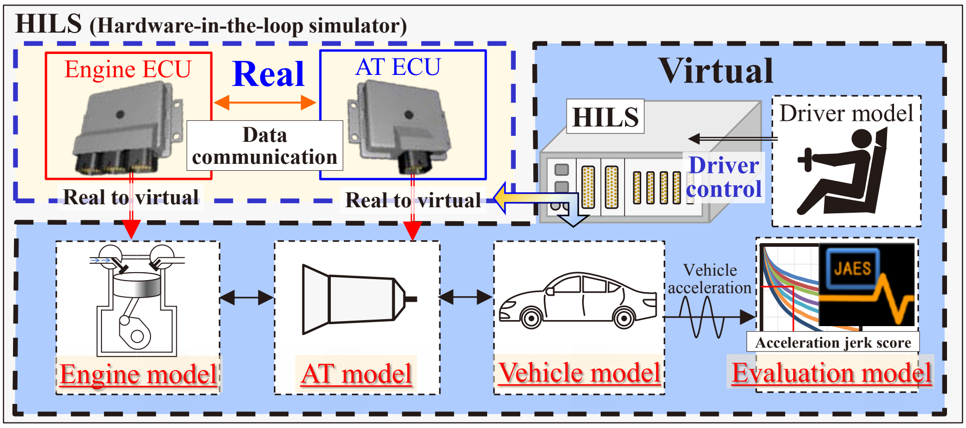

Fig. 2 HILS system with AT ECU + engine ECU

system to confirm the performance of the onboard electronic control unit (ECU) of the AT as a substitute for actual vehicle experiments. However, in order to confirm driveability, it is necessary to reproduce coordinated control for adjusting engine torque. Application of the previous HILS system with only the AT ECU has been limited due to its poor accuracy.

3. Solution to the issue

The following three measures were applied to the previous HILS-based theoretical experiment system to improve its accuracy so as to enable confirmation of driveability.

(1) Development of a HILS system that also operates the engine ECU in addition to the AT ECU in order to enable coordinated engine control.
(2) Enhancement of the accuracy of the AT and vehicle models to enable driveability evaluations.
(3) Implementation of an automatic evaluation system for obtaining higher efficiency.

4. HILS system with engine & AT ECU operation applied to a 9-speed AT

A HILS system with both engine & AT ECU operation was developed for application to a 9-speed AT for rear-wheel-drive vehicles. The system configuration is outlined in Fig. 2. This is a theoretical experiment system that incorporates simulation models other than for the ECUs. An automatic experiment system enables efficient evaluation of a vast number of operating conditions, including driving environment conditions. It is well suited to wide-ranging searches for calibration constants and to narrowing down conditions causing performance problems.

4.1 Improvement of engine model

The intake air volume etc. sent to the sensors must be calculated in order to operate an actual engine ECU. However, implementing a detailed simulation would require an enormous amount of effort and computational complexity, making it difficult to use the HILS system that requires real-time processing. Therefore, a method was adopted for calculating the intake air volume with a simple computational model (Fig. 3). This model uses the mean value of the intake air volume fluctuation among the cylinders, which is found with what is generally known as a mean value engine model (MVEM).

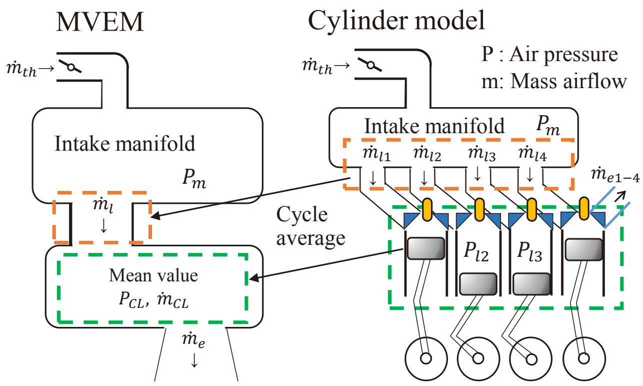

Fig. 3 Mean value engine model (MVEM)

A method of referring to a map of experimental data is used to calculate engine torque and other values.

This method makes it possible to reproduce the coordinated control between the engine ECU and the AT ECU. Figure 4 compares the results obtained with the new HILS system and the previous HILS system that includes only JATCO's standard in-house AT ECU. The data indicate that the new system is capable of reproducing the synchronized control that immediately raises the engine speed when the coordinated control procedure works to increase engine torque at the time of a downshift.

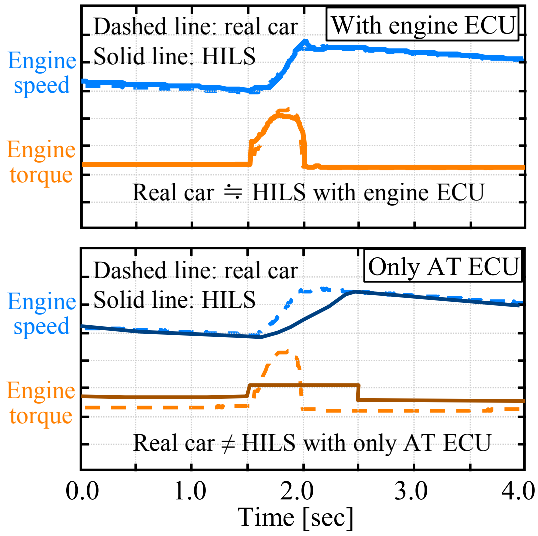

Fig. 4 Comparison of coordinated control for HILS system and real car

4.2 Improvement of AT model

The following improvements were made to the AT model in the new HILS system for the purpose of evaluating driveability during AT shifting.

(1) The equation of motion for the independent inertial moment of each element of the planetary gear set is expressed as a state space representation and calculated.

(2) Drag torque is calculated according to the clearance state of the clutch friction material.

(3) The coefficient of friction of the clutches, which varies depending on the experimental values used for the rotational speed and surface pressure, is calculated in reference to a map.

(4) The elastic modulus of the CVT fluid, which varies according to the hydraulic pressure based on matching with experimental data, is calculated in reference to a map.

These improvements enhance the reproducibility of shift shock, making it possible to evaluate driveability.

4.3 Improvement of vehicle model

A simple mass model was used previously as the vehicle model in performance experiments of an AT unit alone. However, in evaluating vehicle behavior, it is necessary to consider the influence of spring system vibration induced by the suspension and other parts. Therefore, in a cooperative effort with Nissan Motor Co., Ltd., a vehicle model was adopted that can evaluate low-frequency vibration, taking into account a spring element. Figure 5 presents a comparison of vehicle acceleration during an upshift obtained with the improved model, the previous model and a real car. Because the tilting and swaying behavior of the vehicle body induced by acceleration was added to the improved model, it reproduced vehicle acceleration close to the value of the vehicle acceleration sensor.

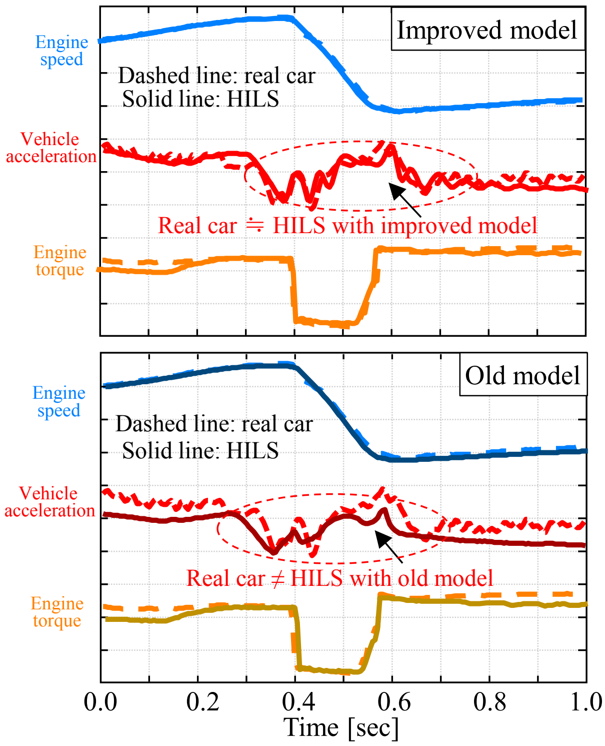

Fig. 5 Comparison with improved vehicle model

4.4 Automatic evaluation system

The Jatco Auto Evaluation System (JAES) developed in-house by JATCO was adopted as the evaluation model. JAES converts the ride quality index, based on the "Evaluation Method for Whole-Body Vibration in ISO2631-1," to JATCO's in-house rating score. This enables automatic operation of the automatic experiment system from the execution of driving operations to the final evaluation of ride comfort.

5. Use of HILS system with both engine and AT ECU operation

This section describes examples of experiments conducted on JATCO's 9-speed AT using the new HILS system that activated the engine and AT ECUs.

5.1 Experiments for varied driving environment conditions

It is now easy to conduct tests on road gradients by changing the values in the simulation. This capability can be used to examine problems suspected to occur under coordinated engine control only on downhill gradients. It has been helpful in clarifying the mechanism involved and in establishing a corrective control procedure by identifying the conditions causing the phenomenon such as the degree of the downhill gradient and rate of vehicle deceleration.

5.2 Use of automatic capabilities of HILS system

Confirming the standard menu of various shift patterns in actual vehicle experiments takes 7.5 months to check approximately 5,000 patterns, but confirmation can now be completed in seven days with the HILS system because it operates continuously day and night. Based on the results, operating regions where it is suspected performance problems may occur are identified and further narrowed down in detailed experiments conducted with an actual vehicle. In addition, the patterns can be reused to confirm differences when small-scale specification changes or control system changes are made, enabling efficient confirmation of quality.

5.3 Wide-range search for calibration constants

A wide-range search for multiple constants, which is time-consuming with actual hardware, was conducted by taking advantage of the ability to easily change the calibration constants of the ECU in a theoretical experiment. The color-coded regions in Fig. 6 indicate the operating regions where the evaluation model results were poor when calibration constants for the engagement and release pressures of the clutches were varied. As indicated in the figure, the HILS system contributed to constant calibration by finding an acceptable area in the region of high clutch release pressure, which was not found in the test results of the actual vehicle.

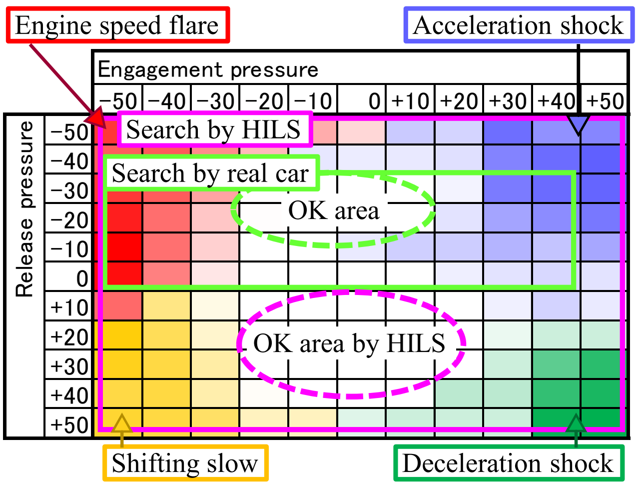

Fig. 6 Calibration constant search by HILS and real car

6. Conclusion

Development costs have been soaring due to the diversified and higher functionality required of vehicles. To address this issue, we included the engine ECU in the new HILS system and made the following improvements in order to expand the operating range that can be confirmed by theoretical experiments. These measures were taken to cope with the explosive increase in experimental conditions especially for the addition of more speed ranges to ATs.

(1) Reproducibility of coordinated engine control was improved by creating the minimum necessary engine model for operating the engine ECU.

(2) Reproducibility of shift shock was improved by further enhancing the AT and vehicle models.

(3) The automatic experiment system now makes it possible to efficiently vary many conditions.

The following results were achieved by using this improved HILS system.

(1) Fine-mesh simulations that included driving environment conditions were conducted at low cost and with high reproducibility, which contributed to the development of the ECU control system.

(2) Potential issues were detected early before in-vehicle testing, wide-range searches were conducted for calibration constants and they were narrowed down.

HILS-based theoretical experiments cannot be substituted for all actual vehicle experiments at the present time because complete accuracy has not yet been obtained. Therefore, we aim to further improve development quality through selective use of the features of each approach. The advantages of the HILS-based automatic experiment system will be utilized to narrow down calibration constants and conditions based on wide-range searches, and experiments will be performed for obtaining highly accurate clarification of the phenomena involved.

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