Improvement of development quality by applying MBD to experiments —Application of a VRS system to CVT development—

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Summary

Development costs have tended to increase in recent years due to the diversified and higher functionality required of vehicles. The cost of conducting actual vehicle experiments is especially huge, and there is a need for higher efficiency on top of ensuring quality. This article describes the use of a virtual and real simulator (VRS) system to conduct test bench experiments for making evaluations that previously could only be done in actual vehicle experiments. This system selectively uses virtual parts embodying model-based development (MBD) technology and real parts of an actual unit in appropriate places. By enabling advance evaluations to be conducted efficiently, this system supports the creation of solid quality while holding down development costs.

1. Introduction

Development lead time and costs have tended to increase enormously in recent years owing to the diversified and higher functionality required 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 resolve this issue, JATCO has promoted the use of model-based development (MBD) technology to conduct theoretical experiments and test bench 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 automatic experiment capabilities.

This article presents an example of the use of a virtual and real simulator (VRS) system embodying MBD technology in actual CVT development work to perform test bench experiments in place of actual vehicle experiments. The use of this system builds solid quality while suppressing development costs.

2. Issue

A CVT is built with a variator capable of executing stepless shifting using a belt and pulley system. Precise hydraulic pressure control of each pulley ensures stable shifting and enables torque transmission (Fig. 1).

In addition, the transmission must always ensure shift stability and provide satisfactory vehicle driveability in various driving operations envisioned on a wide range of real-world road surfaces, including those at high elevations and with road gradients.

Numerous actual vehicle experiments on a test course and on real-world road surfaces are necessary in order to confirm such performance. Because of the diversification of requirements and higher functionality needed, it is becoming very difficult to confirm all of the performance requirements using actual vehicles.

As one solution to this situation, JATCO has been

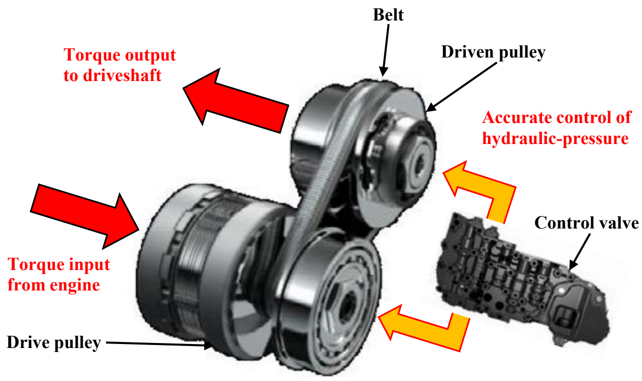

Fig. 1 Variator system of CVT

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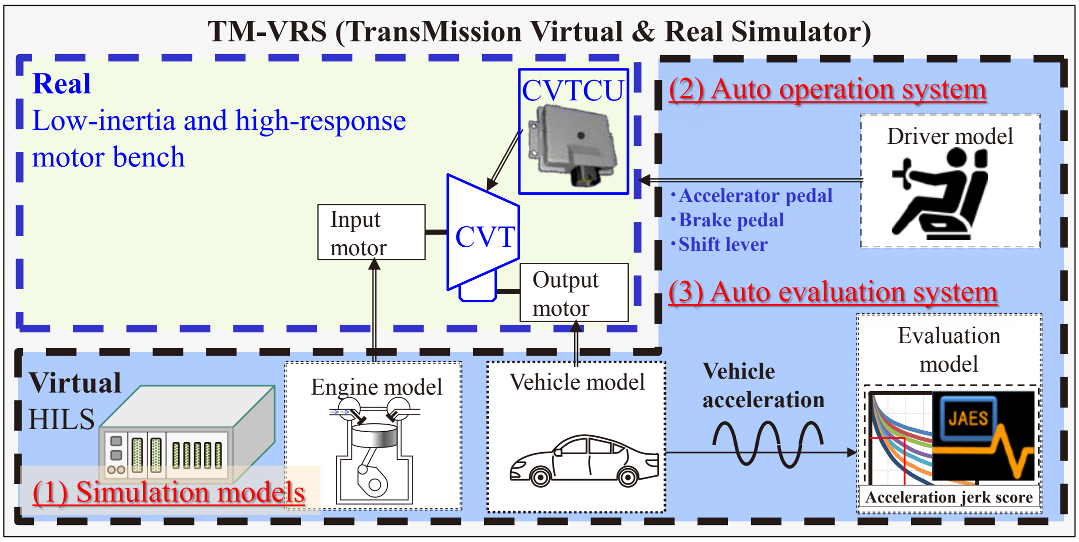

Fig. 2 TM-VRS System

promoting the use of MBD technology to substitute theoretical experiments and test bench experiments for actual vehicle experiments. This approach is aimed at both reducing development costs and ensuring desired quality.

However, a major issue in both theoretical and test bench experiments is to accurately reproduce actual vehicle behavior. In a theoretical experiment, models are substituted for all the vehicle systems including the CVT that is the target of the evaluation. It is desirable to be able to evaluate driveability at a level that includes the variator and hydraulic pressure control system, which are characteristic elements of a CVT. In this case in particular, it is necessary to use highly accurate models that require an extremely long calculation time. One resultant issue is that it becomes very difficult to efficiently evaluate a large number of experimental conditions, which is one of the advantages of theoretical experiments.

3. Solution to the issue

The following practical solution was developed to resolve the issue of the trade-off between accuracy and efficiency. Actual CVT hardware is used for parts that require accuracy and are difficult to model. Simulation models based on MBD technology are substituted for the other parts. In short, an effort was made to replace actual vehicle experiments with test bench experiments by applying the VRS system that selectively uses both real and virtual parts in appropriate places.

JATCO Technical Review No. 17 contained an article entitled "Development of a VRS Test Bench Capable of Validating Transmission Driveability using a Virtual Engine" (referred to hereafter as the previous article). The present article describes an example of the application of the VRS system in the development of an actual CVT.

4. TM-VRS system

The configuration of the TM-VRS system is shown in Fig. 2. It was created by adding hardware-in-the-loop simulation (HILS) models (Fig. 2(1)), an automatic operation system (Fig. 2(2)) and an automatic evaluation system (Fig. 2(3)) to a low-inertia, high-response motor bench.

The high-response motor bench and simulation models serve to reproduce the behavior of an actual vehicle. A large number of conditions can be efficiently evaluated by using the automatic experiment capabilities incorporated in the automatic operation and evaluation systems.

4.1 Engine model

A simple engine model was adopted that reproduces only the narrowed-down characteristics needed for evaluating a CVT. It is not a virtual engine system like that mentioned in the previous article or used for stepped AT evaluation, which employs an actual engine control unit.

This simple engine model was prepared as a measure for addressing an actual operational issue where it is not possible to construct a virtual engine system on a timely basis because the engine is being developed simultaneously or for some other reason. Compared with a stepped AT that requires a coordinated engine control system for switching between clutches of the planetary gear set when shifting, the coordinated engine control for a CVT is limited, making it possible to substitute this simple model.

4.2 Vehicle model

Compared with the simple model that only included running resistance in the previous article, a vehicle model was adopted like that for stepped AT evaluation, which includes the vibration characteristics of the suspension, engine mounts and other parts. This was done in cooperation with Nissan Motor Co., Ltd., and it improved the reproduction accuracy for vehicle acceleration (G), which is critical for evaluating driveability.

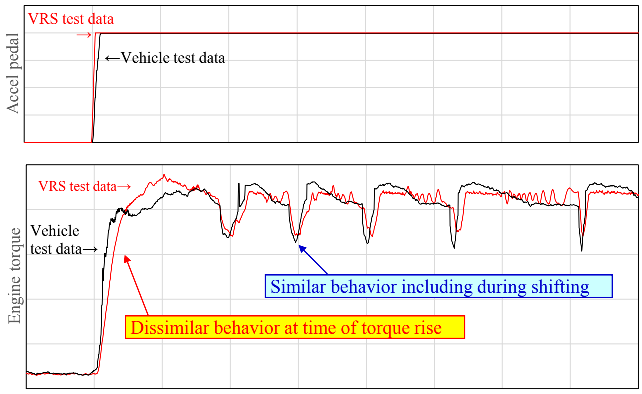

Fig. 3 Engine torque behavior comparison

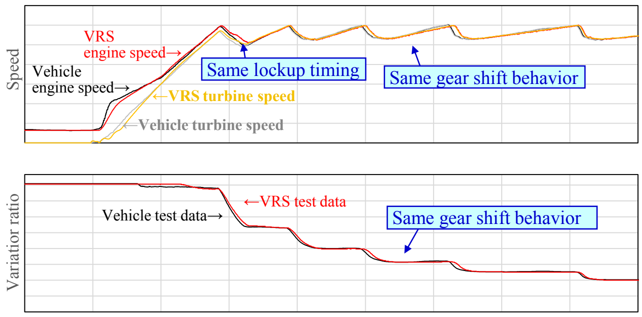

Fig. 4 CVT internal behavior comparison

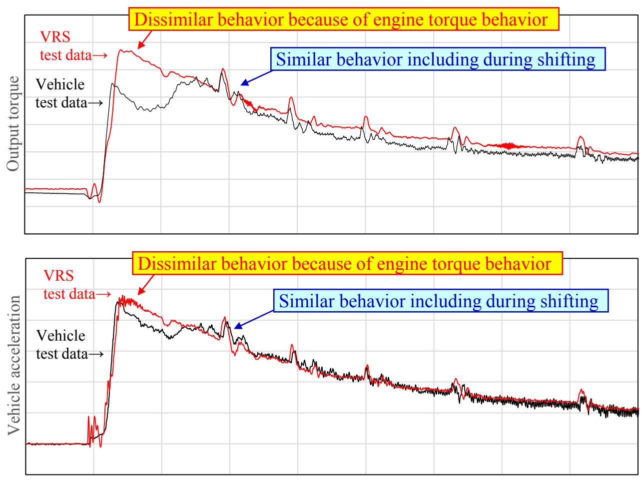

Fig. 5 Vehicle acceleration behavior comparison

4.3 Automatic evaluation system

The automatic evaluation system adopts an evaluation model that is identical to the one mentioned in the previous article and used for stepped AT evaluation. This system enables efficient judgment of the huge volume of data collected by the automatic operation system.

5. Actual vehicle behavior reproduction accuracy of TM-VRS

Figures 3-5 compare the behavior of the time-history data obtained with an actual vehicle and with TM-VRS. Data are shown separately for different parts of the TM-VRS system in order to confirm their reproducibility of actual vehicle behavior.

Figure 3 compares the time-history waveforms for accelerator pedal operation and engine torque that are influenced by the engine model. Except for the start of torque rise, the engine model reproduced engine torque behavior during steady-speed operation and when shifting.

Figure 4 compares the time-history waveforms for the engine speed, turbine speed and variator ratio, which are influenced by the engine model and the actual CVT hardware. It is seen that the TM-VRS system reproduced the same behavior as that of the actual vehicle in each case.

Figure 5 compares the time-history waveforms for output shaft torque, representing the final output, and vehicle acceleration (G). The TM-VRS system reproduced the acceleration behavior of the vehicle, excluding the time when engine torque began to rise.

6. Discovery of development issue and its solution

Figure 6 presents an example of a development issue that was discovered in test bench experiments conducted during the CVT development process before the unit was validated in vehicle testing.

The phenomenon here concerned vehicle vibration that occurred due to variator instability when shifting manually at a low vehicle speed (left-side waveforms in Fig. 6). This issue was discovered for the very reason that the TM-VRS system uses an actual CVT and a high-accuracy vehicle model.

This phenomenon was detected and the issue was resolved before the CVT was validated in vehicle testing (right-side waveforms in Fig. 6).

7. Present issues and benefits of using TM-VRS

One present issue is that test bench experiments cannot fully replace all actual vehicle experiments. However, by

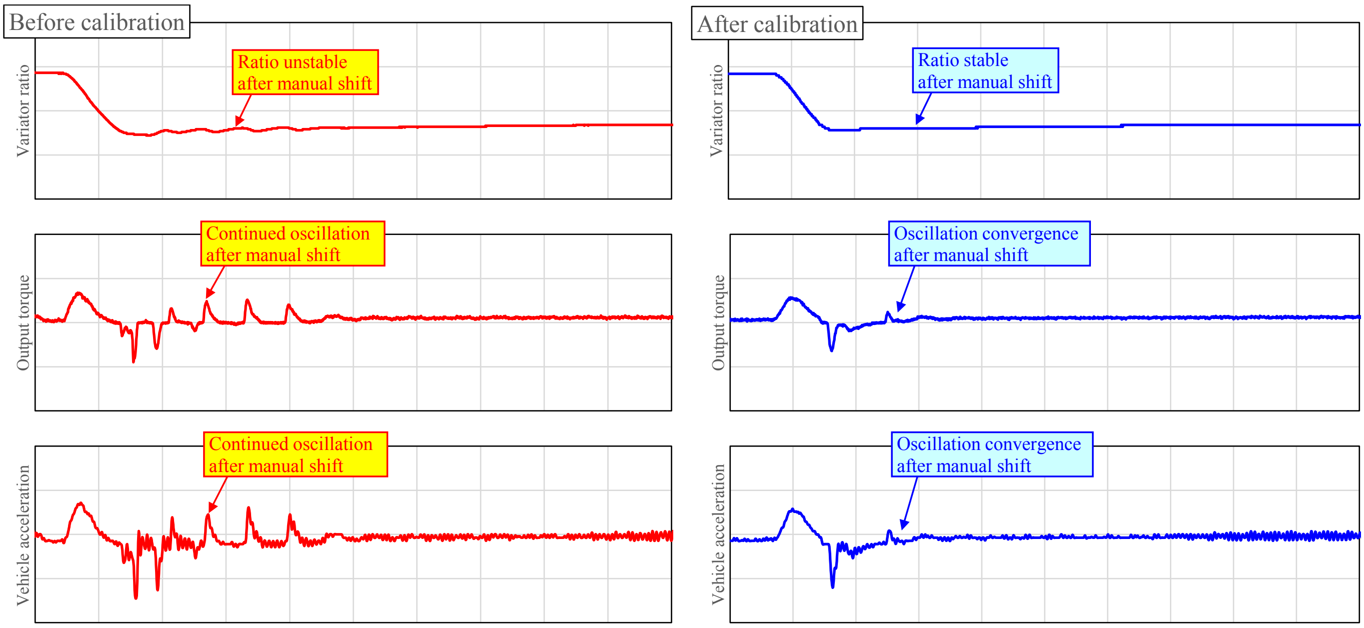

Fig. 6 Problem solution before in-vehicle validation

combining the best features of both approaches as described below, it is possible to both confirm solid quality and ensure efficiency.

Test bench experiments are well suited to a broad examination of many conditions. Specifically, the model-based simulation function enables evaluation of various driving environment conditions simulating real-world road surfaces at an earlier stage than actual vehicle experiments. In addition, the automatic operation and evaluation systems, capable of running day and night including on weekends, enable efficient evaluation of a huge number of conditions. In actuality, vehicle experiments that used to take three months to do on real-world roads can now be completed in one week. As a result, conditions suspected of being development issues can now be identified at an early stage. In addition, by taking advantage of the high reproducibility of driving environment conditions and driving operations, the effects of software changes such as for the control constants or other details and of hardware changes including variability among parts can now be evaluated directly.

Vehicle experiments are well suited to an in-depth examination of a limited number of conditions. Specifically, they can be used selectively to confirm conditions suspected of causing the problems discovered in test bench experiments or when a final judgment must be made by human engineers, among other situations.

8. Conclusion

Development costs have been soaring due to the diversified and higher functionality required of vehicles in recent years. To cope with this issue, JATCO has taken the approach of using a TM-VRS system to substitute test bench experiments for actual vehicle experiments. The following benefits have been obtained by applying this system in actual CVT development activities.

1) Selection of the optimum engine model and improvement of vehicle model accuracy have made it possible to substitute test bench experiments for actual vehicle experiments.
2) An enormous number of conditions can now be evaluated efficiently by using the automatic operation and evaluation systems.
3) Development issues can now be discovered and resolved early by evaluating conditions simulating real-world road surfaces in advance of actual vehicle testing.

In future CVT development activities, we aim to further improve development quality by adopting test bench experiments using the TM-VRS system as a standard process.

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