Development of "Integrated Hybrid Vehicle Simulator"

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Abstract

In recent years, the usage of simulators has shown their reliability as the verification tool for development and establishing the quality of automotive ECUs. Meanwhile, the vehicle control is evolving variously as seen in realization of cooperative control for better performance of the vehicle and employment of integrated control. Such a shift in a vehicle simulator gives effects on the vehicle development environment and the new requirements for CRAMAS are emerging. The "integrated full vehicle simulator" is being introduced actively around the European auto manufacturers.

This report explains the "integrated HV (Hybrid Vehicle) simulator" developed as a worldwide tool in order to respond to customer needs by maximizing the know-how of CRAMAS.

1 Introduction

In recent years, the use of simulators as a verification tool for development and establishing the quality of automotive ECUs has been increasing. The simulators have been utilized in various fields such as in place of an actual controlled system for developing new control algorithms, as test methods for behavior that happens rarely in real vehicles, for the automated testing instead of the manual testing that requires a lot of time, and as the means for the dangerous testing using a real vehicle. Meanwhile, the electronic control of a vehicle has progressed remarkably, as ECUs are networked by various communications (such as CAN, LIN, Serial transmission, etc.) and each ECU controls a vehicle cooperatively. Therefore, the development of simulators (Figure 1) for evaluating the behavior of whole ECUs installed in a vehicle, and the assurance of high quality have come to the forefront as important issues.

Fig.1 Appearance of CRAMAS

1.1 What is CRAMAS simulators

CRAMAS (Computer Aided Multi-Analysis System) was initially planned and developed as an in-house inspecting tool for ECUs, and broadened its application with the modeling of controlled system by ourselves. We have continued to improve CRAMAS with the aim of developing the tool to be applicable world wide, and have sold CRAMAS to automobile-related companies, so today CRAMAS is widely used as the best solution of development process innovation at home and abroad. CRAMAS can considerably reduce the man-hour of vehicle testing, and is expected to progress as a "tool friendly to global environment" without exhaust gas. (Kyoto Protocol requests Japan to reduce the greenhouse effect gas by 6% by 2012.)

2 Needs for full vehicle simulators

2.1 Role of simulators

Generally the purposes of simulators are as follows.

- **Quality inspection of the embedded software in the ECUs**
- **Development of control algorithm**

The followings are the requirements for simulators.

- **The test and the evaluation data shall be measured and analyzed automatically.**
- **The test pattern shall be simulated and generated automatically.**
- **The errors shall be generated at will.**

CRAMAS has satisfied the above requirements for simulators. However, the requirements for automobile development are changing as described in the next section.

2.2 Substantial changes in the "System evaluation"

The vehicle performance has been improved only by the advancement of single ECU. However, such vehicle performance improvement has its limitation, and it is necessary to cooperate and collaborate with other ECUs in order to overcome this limitation. In recent years, vehicles with 100 or more ECUs have come on the market. For example (Figure 2), electric power steering now achieves a lane-keeping function to prevent vehicles from deviating from the lane by helping the driver's steering operation. Such control cannot be realized only by the electric power steering ECU, but can be realized by the collaboration with other ECUs collecting surrounding information. On the other hand, as the available space in a vehicle is limited and the number of installed ECUs has increased, it becomes difficult to find the place for more ECUs. Thus the development of multiple functional ECUs that leads to a smaller number of ECUs in a vehicle (elimination and integration) to take less space and at the same time to decrease the volume of the wire harness is being accelerated.

However, while the use of such cooperative controls or integrated controls has increased, the role of evaluation and verification is changing as follows.

1) Evaluation on Interference among controls becomes necessary.

- Concerns about mutual interference among plural ECUs
  (The matter of transmitting and receiving signals among ECUs in the communication network.)

2) Evaluation of integrated controls

- Increase of the test volume for sophisticated control software
- Response to multiplied and diversified test circumstances

3) Evaluation of cooperative controls with security and safety functions

- Recurrence experiment using surrounding vehicle data

Therefore, because enormous amount of experiments is now required, it becomes difficult to rely upon manual experiments done one by one to assure quality. As a result, the demand for simulators to automate the test is growing.

Fig.2 Vehicle Image

2.3 Changes in the "evaluation by real vehicle"

Among automobile manufacturers there is a movement to build up verification and validation using simulators before the ECU evaluation on a real vehicle. Because the risks of troubles occurring with a real vehicle test have grown due to the increased volume of communication data among cooperative and integrated ECUs, the needs for reducing these risks have emerged. (Because these troubles often waste a lot of time before being solved, the risk should be avoided as much as possible.) The verification and validation does not only evaluate one ECU on a simulator but also aims at evaluating plural ECUs simultaneously. (Figure 3)

Also some suppliers are going to evaluate ECUs by introducing simulators that simulates a feedback environment of a real vehicle.

The purpose is to maintain and improve the quality of ECUs including both software and hardware.

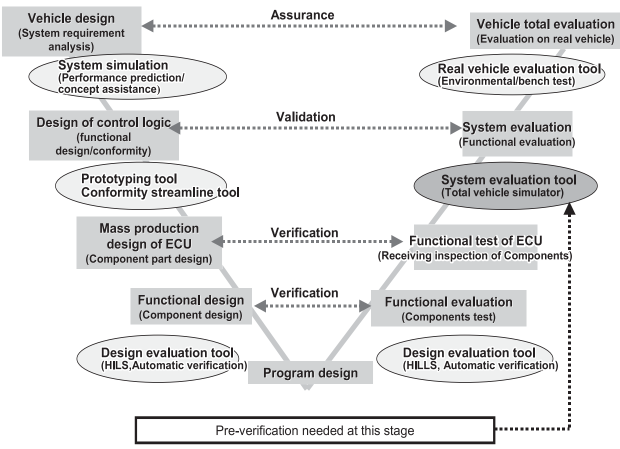

Fig.3 Necessary Phases for Full Vehicle Simulator

3 System configuration of full vehicle simulators

3.1 Issues of full vehicle simulators

The target vehicle for this simulator establishment is hybrid vehicles (Figure 4) that many cooperative and integrated controls are applied to. Evaluation targets of simulators include plural ECUs for "Run", "Stop" and "Turn". However evaluating plural ECUs by a single CRAMAS may fail as simulators, because it needs the real-time processing ability beyond actual ability.

Therefore the following three issues are necessary to be solved.

- **To develop a large scale CRAMAS system for evaluating plural ECUs**
- **Increase of model processing volume involved in advancement of ECUs.**
- **Increase of input and output signal ports involved in higher performance of ECUs**

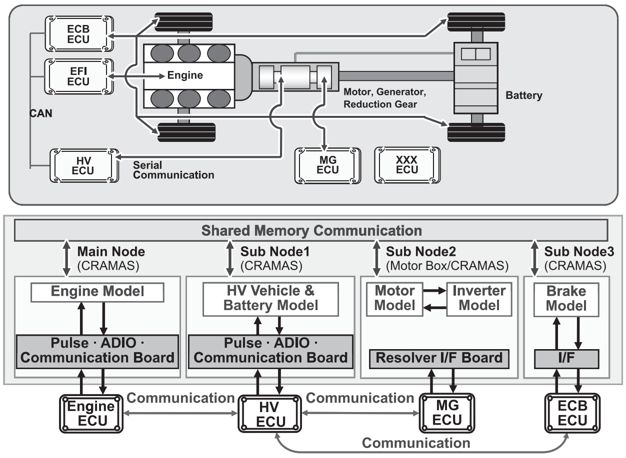

Fig.4 System Configuration for the Target Vehicle

3.1.1 Evaluation simulator targeted plural ECUs

Developing our simulators for evaluating plural ECUs is started in around 1999, and two predecessor systems of the current CRAMAS were used as two node systems (operating two systems in parallel). At that time, this system (Multi-node system for HV) was designed to simulate the "Run" function (drive control and motor ECU) of the hybrid vehicle separately controlled. (Figure 5)

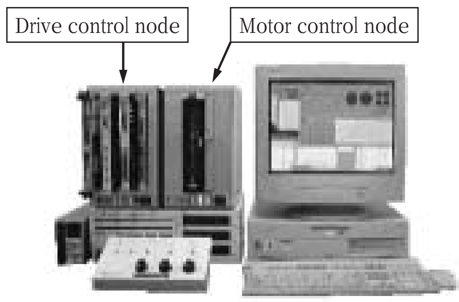

Fig.5 Two (2) node Simulator (Brief overview)

In this system, the model representing vehicle behavior needed at least two parts so as to be simulating both the motor and the engine. However, the motor model was required to have a shorter processing cycle (100μs or less) than that of engine model (1ms) because of the quick behavior of the motor. The real-time processing of a large model was impossible because the processing capability of the CPU at that time was lower than today. Thus, we decided to calculate the motor model with a short processing cycle and the engine model with a long processing cycle using separated CRAMAS. At that time, the number of mutual data communicated between two CRAMAS was only a several and we could adapt the RS232C communication function which did not have a high performance. However, there was an increase in a number of targeted ECUs of a simulator and each ECU had high performance. Therefore it brought the following concerns.

- **Control failure due to the significant increase of model processing volume**
- **Limit of data transmission volume between CRAMAS (between models)**
- **Data transmission delay between CRAMAS (between models)**

We solved these concerns through our know-how and the newly developed board. In particular, we did as followings.

- **Distributing the processing load by operating plural CRAMAS in parallel**
- **Simulating the target controlled system of each ECU (model processing) by using each CRAMAS**
- **Adapting the optical fiber cable for the data communication between CRAMAS**

3.1.2 Response to the increase of model Processing volume

In the above section, we mentioned that it is impossible to simulate the motor model and the engine model in the same processing cycle. Also the number of motors installed in a vehicle has increased and the motor control ECU is more sophisticated. As a result, processing the motor model on the CPU became impossible. So we decided to use our product "motor board" in order to solve it.

Simulation of the motor on CPU increases according to the model processing volume proportionally to the number of motors, that is, the processing speed shall be upgraded accordingly. However, the processing capability is limited, therefore it cannot be upgraded indefinitely. Meanwhile, as one motor board simulates one motor, we can simulate the number of motors needed by increasing the amount of these boards. Using the motor boards distributes the processing loads to each board, reduces the processing load to increase the model contents (processing volume) and makes a highly accurate real vehicle simulation possible. (Figure 6)

Since a motor board simulates a target motor with high capacity FPGA, the motor board can process every 1μs. Motor parameters can be set by users, and the motor board has a mechanism for easily processing and measuring the three-phase current that is required for the full vehicle simulation.

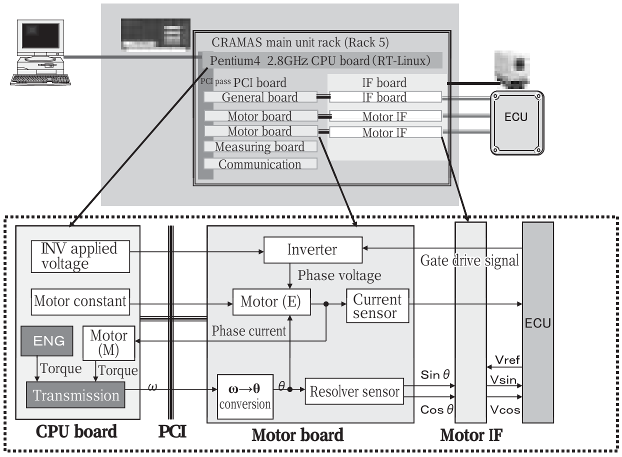

Fig.6 Motor Simulator (Brief overview)

3.1.3 Set-up method of the system

In setting up full vehicle simulators, we aimed to shorten the set-up period of CRAMAS, and to utilize our know-how, the method was applied to minimize things to be newly prepared. That is, we tried to set up a simulator based on CRAMAS/harness/model/ECU used by existing customers (each department) for evaluating single ECU. This method also has the advantage of problems being solved only by consulting with the existing customers (each department). Actually many problems were solved by verbal inquiries to the existing customers (each department). Further employing such method (Figure 7) prevented large problems (miss-wiring, false input/output signal).

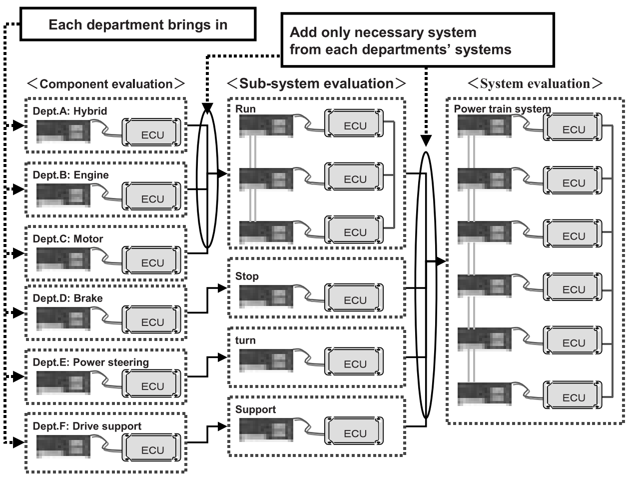

Fig.7 System Building Method

Fig.8 Simulator Consisting of Sub-systems

Fig.9 Simulator Consisting of System

Expanding the system scale step-by-step, that is, building-up the system from Component evaluation (Figure 1) to Sub-system evaluation (Figure 8), to System evaluation (Figure 9) leads to the skill-up of engaged engineers and is utilized as a personnel training tool.

3.2 Issues after system formulated

A new problem arouse through making CRAMAS the multi-node system. The problem is that all CRAMAS can not be controlled by a host PC, because each CRAMAS operates independently. We developed the "center controlled DB system" in order to solve this problem. This system is planned to improve the operation capability by controlling the setting data in each CRAMAS host PC by single database server. Specifically, it is the system operating the host PCs (Slave hosts in Figure 10), which control CRAMAS, by a single PC (Master host in Figure 10) via HUB. Accordingly, single PC (Master host) can control all CRAMAS in the same manner as conventional CRAMAS and various setting data of CRAMAS collectively.

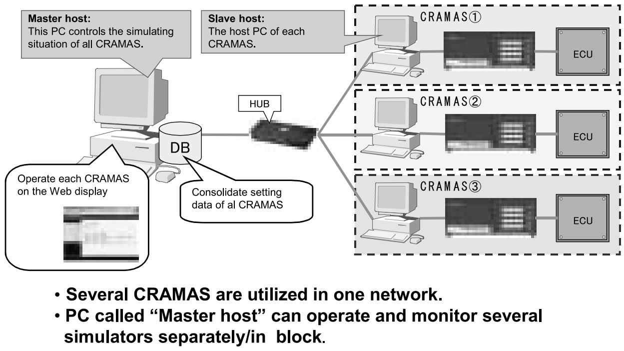

Fig.10 Center controlled DB (Brief overview)

4 Confirmation of consistency with a real vehicle

4.1 Comparison to a real vehicle simulation

The real vehicle simulation using formulated CRAMAS system has been confirmed as equivalent to testing on a real vehicle.

Figure 11 shows the comparison between the real vehicle data and the simulation data. Both data come close to each other and the test by CRAMAS system is proved to be equivalent to a real vehicle.

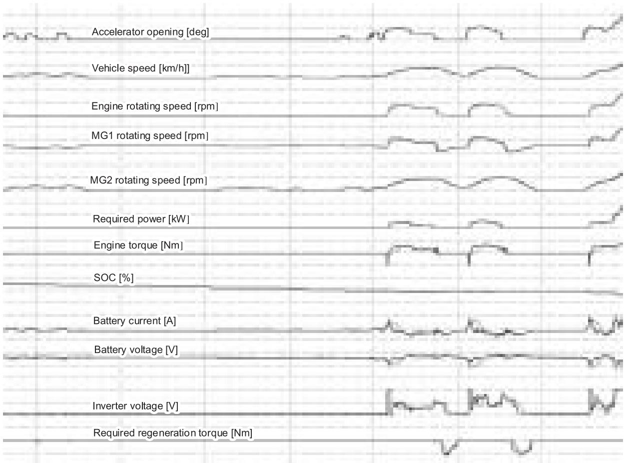

Fig.11 Comparison result between simulation and actual vehicle behavior

Figure 12 shows the simulation data showing the behavior of the ABS hydraulic brake during deceleration from 180km/h to 0km/h by a harsh braking. If the same data is to be calculated from a real vehicle, the data will be measured while hitting the break harshly after accelerating up to 180km/h. A safe test can be conducted with a simulator even if the test involves dangerous risks when carried out by a real driver.

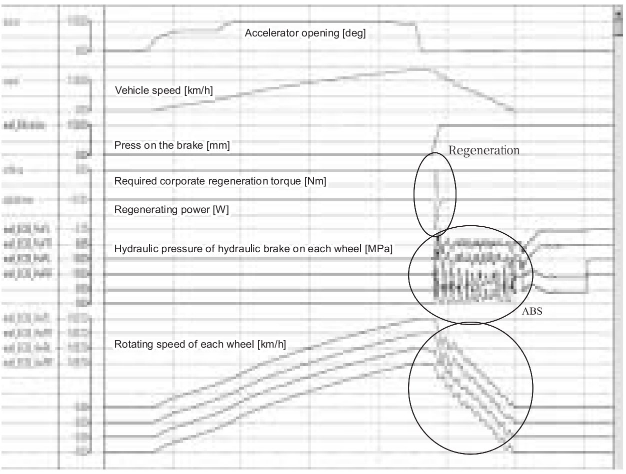

Fig.12 ABS behavior at harsh braking

Figure 13 shows the motor current waveform responding to the gate drive signals from motor control ECU. The simulator can safely simulate the behaviors and measure the three-phase current with dangerous high voltage on a real vehicle and the normalized phase voltage to the motor neutral point which cannot be measured on a real vehicle.

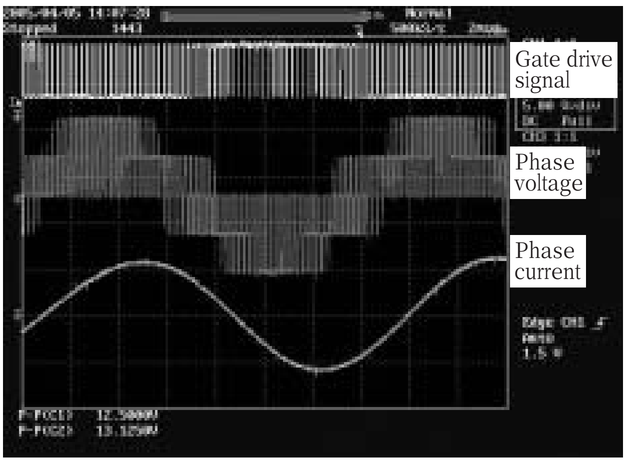

Fig.13 Motor current waveform

The formulated full vehicle simulator is obviously effective in measuring data and confirming the vehicle behavior which it is impossible to test on the real vehicle.

4.2 Application of the automatic inspection tool

In corporation with the full vehicle simulators, the automatic vehicle test development circumstance as shown in Figure 14 has been also developed. The automatic test tool enables us to draw and make the visible test patterns as if we do it on conventional "write graffiti tool". Also we established is the new function to automatically fill in the test result and the test information on the report designated by the customer format s. Using this automatic test tool dramatically improved the efficiency of the evaluation of ECUs.

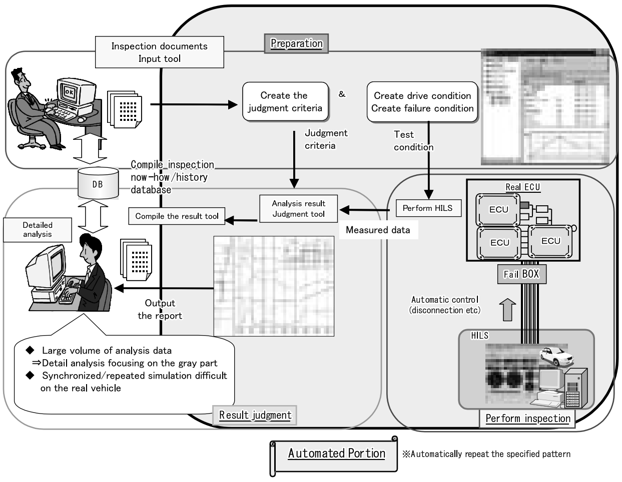

Fig.14 Development environment for automatic test

Furthermore, this automatic test tool has been improved in order to bring the test specifications used in a real vehicle test into CRAMAS. The result of a fail-safe test (detecting disconnection, confirming the correct diagnostic behavior, and validating the control response of sifting to safety side) using this system reaches concordance rate of 98% with a real vehicle. For reference, the 2% of non-match rate is attributed to the test items damaging CRAMAS and the test items with partially different configuration with the real vehicle (such as unable to handle a large current and the GND wiring differs from a real vehicle).

5 *Formulation, operation and maintenance of full vehicle simulators*

The followings are necessary to formulate, operate, and maintain such a large scale of system:

- **Ensure the resource for the simulator formulation**
- **Educate the user's operation capability**
- **Maintenance of the facility**

That is, development engineers for hardware, software, and model as well as managers are necessary just as they are needed in the real vehicle development. Full time organization may be necessary for increased number of these systems. Moreover, the assistance from ECU development engineers for followings is required;

- **Discrimination between the simulator and ECU for problems**
- **Plant modeling**
- **Analysis of the simulated data(comparison to the data on the real vehicle)**

Of course the larger the simulation scale is, the more man-hour/cost for the initial set-up is necessary. Furthermore, as the vehicle model becomes more precise, the CPU for the simulator should have the higher processing capability.

The formulated full vehicle simulator brings questions such as the improvement of user's operation capability, the method of wiring harness, and the installation method of equipment. It is important to plan and develop new products satisfying user expectations for a full vehicle simulator in which it is simpler to set up the system and easier to operate is required.

6 Conclusion

The number of automobile manufactures introducing full vehicle simulators is increasing. The reason is that ECU functions of a vehicle have been drastically expanded by the advancement of control technology and electronics due to the changes in the environmental control and various safety regulations compared to 10 years ago. Another reason is the acceleration of shortening the automobile development period due to the growth and the expectations of automobile industries.

In such circumstances, requirements for large scale simulators will definitely increase. We will contribute to the advancement of vehicle control by catching such change of circumstance, continuously improving and providing the "development support tools" for the automobile industries.

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