

Development of an Engine Performance Data Acquisition System

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ABSTRACT

In response to the trend of complex engine control, we developed a new generation engine data acquisition system equipped with high precision analyzing capabilities. This system enables measurement data processing using the Windows operating system and is able to perform cylinder pressure analysis. Further, the system can be used with engine test cells and electronic control units (ECUs) with various specs. It can also be used for automatic testing.

This system allows for the effective use of existing equipment. It is a simple system using a personal computer to process the acquired data. Also, the system employs a real-time operating system to control timing and thereby enable simultaneous data acquisition and processing.

As a result, we were able to achieve stable data acquisition, improved analysis capabilities, and a reduction in analysis time.

(Windows is the trademark of Microsoft Corporation.)

1. Introduction

There continues to be an increasing demand for a reduction of automobile fuel consumption and emissions in order to address global environmental issues. The computerized engine control unit (ECU) that controls fuel and intake air amount, ignition timing and so on has improved performance and speed⁽¹⁾. More detailed engine data is required to make engine control more precise. Therefore, the development of data acquisition systems with greater accuracy and higher performance is required.

We have developed an engine performance data acquisition system that can be easily operated to instantaneously confirm and analyze measurement results, and that can make comparisons with other data over a network at any time. The system can also acquire data during automatic testing. Use of this data acquisition system makes it possible to make finer ECU settings and reduce testing time.

This paper will present an introductory overview of the engine performance data acquisition system (Engine Analyzing SYstem, i.e., EASY) devices and the results obtained by application of the system.

2. Engine Performance Data Acquisition System (EASY)

In developing this highly accurate, high-performance data acquisition system, we examined the various tools previously used to test engine performance. We ascertained their problem areas and identified the needed improvements.

The major measurement and analysis tools used conventionally in engine performance testing are as follows:

- Engine performance data acquisition devices
Description: Personal computer-based engine performance data acquisition and storage system.
Functions: Acquisition and storage of performance data.
Generation of graphs and diagrams based on engine performance data.
- ECU monitor (Monitor Mark 5, hereafter MM5)
Description: Monitor ECU data during engine operation.
Functions: Monitor ECU data, data communication (serial communication).

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- Combustion analysis system

Description: Cylinder pressure measurement and analyzer developed in-house.

Functions: Acquire cylinder pressure measurements, calculate IMEP, and perform thermal calculations.

These tools are a group of independent measuring instruments. They do not form a system that would enable simple operation for instantaneous confirmation and analysis of measurement results. Moreover, the separate systems use different data formats, some of them being proprietary file formats that cannot be processed on the widely used Windows operating system. Due to these and other problems, the organizing and analyzing of data imposed high man-hour costs.

Therefore, we developed a system that integrated the function of this group of tools in order to resolve those problems.

3. Overview of the EASY System

3.1. The EASY Concept

The development objective was an integrated engine performance data acquisition system that combined the capability to acquire large amounts of engine test information, compare it with other data during measurement, and analyze the data, while also analyzing the combustion process.

In addition, the above capabilities are integrated into an efficient data acquisition system that operates on a personal computer (hereafter PC) platform to regulate the test engine operating conditions based on ECU data, and that also enables testing without an operator.

3.2. System Configuration

The EASY system was built to meet the following basic requirements:

- (1) Use the same software to perform performance data acquisition, ECU data acquisition, cylinder pressure analysis, and automatic testing.
- (2) Put data into a format that can be processed in Windows.
- (3) Design hardware capable of data acquisition at engine speeds up to 8000 rpm.
- (4) Utilize existing devices (engine test cell data acquisition systems, exhaust gas analyzers, etc.) as much as possible.

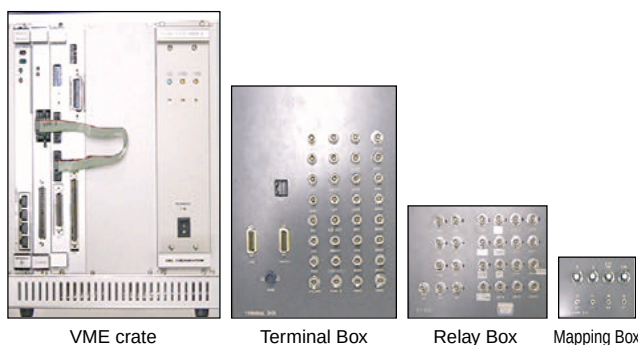


Fig.1 EASY system hardware

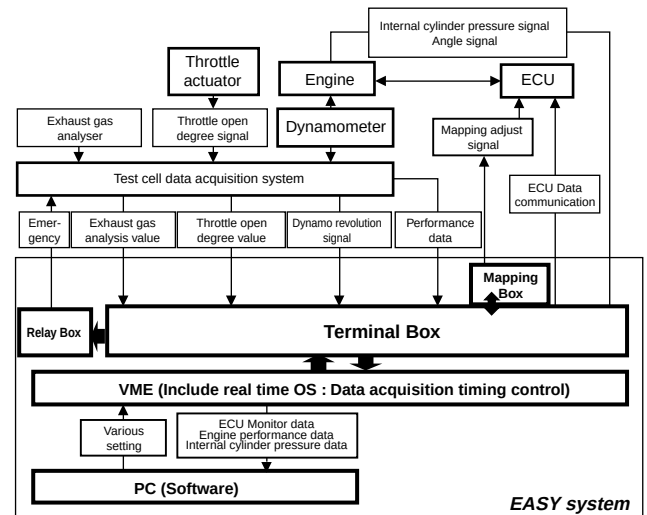


Fig.2 EASY system block diagram

The EASY hardware components are shown in Fig. 1, and the overall system configuration is shown in the block diagram in Fig. 2.

The EASY system adopted the method whereby data acquisition system measurement data (GP-IB communication), cylinder pressure data, and ECU data (Honda original protocol) are input together into the terminal box. There, the data is transferred to a standard bus unit (Versa Module Europe, hereafter VME), which was recommended by Motorola, Inc. The system configuration also includes a relay box and a mapping box. The relay box is linked to the terminal box to provide interlock during automatic testing. The hardware specifications for this configuration are as shown in Table 1.

Next we will give an overview of the various hardware components:

(1) VME Crate

The VME crate contains a CPU board, a high-speed analog-to-digital (A/D) converter board, a GP-IB board, and memory for temporary storage of data. Installation of a real-time operating system allows the VME crate to provide event timing control and communications for the EASY system as a whole. The VME crate is also assigned a portion of the

Table 1 Hardware specifications for the EASY system

High-speed A/D	100kHz/8ch (Simultaneous sampling of each ch)
Low-speed A/D	100Hz/8ch (Simultaneous sampling of each ch)
Memory capacity	4MB (1MB : exclusive for converted A/D data)
ECU monitor communication method	Honda original protocol (50 ~ 375kbps)
GP-IB communication method	Master and slave function (1ch each)
Engine revolution sensor	1pulse/revolution 360pulse/revolution
Relay input/output	Input 8ch/output 16ch
Mapping operation terminal	4ch
Power supply	AC100V

calculations in order to reduce the load on the instrumentation PC⁽²⁾.

The high-speed A/D converter used for acquisition of cylinder pressure signals utilizes operational input to assign a reference potential in order to improve response and cancel out, thereby eliminating the influence of, electrical noise.

The memory is configured for cylinder pressure data acquisition on a maximum of four channels for 400 cycles. (When using eight channels, it is able to operate continuously for 100 cycles.)

(2) Terminal box

The terminal box receives many different kinds of measurement signals, such as engine test cell data acquisition system data, ECU data, and general-purpose analog signals, all together. It integrates these and conducts data interactions with the VME crate.

The terminal box is also connected to a relay box that activates an interlock feature when a problem occurs during engine operation and to a mapping box that performs fine adjustments in operating conditions.

(3) Relay box

The relay box is a terminal box that integrates engine test cell data acquisition system interlock contacts during automatic testing. This relay box is connected to the VME crate by means of the terminal box. When a problem occurs, it activates the data acquisition system interlock contacts to protect both the engine and the device.

(4) Mapping box

When implementing automatic testing, the operating condition set-up file software controls all the operating condition settings. However, the system must switch between manual and automatic modes when automatic testing begins and ends. This mapping box is used to enable appropriate manual control of ignition timing and fuel injection volume at these times in order to allow a smooth transition from manual to automatic and automatic to manual operation.

3.3. Data Acquisition

The EASY system is set up to allow the acquisition of a series of performance data and cylinder pressure data to be handled by a single piece of common software.

On the other hand, it is also possible to acquire data without using the VME crate when cylinder pressure analysis is not being performed. Common software is used regardless of the presence or absence of a VME crate. The processing flow is shown in Fig. 3.

The EASY system allows the effective use of existing engine test equipment by means of selectable set-up software for various types of engine cell data acquisition systems, ECU communication and so on.

(1) Acquisition of performance data and ECU data

The flow of performance data and ECU data acquisition in EASY is shown in Fig. 4. Performance data and ECU data are first combined in the terminal box and then transferred through the VME to the PC, where the processing takes place.

(2) Cylinder pressure analysis

EASY is capable of using the high-speed A/D board incorporated into the VME for cylinder pressure acquisition.

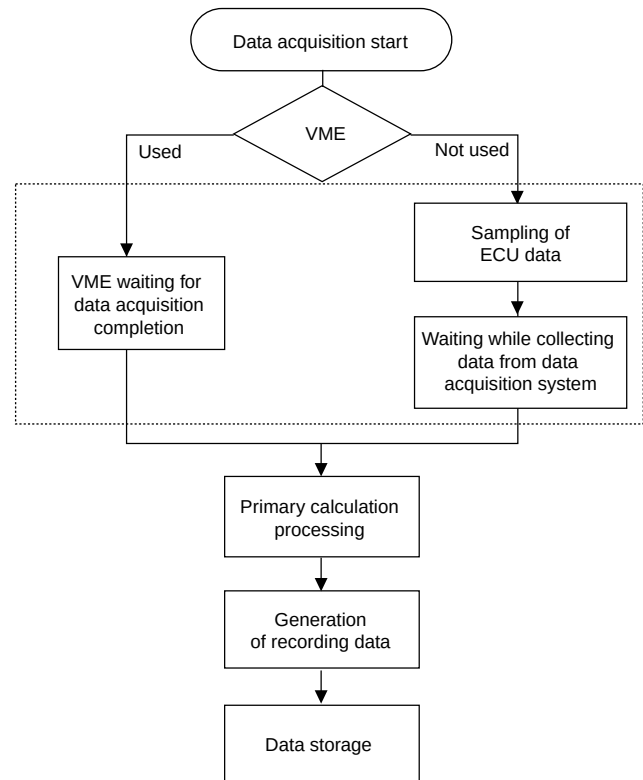


Fig.3 EASY data acquisition flow chart

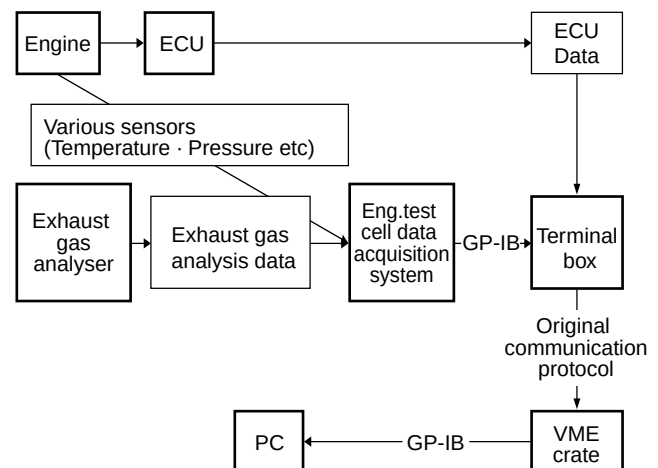


Fig.4 EASY system recording flow chart for engine performance data and ECU data

The data acquisition flow is shown in Fig. 5.

The cylinder pressure data acquisition screen displayed when EASY acquires this data is shown in Fig. 6.

EASY takes into account actual engine development by giving cylinder pressure analysis the following characteristics, which enable the stable measurement of cylinder pressure without variations in the data⁽³⁾⁻⁽⁵⁾:

- Number of acquisition channels: 8 channels maximum
- Continuous acquisition cycles: 400 cycles maximum
- Trigger function using TDC and crank signals
- Selectable cylinder pressure pegging method
- TDC adjustment function (fine adjustment and TDC inversion)
- Stored signal data file name link to performance data

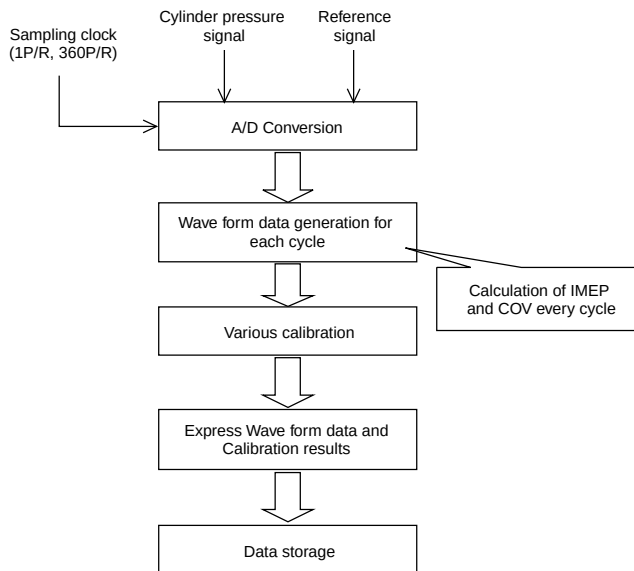


Fig.5 EASY system cylinder pressure data acquisition flow chart

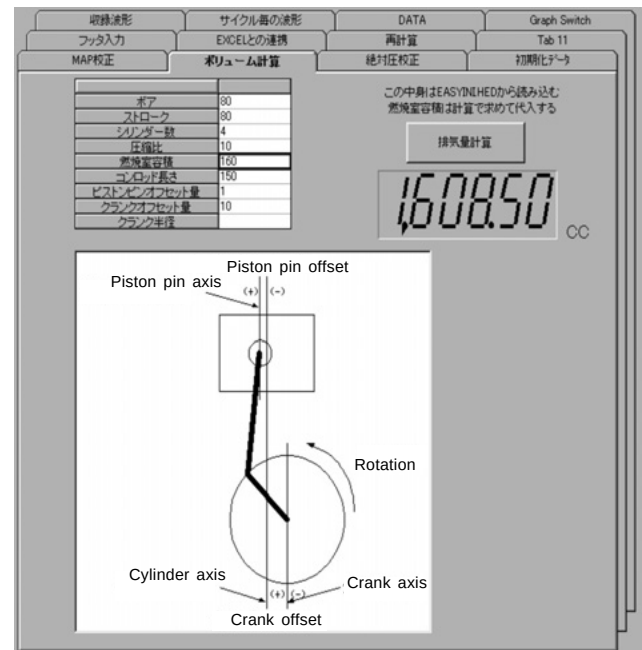


Fig.7 EASY engine specification screen

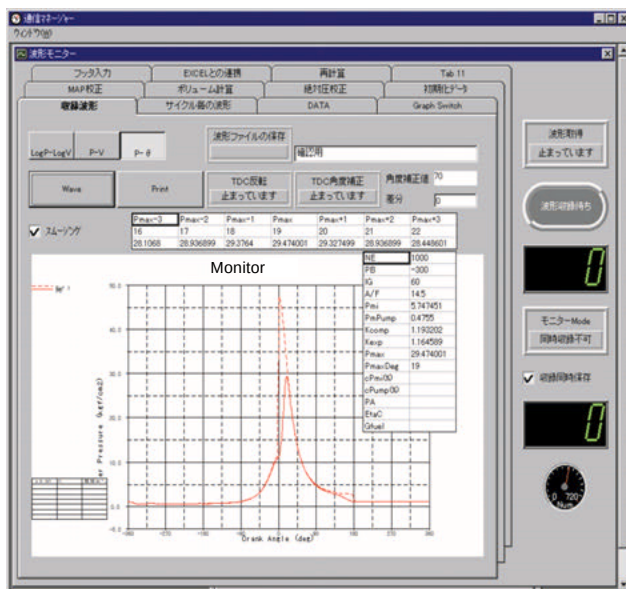


Fig.6 EASY cylinder pressure data screen

- Simplified engine specification set-up screen (positive/negative direction, direction of revolution, input items: see Fig. 7)

3.4. Communications

Apart from communications with engine test cell data acquisition systems, the EASY system also performs a variety of data communications, including ECU communications for the purpose of ECU data acquisition. These are outlined below:

(1) Engine test cell data acquisition system communications

The transfer of various types of measurement data from the engine test cell data acquisition system devices to the PC occurs via GP-IB communications. As shown in Fig. 8, the use of the GP-IB communications protocol enables

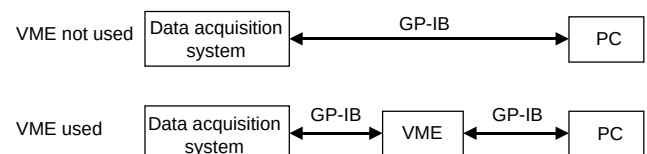


Fig.8 EASY communication between EASY and engine test cell data acquisition system

operation by a common system without any change to the PC communications interface regardless of the presence or absence of a VME⁽⁶⁾.

Reflecting the measurement needs of present-day circumstances, there are many engine test cell data acquisition systems of different types from different manufacturers. EASY is designed as a universal system that can support all of these systems by means of set-up files that enable set-up of GP-IB data definition and other configuration information in an integrated operation.

(2) ECU communications

The ECUs from different manufacturers utilize a variety of protocols for data communications. Therefore, EASY was made universally applicable by giving it the capability to select the communications type, baud rate, and endian status (word data order) with the software.

In addition, EASY uses a method that can comply with either of the two different file formats used for the labels and ECU address lists employed in ECU communications.

On the other hand, as noted above, there are also occasions when data acquisition is conducted without using a VME crate because of the nature of the tests. Therefore, the system also allows ECU communications using RS-232C serial communications by means of an MM5, as shown in Fig. 9.

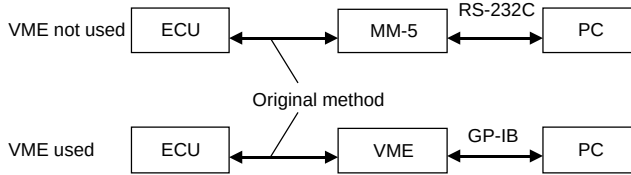


Fig.9 EASY communication between EASY and ECU

3.5. Acquired Data Files

EASY can acquire and analyze the following kinds of data:

- Performance data (rpm, brake horsepower, fuel flow, etc.)
- ECU data
- Cylinder pressure data (IMEP, maximum pressure values, etc.)

In order to reduce the man-hours required for data analysis, the acquired data are stored in file formats that can be processed by commercially available Windows applications. This has a particularly large impact on engine combustion analysis, where large volumes of data are processed.

Acquired data are stored in files with a proprietary format. EASY takes the unified approach of writing ECU data and cylinder pressure calculation results from these stored files into the performance data files together. With regard to cylinder pressure data, we also took into consideration the fact that secondary analysis is performed on the actual acquired waveforms and designed EASY to save additional copies of the waveforms named with the performance data file names plus identification numbers. This makes it possible to easily retrieve the relevant cylinder pressure for the operating conditions when the performance data is searched by operating condition.

4. Automatic Testing

EASY also has an automatic testing function. By setting the engine operating conditions (rpm, intake boost pressure, ignition timing, etc.), the engine can be made to operate

automatically under the target operating conditions while data is being acquired.

This function makes it possible to set the operating condition convergence time, automatically calibrate the exhaust gas analyzer, and set the interlock as required during the test. It can also automatically measure for performance at wide-open throttle, volumetric efficiency characteristics investigations and other engine performance tests.

Under present conditions, however, there is some difficulty in setting the operating conditions and with stability in the control convergence time. These issues will be addressed in the future.

The operating condition items that are set for the EASY automatic testing function are shown in Table 2.

5. Effects of EASY System Introduction

5.1. Improved Data Analyzing Power

The latest engine development efforts have increased the incidences that require cylinder pressure analysis for lean burn limits, combustion speed, and so on. However, the commercially available combustion analysis tools are expensive and they are difficult to use at many test cells at the same time.

The addition of combustion analysis to the EASY system has made it possible to easily implement combustion analysis on many engine test cells at the same time. This has resulted in improved data analysis accuracy.

Development of ordinary mass-production engines also involves combustion analysis. EASY allows on-the-spot comparison with past data and the use of measurement results to substantiate the adjustment of settings, so that combustion analysis can now be used effectively as a development tool for mass-production engines.

5.2. Reduction of Man-hours Required for Data Organization and Analysis

EASY uses files in formats that can be processed in Windows. As a result, it is possible to reduce the time required for data organization and analysis, as shown in Fig. 10.

The use of a company LAN also makes it possible to improve data communications, as shown in Fig. 11.

Table 2 Items of condition for EASY automatic operating functions

Automatic operating functions	Item of condition
Ignition switch	ON/OFF
Exhaust gas analyser switch	ON/OFF
Input/output switch	ON/OFF
Main circuit switch	ON/OFF
Blower switch	ON/OFF
Relay connector	ON/OFF
Engine revolution	Target value
Throttle	Target value
Injected fuel amount	Value of CO or air-fuel ratio
Ignition timing	Control panel or ECU
Quantity of EGR	ECU
Data recording	ON/OFF
Timeout period	Time (s)
Waiting period	Time (s)
Holding period	Time (s)

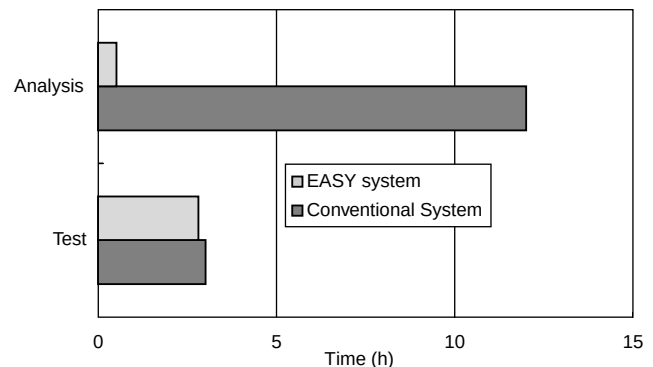


Fig.10 Comparison of time required for cylinder pressure data analysis performed with conventional and EASY systems

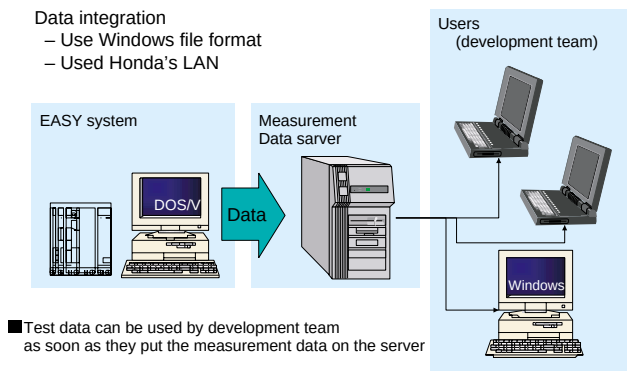


Fig.11 Data communication using Honda's LAN

6. Summary

This EASY engine data acquisition system development project provides universal data communication and interaction among various devices. This makes it possible to utilize a variety of existing equipment, while configuring the system for the PC platform made it relatively painless to install multiple units. The utilization of a real-time operating system to control EASY as a whole made it possible to exercise appropriate control of data acquisition timing and other sequences of actions.

We provided EASY with features such as these in order to provide stable data acquisition, improve the accuracy of data analysis, and enhance the reliability of the acquired data. The following effects were obtained in actual engine development:

(1) Improved accuracy of data analysis

Facilitating combustion analysis also increased the frequency of combustion analysis testing, which brought about advances in the applied analysis of phenomena. This enabled the use of combustion analysis results to substantiate various specification settings and, thus, the use of the system as a development tool.

(2) Improved reliability of acquired data

Tests can now be performed under stable conditions regardless of who is performing the tests. This has eliminated the variations caused when set-up is performed by different individuals, and improved the reliability of acquired data.

(3) Reduced time for testing and data processing

The formats for acquired data have been unified to enable processing on Windows, which reduces the time required for data analysis. Furthermore, it is now possible to perform comparative evaluation of data instantaneously, which means that it is also possible to reduce the time required for the testing itself.

(4) Automatic testing

EASY was given additional functions for performing measurements such as performance tests at wide-open throttle and volumetric efficiency characteristics investigations with the engine operating automatically. This was done to increase the time available for analysis and investigation in order to increase development efficiency.

7. Conclusion

The project succeeded in developing an engine data acquisition system with highly accurate data analysis and reliable acquired data.

Since the quantity of ECU data is likely to increase in the future, it will be necessary to reevaluate the system, especially in terms of enhancing those functions involved in automatic testing, in order to reduce the man-hours required to handle ECU data settings.

As matters now stand with regard to cylinder pressure analysis, the major focus is on engine test cell analysis. However, it is likely that analysis performed on actual vehicles, transient analysis, and simultaneous multiple-cylinder analysis will become increasingly important. Consequently, systems that are capable of data acquisition under those conditions will become necessary.

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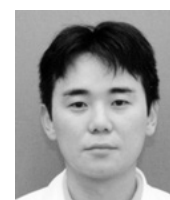
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