

Investigation of Combustion Diagnosis System Applied for the Development of General Purpose Utility Engines

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ABSTRACT

The chief goal of engineers studying internal combustion engines is to improve energy efficiency in the face of the increasingly severe global warming and energy issues. Hence, there have been numerous studies focusing on the combustion reactions in order to develop clean and reliable combustion that is capable of operating using less fuel. And to improve the comprehension of engine performance and its combustion reactions, development of comprehensive measurement technique for engine performance, in-cylinder visualization technique, and numerical simulations, is essential and strongly demanded. There have hitherto been numerous studies about combustion diagnostics and analysis, including high-efficiency measurement techniques using response surface method the air-fuel mixture distribution and flame propagation measurement with optical visualization techniques, and numerical calculations of combustion reaction with elementary reactions. However, there is room for further work into these technologies during the actual engine development process. Some of the more prominent issues include the need for installing massive equipment, deviation from actual combustion conditions due to the use of visualization windows, and the need for special experiments to evaluate the numerical calculations.

Thus, the goal of this research is to build the efficient and reliable measurements system that can be applied for actual development process with capability of diagnosing engine performance and combustion from a variety of different perspectives. This diagnostic system has been designed a best mix of the advantages of actual engine measurements, combustion diagnostic techniques and numerical simulation. In this system, the automatic measuring with response surface method and optimization algorithm provides a comprehensive overview of engine performance. And the direct measurement of flame propagation and numerical simulation of air-fuel distribution and flame propagation contribute to analyze combustion reaction. And in order to verify this diagnostic system, it has been applied for general purpose utility engines with two different combustion chamber geometries.

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INTRODUCTION

In recent years, the global-scale problems represented by global warming and exhaustion of fossil fuels are becoming a serious matter through the emerging nations' remarkable economic growth. Therefore, internal-combustion engines, which take the central role as a source of mechanical and electrical power, are strongly desired the further progress in their efficiency. In the same way, reduction of the engines' vibration and noise and making exhaust gas clean are still important subjects towards the improvement of users' working environment. And general purpose utility engines, which are intensely focused on this research, are used as the power supply for operating machines. They are carried or held, and operated near workers, thus they are required to

have high output power, but also to be light and compact. In order to reduce workers' physical stress, a small amount of vibration and noise is desired and the residual gas needs to be as clean as possible.

In order to satisfy these demands, up to the present, various studies of combustion mechanisms have been conducted. At the same time, various types of analysis techniques have been researched to figure out the complicated physical phenomenon. For instance, a high-speed measuring equipment system to capture the combustion reaction, a visualization technique to directly observe the in-cylinder flow field ¹, an air-fuel mixture distribution and flame propagation, and a thermal fluid numerical calculation to predict the combustion reaction and abnormal combustion

such as knocking. Conversely, combustion visualization, flame propagation measurement and elementary reaction of numerical calculations are developed separately for each purpose. Thus, a direct comparison of measured data was difficult due to imprecise matches. In the case of the visualization of combustion, the visualization windows are installed into the engine sleeve or into the top surface of the piston. These change the heat transfer and make the combustion differ from the actual phenomenon. Also various physics numerical models are validated the accuracy under special conditions and it is difficult to specify the range of application. As described above, there is room to improvements for combustion diagnosis to integrate between measurement and calculation at actual combustion phenomenon.

For several years, the model-based development system has been rapidly adapted for engine development due to the complexity of influential factors of engine controls.^{2,3} And the response surface method and the multi-objective optimization technique is being introduced into the control system for engine dynamometer. This model-base analysis system is expected to take one of the central roles in balancing the trade-off parameters at higher level in order to satisfy the further requirements for engine performance. However, in the case of applying the system to the development of general purpose utility engines, there are several important subjects. The reasons are general purpose utility engines are installed as a power unit for wide variety of applications. Therefore, engines have to be developed for a wide range of displacement and different power takeoff types. In addition, regulations differ from region to region, so each design requires some adjustment to conform to each country or region. That means that the system has connectivity for various sizes of engine dynamometers and extensibility to introduce new features in cases where applying model-base analysis system for the development of general purpose utility engines. In order to solve these subjects, interfaces for the engine dynamometer and scalable system architecture must be designed.

Therefore, this study aimed to build the integrative combustion diagnosis system, which solves these issues of applying a model-base analysis system for the development of general purpose utility engines. In order to be an integrative combustion diagnosis system, optical measurements and numerical analysis are applied under the same test condition. And for applying the development of general purpose utility engines, the system is required connectivity for various sizes of engine dynamometer and extensibility to introduce new features. In addition, in order to validate this, general purpose utility engines with two different types of combustion chambers have been tested with this system. The validation is studied to see other results which are unobtainable with stand-alone measurement.

COMBUSTION DIAGNOSIS SYSTEM

This combustion diagnosis system must solve three issues in the development of general purpose utility engines. The first issue is the difficulty of detail analysis under the actual combustion condition. The second issue is the system requirement of connectivity for the various sizes of engine dynamometer, and the third issue is the extensibility to introduce new features.

In order to solve the first issue, the integrated combustion diagnosis system was designed. [Figure 1](#) indicates the concept of the system in this study. This system consists of three sub-systems: an overhead engine performance analysis system, a combustion characteristic analysis system and a combustion factor analysis system. Through use of these three subsystems, combustion diagnosis is executed in three steps. First, the overview characteristic of engine performance is measured. At this stage, the objective function of the test engine performance is shown as the response surface of control factors. The degree of contribution of the control factors for the objective functions is figured out by the analysis of correlative evaluation of factors. In the next diagnosis step, the combustion characteristic is measured under certain conditions specified in the first step. The combustion characteristic is analyzed on the basis of the initial flame growth and flame propagation. In the final step, the cause investigation of combustion characteristic is carried out with numerical calculation. The flame propagation is calculated under the measured boundary conditions, which are produced from the measured pressure in the intake pipe and exhaust pipe. In application, the measured data remains consistent with actual engine operation. The detail analysis under the actual combustion condition is attained with a combination of above diagnoses.

The second requirement is the connectivity for various sizes of engine dynamometer. In an effort to solve this issue, this combustion diagnosis system is designed as an independent system from the engine dynamometer controller. And its interface is simplified between the diagnosis system and engine dynamometer, and the command signal is minimized, which includes number of rotations, torque and emergency stop signal. The external view of the hardware is illustrated in [Figure 2](#).

The final requirement for the system of the extensibility is the system be designed as platform and module architecture. The real-time automatic measurement system works as platform system. And the modular components have respective functions, which are mainly engine cycle calculation, response surface method and optimization, and combustion characteristic measurement. Through use of these platform structures and modules, it is possible to add a new feature to this combustion diagnosis system.

Hereinafter, real-time automatic measurement platform, Engine Cycle Calculation module, response surface method and optimization modules, combustion characteristic

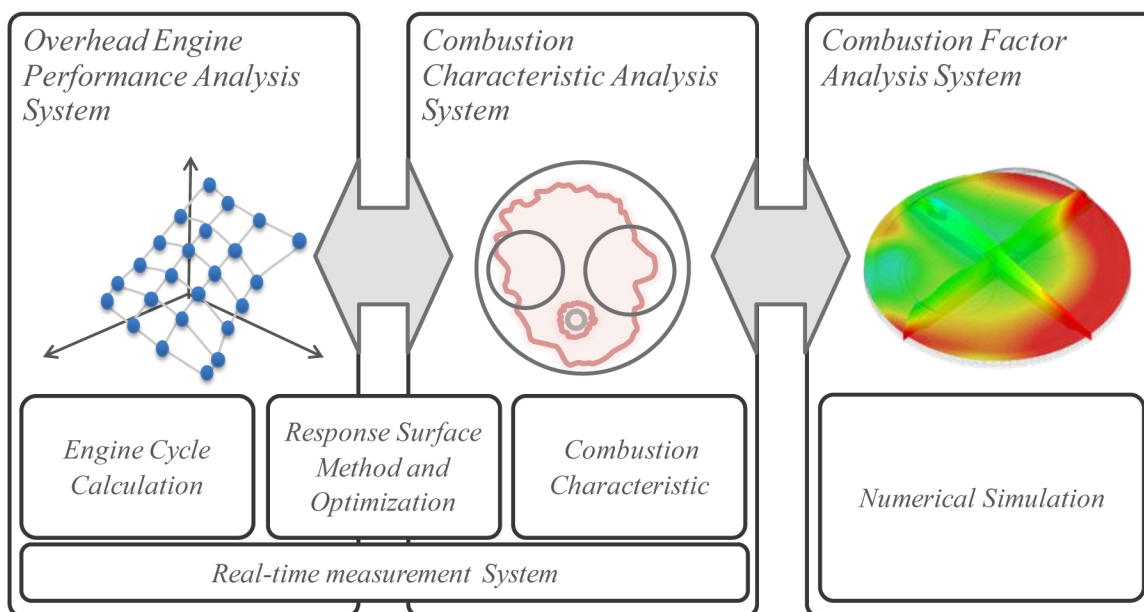


Figure 1. The System Concept of Combustion Diagnosis System

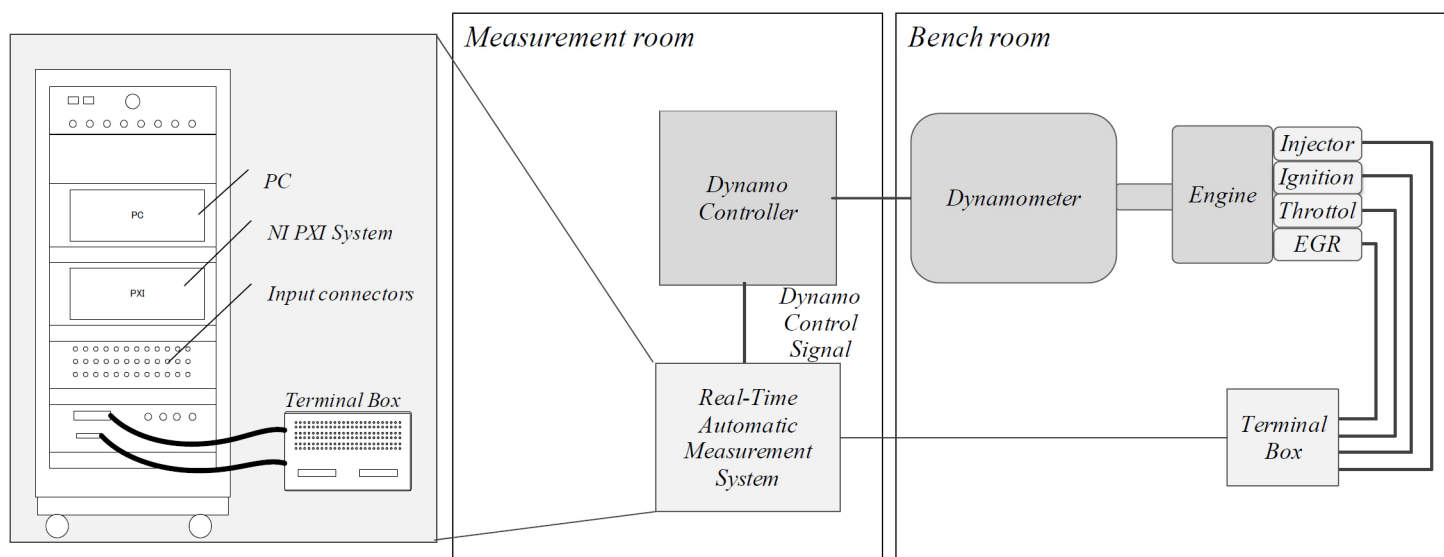


Figure 2. External View of Real-Time Automatic Measurement System

measurement module and numerical calculation are described in more detail.

2-1. Real-Time Automatic Measurement System

The real-time automatic measurement system is the platform system of this combustion diagnosis system. The hardware of this system consists of the PXI platform system and data acquisition component, hereinafter referred to as DAC, produced by National Instruments Corporation. The sampling frequency of DAC is varied according to the measured data, and the modules are composed of three

different types of PXI components. Hardware specifications of real-time measurement system are indicated in Table 1. The DAC of high-speed sampling is applied for crank angle-series measurement such as in-cylinder pressure, pressure at intake and exhaust port. The capability of the DAC is the maximum of 40MHz, and data is monitored by 0.1 degree of crank angle in order to capture the knocking signal. In contrast, low-speed sampling DAC is used for the slowly-varying parameters such as temperature or engine rotational speed, and its sampling frequency is 75Hz. The third components control the injection and ignition timing, and the frequency is 1MHz of simultaneous sampling. The software