4. Task 4 Development of Power Generation Technology

4.1 R & D Targets

4.1.1 Development Targets for WE-NET Phase II (FY 1999 – FY 2003)

(1) Development of a single cylinder 100 kW class hydrogen combustion diesel engine for the purpose of developing an open-cycle hydrogen combustion diesel engine (600 kW class) with a thermal efficiency of approximately 40% after Phase II of the WE-NET Project.

(2) Implementation of the performance test of the developed single cylinder engine to identify R & D targets for the practical application of such an open-cycle hydrogen combustion diesel engine.

4.1.2 Targets for FY 2001

(1) In relation to the element technologies for an open-cycle hydrogen combustion diesel engine system, the function and capability of a developed hydrogen injection unit is confirmed through testing; as for the engine system the building of a single cylinder test diesel engine as well as testing facilities (a hydrogen diesel engine laboratory building, a hydrogen compressor and a gas supply unit) for it is completed.

(2) Numerical analysis of the phenomena in the hydrogen combustion diesel engine is made, so that the results will be reflected in the process of engine development.

4.2 Results on Accomplishment in FY 2001

4.2.1 Development of Element Technologies

(1)Development of Hydrogen Injection Unit

A test was conducted to confirm the proper functioning of the electronically-controlled and hydraulically-actuated hydrogen injection unit for the experimental 100 kW class single cylinder diesel engine and the proper operation of the injection valve, solenoid controller and hydraulic unit was confirmed. The injection duration at the rated power condition was found to be approximately 40° by crank angle compared to the target of 25° crank angle.

4.2.2 Investigation of the Single Cylinder Test Engine System

(1) Study on Measures to Improve Thermal Efficiency

The thermal efficiency of two types of diesel engines fueled with hydrogen and diesel fuel was calculated for comparison from the P-V diagram for the diesel cycle. The comparison showed that at the same compression ratio, the indicated thermal efficiency of the hydrogen combustion engine is lower than that of a corresponding diesel engine because of the increased quantity of water vapor generated by combustion but that it is almost the same as that of a corresponding diesel engine when a lower air supply pressure and a higher compression ratio are employed for the hydrogen combustion engine exploiting the fact that the air volume per quantity of heat due to combustion is less.

Investigation of the jet using the spray momentum theory concluded that the hydrogen jet has twice the excess air ratio of that of diesel fuel. This finding suggests that the thermal efficiency of the hydrogen combustion engine is improved because of its shorter heat release period than that of an engine using diesel fuel.

As a result of engine performance simulation calculation, if the present heat release period of some 100° crank angle is shortened to 80° by means of fast combustion, the development target for the hydrogen combustion engine, i.e. 2% higher than the thermal efficiency level of a corresponding engine using diesel fuel, is expected to be achieved.

(2) Study of Ignition

The possibility of the self-ignition of a hydrogen combustion engine with a high compression ratio was investigated in view of the compression temperature of the working gas and the results of the fundamental test on self-ignition conducted in FY 1998. It was found that the self-ignition of hydrogen is possible at normal air supply temperatures but that an ignition system is necessary at the time of starting when the temperature of supply air is not enhanced by compression in the compressor of the exhaust turbocharger.

(3) Study of NOx Reduction Measures

According to a report by MAN B&W for a high pressure injection-type hydrogen combustion engine, the NOx emission level is as high as 10g/kWh at an early injection timing. Based on this estimation the NOx emission needs to be reduced to 1/30 to meet the strictest emission standard of 0.35g/kWh for gas engines regulated by municipal authorities.

It was also found that in the case of hydrogen being supplied in liquid form, the air charge cooling obtained by taking advantage of the cold heat from the liquid hydrogen is effective to reduce NOx emission.

4.2.3 Construction of Single Cylinder Test Engine System

(1) Construction of Test Engine

A single cylinder test engine for an open-cycle hydrogen combustion engine was constructed. A conventional-type single cylinder diesel engine originally designed for diesel fuel was built and its fuel injection system was replaced by a hydrogen injection unit. Fig. 4.2.3-1 is a photograph of this engine.

Fig. 4.2.3-1 Assembly of Single Cylinder Test Model

(2) Construction of Test Facilities

A laboratory building for the testing of the hydrogen combustion engine was constructed and a gas supply unit and a hydrogen compressor were installed in the laboratory. Fig.4.2.3-2 presents the external view of the laboratory building. Figs.4.2.3-3 and4.2.3-4 are photographs showing the installation of the hydrogen tank and the hydrogen compressor respectively.

(3) Installation of Instruments and Electric Dynamometer

Instruments to measure and record the test data of the single cylinder hydrogen combustion engine were installed inside the operation control room.

Fig. 4.2.3-2 External View of Laboratory Building

Fig.4.2.3- 3　Hydrogen Tank

Fig.4.2.3-4　Hydrogen Compressor

4.2.4 Numerical Analysis

(1) Investigation of Self-Ignition of Open-cycle Hydrogen Combustion Diesel Engine

In order to study the conditions for self-ignition of hydrogen under the air open cycle, combustion analysis of hydrogen jets was conducted where the ambient gas was changed from argon to air and the compression ratio was increased to increase the compressed air temperature in the cylinder. The calculation revealed that self-ignition occurs when the air temperature is 1,000 K or higher at the time of hydrogen injection but that it does not occur if the temperature is below 900 K.

(2) Verification of Hydrogen Combustion Model

In order to conduct the numerical simulation of the combustion process of the hydrogen jet, a combustion analysis model was conducted, and the calculated results were compared with the laboratory test results to verify the model. For this analysis, an analysis model was constructed that combines the piston (a miniature model of one-quarter sector form of a real piston) and an injector with two nozzle holes used in a combustion test using a rapid compression/expansion machine in FY 2000. The combustion of hydrogen jet was simulated using the model combined with a chemical kinetic model. As the simulated results of the cylinder pressure showed good agreement with the experimental results, it was concluded that the analysis of hydrogen jet combustion for actual engines is feasible.

4.3 R & D Themes in the Future

4.3.1 Development of Element Technologies for Hydrogen Injection Unit

Following the simulation exercise using actual data to examine possible measures to shorten the injection period, reduction of the mass of the moving parts (an actuating piston and a needle valve), strengthening of the spring force and matching of the orifices at the inlet and outlet of the working fluid will be attempted.

4.3.2 Development of Single Cylinder Test Engine System

(1) Development and Testing of Ignition System

The self-ignition characteristics of a hydrogen combustion engine with a higher compression ratio than that of a conventional diesel engine will be evaluated using a single cylinder test engine to clarify the air supply conditions and the ranges of the load and speed requiring forced ignition. Following clarification of these issues, the type of ignition unit and its installation location will be selected. The important points to be considered for such selection are that ignition energy can be supplied to the location where combustible mixed gas exists and at the right timing and that the ignition system has sufficient durability.

(2) Basic Performance Test

Basic performance data on the thermal efficiency, exhaust gas emission and temperatures on the combustion chamber will be obtained through the testing of the single cylinder test engine of which the specifications do not incorporate measures to improve the thermal efficiency and to reduce the NOx emission of a hydrogen combustion engine.

(3) Thermal Efficiency Improvement Test

The thermal efficiency improvement effect due to a lower air supply pressure and a higher compression ratio for a hydrogen combustion engine will be evaluated. In addition, the effect of shortening of heat release duration on the improvement of thermal efficiency will be evaluated by shortening of the fuel injection period and mixing enhancement with an optimized air swirl in the combustion chamber.

(4) NOx Reduction Test

The effects of measures relevant to combustion, including exhaust gas recirculation, will be evaluated. The feasibility of NOx reduction by way of the combination of the above measures and the application of an after treatment system using a selective catalytic converter.