Blowdown Combustion Test Facility Supporting Decarbonization of Gas Turbines

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As part of a NEDO project, we developed a combustion test facility employing a blowdown method for screening tests of cluster-type combustors that can be used with a wide range of hydrogen concentrations. Through trial operation, it was confirmed that the test facility can increase the load up to the rated conditions of the actual combustor and reproduce and evaluate the NOx and combustion oscillation trends of actual combustors.

1. Introduction

As decarbonization progresses, reducing CO_2 emissions in gas turbines (hereinafter referred to as GTs) has become essential. As such, the technological development of a low-carbon power generation system combining integrated coal gasification fuel cell combined cycle (IGFC) power generation and CO_2 capture, utilization, and storage (CCUS) technology is being carried out as one of the NEDO projects [(1)]. In this system, the fuel properties change to cope with rapid load fluctuations, and the hydrogen concentration changes significantly. In response, Mitsubishi Heavy Industries, Ltd. is developing a cluster-type combustor that can be used with a wide range of hydrogen concentrations (**Figure 1**). To accelerate the development of combustors, we have recently developed combustor screening and verification equipment. This equipment is characterized by the ability to set any hydrogen concentration and reproduce the multi-combustor coupled combustion oscillation that occurs in an actual combustor. This report summarizes the blowdown combustion test facility of this equipment.

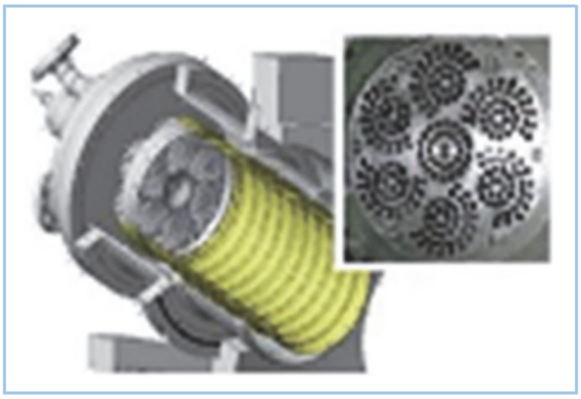

Figure 1 Cluster-type combustor

2. Configuration of blowdown combustion test facility

A combustion phenomenon is highly pressure-dependent and needs to be tested under the same pressure as the actual GT. Major test methods employed in high-pressure combustion test facilities use compressors to supply high-pressure air, and to enable air supply to a combustor of large GTs, a large-capacity compressor driven by a GT is used [(2)].

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This has the advantage that the testing time can be longer, allowing data acquisition for a large number of test points, but it also has the problem of high testing cost [1]. In contrast, a blowdown combustion test facility uses air from an air reservoir stored in advance, so a small compressor can be used, and the construction and testing costs are relatively low [3]. Although the testing time in a blowdown test facility is limited, data acquisition at multiple points in a short period of time has been possible using a technology we have newly developed. Therefore, the test facility employed the blowdown method for supplying air.

(1) Systems of blowdown test facility

Figure 2 shows a system schematic of the blowdown test facility. This is the largest GT combustor test facility in Japan in terms of test pressure and flow rate to enable verification under conditions for large GTs. For combustion air, approximately 19 MPa of air stored in the air tank over a period of several days is used. The air is depressurized through a hydraulic flow control valve, heated to the compressor outlet temperature of the actual GT by heat-exchanging using a pebble heater-type air heating device, and then supplied to the test section. To ensure sufficient heat capacity to heat the air flow of the large GT combustor, the air heater has a diameter of approximately three meters and a height of six meters, and contains 50 tons of ceramic balls inside.

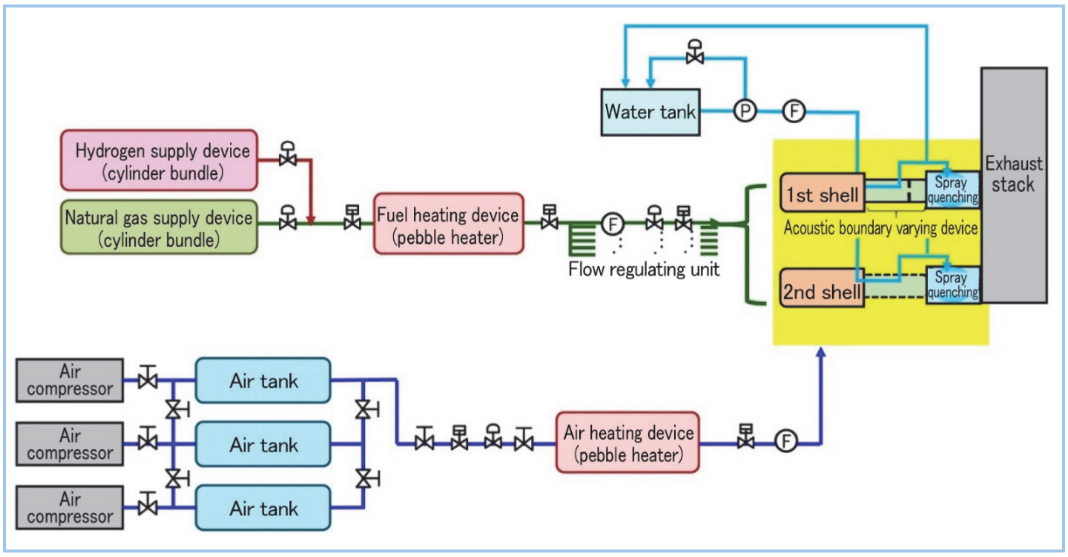

Figure 2 System schematic of blowdown combustor test facility

Fuel is supplied from a cylinder bundle installed in the fuel yard. Two kinds of gas, natural gas and hydrogen, are used in the cylinder bundle, and the hydrogen concentration can be set to an arbitrary value by controlling the mixing ratio with a flow control valve. The fuel is also heated by using a pebble heater-type fuel heating device, allowing the test to be conducted at fuel temperatures that simulate those of the actual GT. The nozzle of the combustor is divided into multiple blocks, and the fuel staging for stable combustion is carried out by controlling the flow rate ratio between the blocks [4]. Therefore, the fuel after heating is branched into each fuel system by the flow control unit on the machine side, and the fuel staging can be simulated by the precise control by the flow control valve.

A combustor to be verified is placed inside the shell, and the aforementioned air and fuel are supplied to it. The blowdown combustion test facility developed this time has two test sections, the first shell and the second shell. By switching these test sections that installed test targets in advance using the piping, the test targets can be switched quickly. This is designed to speed up the development process. High-temperature exhaust gas after combustion is sampled and measured by a probe, then passes through an acoustic boundary adjusting device (described below), and is released from the exhaust stack after cooling with spray water. The area through which high-temperature combustion gas passes has a double-walled water-cooled structure to reduce the temperature of the equipment. Part of the water used to cool the equipment is reused as spray water for cooling of exhaust gas, thereby reducing the discharge volume of the cooling water pump.

The test facility is controlled by DIASYS Netmation®, which is also used to control actual GTs. By inputting a series of sequences in advance, from raising the load, acquiring data under the rated condition, to shutting down, the test facility is operated automatically. This allows the person in charge of the test to concentrate on acquiring measurement data and enables a small number of staff to safely conduct combustion tests of a GT combustor under actual GT conditions.

(2) Measurement technology

Blowdown combustion testing measures combustion oscillation and emissions of CO, NOx, and other gases. Combustion oscillation is measured by pressure sensors attached to the wall of the combustor as in actual GT [5]. NOx and other emissions are measured at 46 sampling points from 6 probes (7 points per probe) placed at the combustor outlet and 4 probes placed on the wall of the measurement duct. The 46 sampling gas flow rates are set by the flow regulating valves of the sampling switcher. Thus, the area weighted average value can be continuously measured by collectively measuring the suction volume according to the area in charge of each measuring point. The gas at each measurement point can be branched apart and stored in 46 sampling bottles at any time during testing, and the exhaust gas concentration distribution at the combustor outlet can be evaluated in detail by conducting a point-by-point gas analysis after the test. **Figure 3** shows a schematic diagram of the measurement system. The sampling switcher used was developed for blowdown combustion test facilities. A comprehensive exhaust gas analyzer was used for detection.

To evaluate flames, light emitted from the flame during combustion is measured by a highly sensitive ultraviolet light detection device using a photomultiplier tube (PMT) (**Figure 4**). This measurement method enables not only fast detection of ignition and misfires, but also evaluation of heat release rate fluctuations.

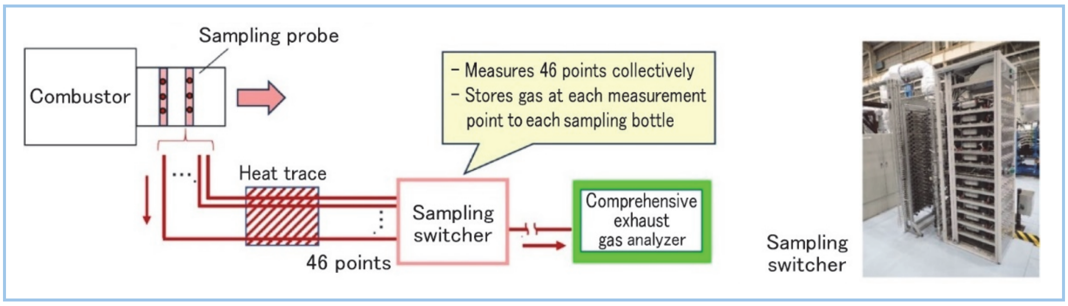

Figure 3 Exhaust gas measurement system

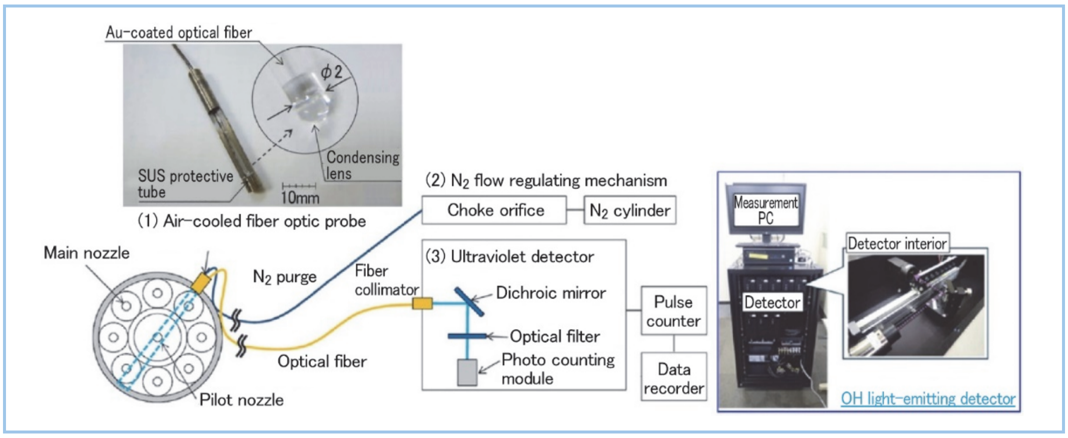

Figure 4 High-sensitivity ultraviolet photodetector [3]

(3) Simulation of combustion oscillation

In actual GT, more than 16 combustors are coupled to generate multi-combustor coupled combustion oscillation [5], which is a combustion oscillation with a different frequency from that generated by a single combustor. To simulate the actual GT combustion oscillation in blowdown combustion test of a single combustor, we developed an acoustic boundary adjusting device that is installed downstream of the combustor to simulate actual GT combustion oscillation. **Figure**

5 shows the concept of the device. The frequency to be generated by the acoustic boundary adjusting device can be adjusted by changing the orifice installation position. This enables to simulate the actual GT in single combustor combustion test, contributing to the development of combustors with reduced combustion oscillation.

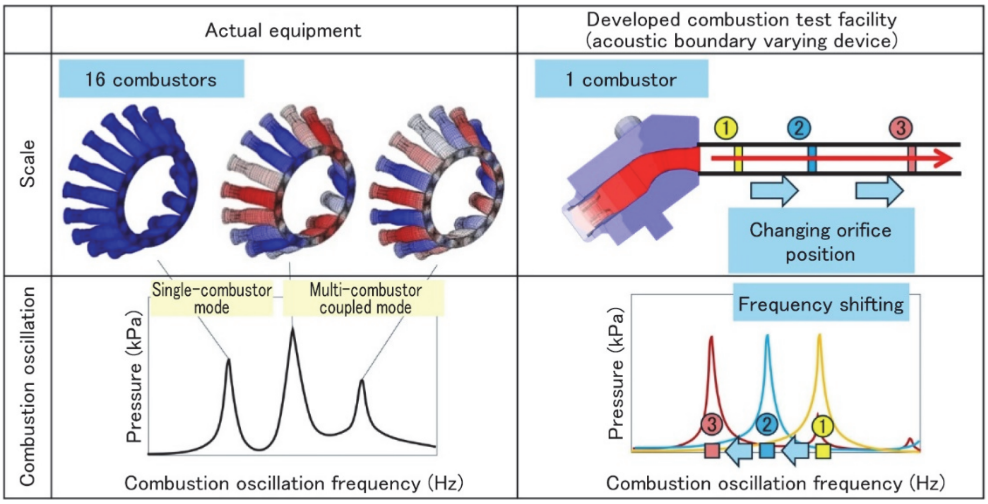

Figure 5 Simulation of combustion oscillation using acoustic boundary adjusting device

3. Completed blowdown combustion test facility

Figure 6 shows the completed blowdown combustion test facility. Air is supplied from the air tank installed shown on the left side of the figure and heated by the air heating device. Fuel is also supplied from the gas cylinder bundle shown on the left side of the figure, after being heated by the fuel heating device, and then flow-controlled by the flow control unit. Air and fuel are supplied to the combustor placed in the shell for combustion, and exhaust gas is cooled and then discharged from the exhaust stack. Since a large amount of exhaust flow from a large GT combustor is discharged, the noise level could be high, so a cell-type silencer was installed in the exhaust stack to reduce the noise.

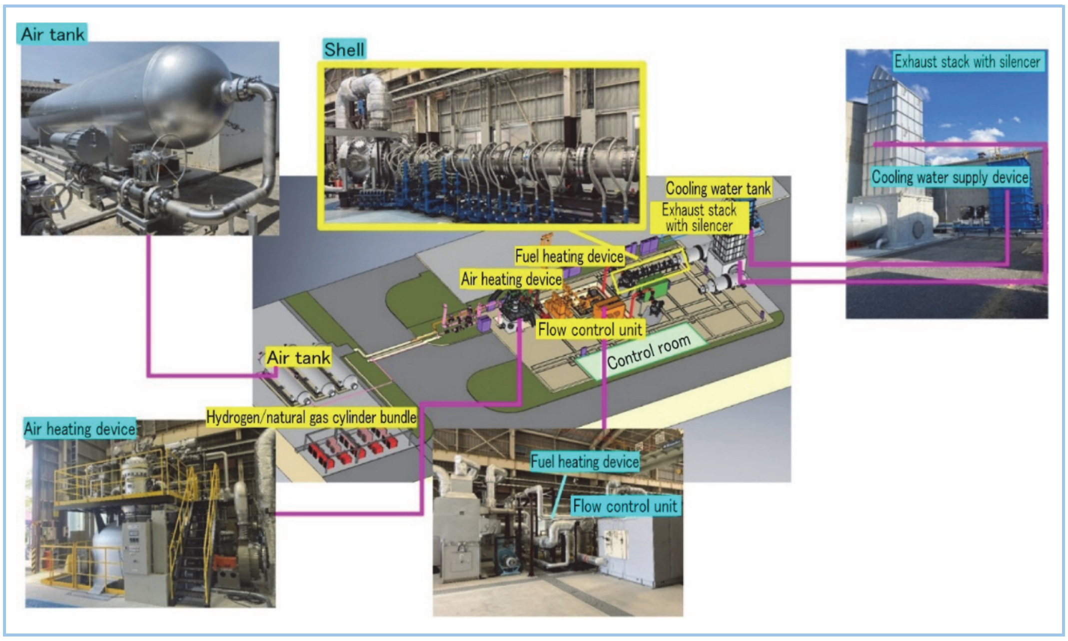

Figure 6 Completed blowdown combustion test facility

4. Results of trial operation

We conducted a trial operation of the test facility for a large frame GT combustor. This chapter presents the results of the trial operation. **Figure 7** shows the verification of the fuel switching conducted in advance, in which the hydrogen concentration was increased to 100%, starting from a

100% natural gas state. It was confirmed that the rate of increase in hydrogen concentration was sufficient to meet the target of 2.3 vol%/min set by the NEDO project.

Figure 8 shows the results of the combustion trial operation using a combustor for natural gas-fired large frame GT, for which abundant comparative data is available, to verify the test facility. It was confirmed that the test facility could achieve increases to rated conditions in as short a time as approximately 90 seconds and to automatically set the temperature, pressure, and fuel staging conditions (fuel systems A and B), following the planned ones. To achieve short-time load-raising control, the control parameters were tuned in advance using a simulator that can reproduce the dynamic characteristics of the fuel and air systems. Thus, both followability and stability of the control could be achieved. **Figure 9** shows the measurement results of NOx emissions and combustion oscillation. In this figure, the actual GT measurement results are also shown for comparison. It was observed that the NOx emissions were almost equal to the actual GT measurements and increased with the change from condition A to B, and that the combustion oscillation amplitude increased with the change from condition C to D. As described above, it was found that the blowdown combustion test facility reproduces the characteristics of actual GT and is effective as a screening facility.

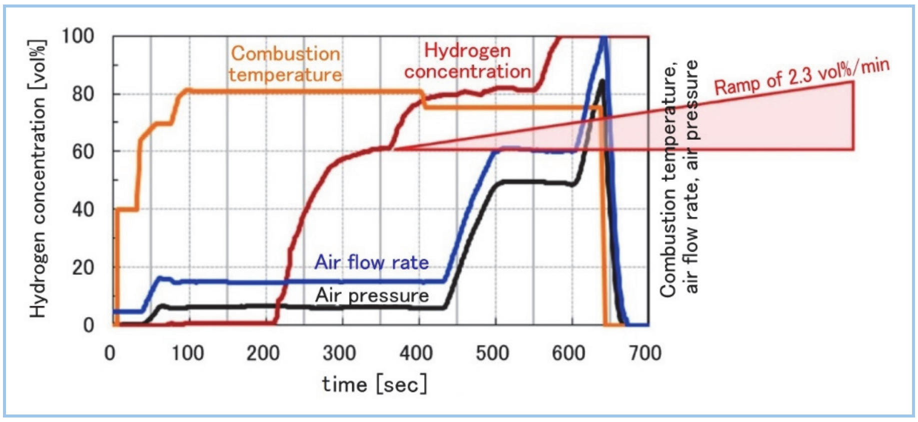

Figure 7　Verification of hydrogen concentration control

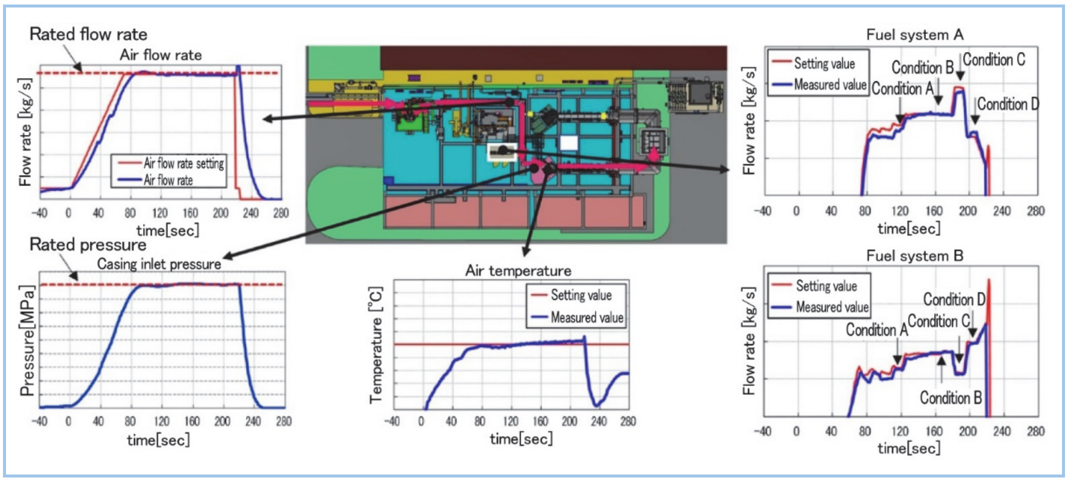

Figure 8　Results of trial operation

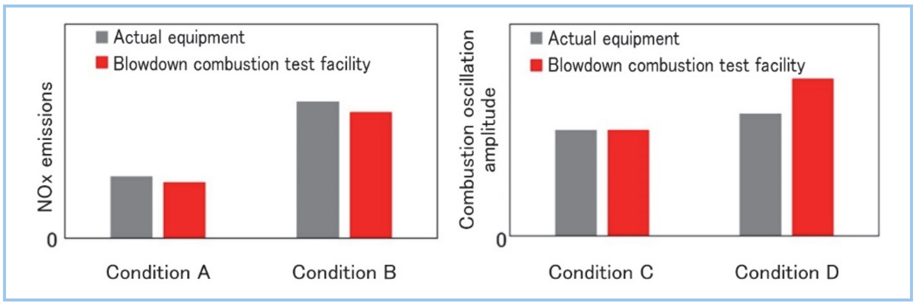

Figure 9　Evaluation of actual GT reproducibility

5. Conclusion

To accelerate the development of combustors, we developed a blowdown combustion test facility for screening tests as part of a NEDO project. Through trial operation, it was confirmed that the test facility can reproduce the NOx emissions and combustion oscillation of the actual GT and achieve the performance as designed. Moving forward, we plan to utilize this test facility in the development of cluster-type combustors that can be used with a wide range of hydrogen concentrations.

The achievements presented in this report were obtained as a result of a project, JPNP16002, subsidized by the New Energy and Industrial Technology Development Organization (NEDO). We would like to express our thanks.

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References

(1) https://www.nedo.go.jp/content/100967763.pdf (in Japanese)
(2) K. Inoue et al., Development of Hydrogen and Natural Gas Co-firing Gas Turbine, Mitsubishi Heavy Industries Technical Review Vol. 55 No. 2 (2018)
(3) J. Noda et al., Combustion Technology of Oil-Fired Combustors for Dual Fuel-Fired Gas Turbines, Mitsubishi Heavy Industries Technical Review Vol.57 No.1 (2020)
(4) https://www.nedo.go.jp/content/100980489.pdf (in Japanese)
(5) T. Koda et al., Development of Acoustic Damper and Short-Term Prediction Technology for Stable Operation of High Efficiency Gas Turbine, Mitsubishi Heavy Industries Technical Review Vol.58 No.1 (2021)