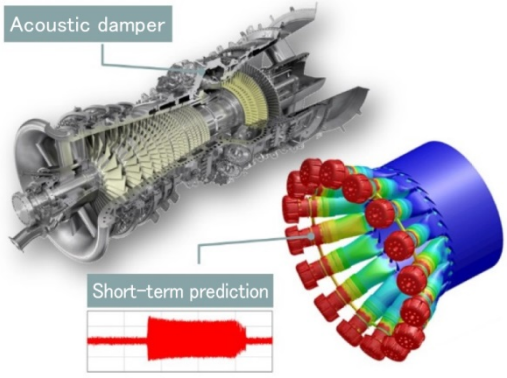
Development of Acoustic Damper and Short-Term Prediction Technology for Stable Operation of High Efficiency Gas Turbine



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A lean premix combustion method, which is used to raise the inlet temperature of gas turbines to increase the efficiency and output thereof and to achieve low emissions, has the risk that combustion becomes unstable and pressure fluctuation (combustion instability) of the combustor increases. In order to realize stable gas turbine operation, we have developed an acoustic damper, which is a device that stabilizes combustion instability by applying acoustic damping and a technology for the short-term prediction of combustion instability that sharply increases in amplitude in a short period of time. We verified these developments in the gas turbine combined cycle (GTCC) power plant validation facility (hereinafter, power plant validation facility) at Takasago Works of Mitsubishi Power, Ltd. to contribute to the realization of stable gas turbine operation.

1. Introduction

A common issue for products related to combustion is pressure fluctuation (combustion instability) caused by unsteadiness of flame. Combustion instability is self-excited vibration generated by the coupling of the unsteady heat release of the flame and the acoustic field of the combustor. Large pressure fluctuation of combustion instability causes fatigue fracturing of the structure or flashback and in the worst case, the combustor is damaged in a short period of time as a result.

In the case of gas turbine combustors, combustion instability is increased by a higher turbine inlet temperature and lean premixed combustion and there are problems such as an increase in the combustion instability amplitude and the generation of suddenly-changing combustion instability such as vibration growth in an extremely short time.

This report presents these combustion instability suppression and short-term prediction technologies.

2. New acoustic damper that achieves reduction of both NOx emission and combustion instability

2.1 Conventional acoustic damper

In order to realize stable gas turbine operation, an acoustic damper, which is a device that stabilizes combustion instability by applying acoustic damping, is used[(1)]. The acoustic damper is a resonator composed of a perforated plate at the inlet and a back cavity. Pressure fluctuation of the combustor is guided into the damper by a resonance phenomenon. As the fluid moves in and out of

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the perforated plate, a vortex is generated and the pressure fluctuation energy is dissipated (**Figure 1**).

Conventional acoustic dampers require cooling air because they are installed in a combustion region. Since part of the combustion air is used for cooling, the flame temperature rises, which leads to an increase in NOx emissions. In order to improve the sound absorbing performance, it is effective to increase the opening area, but this requires more cooling air and lowers the NOx performance. In addition, increasing the opening area also requires the volume of the back cavity behind it to increase, but a further increase in the size is difficult due to the limitation of the installation space. For these reasons, conventional acoustic dampers have a problem in that it is difficult to improve the sound absorbing performance.

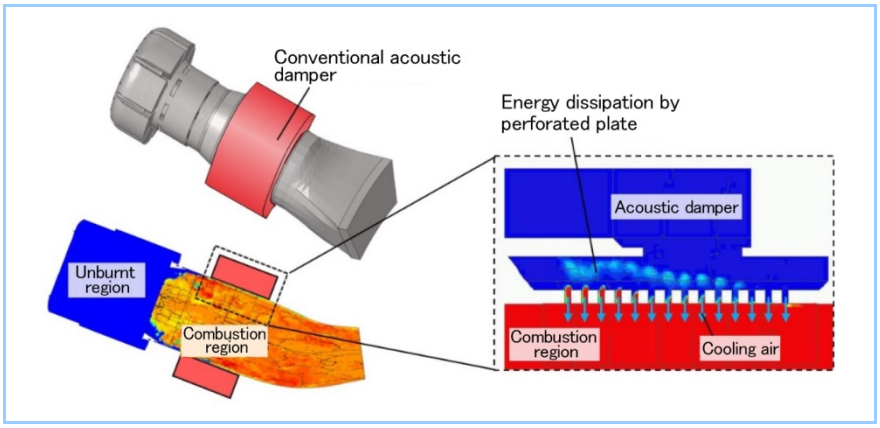

Figure 1 Principle of acoustic damper

2.2 Development of new acoustic damper

Conventional acoustic dampers are installed in a combustion region, which is an antinode of the acoustic mode and a position where the heat release of the flame occurs. However, as a result of analyzing the acoustic mode of actual combustor, it was found that an unburnt region on the upstream side also has a mode amplitude. Therefore, we developed a new acoustic damper that eliminates the need for cooling air since it is installed in an unburnt region at the inlet of the combustor and reduces combustion instability without increasing NOx emissions (**Figure 2**).

Since the boundary conditions such as sound pressure, grazing and bias flow are different between the combustion region and the unburnt region, it was expected that the damping in the acoustic holes would decrease and the damper resonance magnification would increase. We clarified the changes in acoustic damping due to these condition changes through elemental experiments and large-scale unsteady CFD (Computational Fluid Dynamics). By optimizing the acoustic damping of the perforated plate for the unburnt region, the damping of the acoustic damper was maximized.

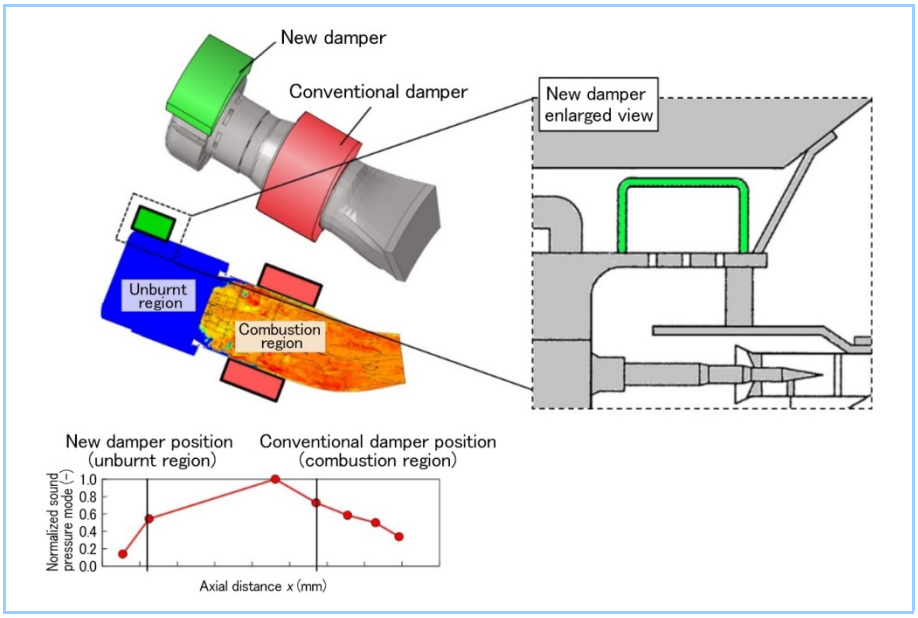

Figure 2 Structure of new acoustic damper

2.3 Actual combustor verification

We conducted actual combustor verification of the new acoustic damper using the power plant validation facility. This verification included the measurement of the transfer function at the damper inlet and end for confirmation of the acoustic performance of the damper alone. As a result, it was confirmed that the analysis and the actual measurement were in good agreement with each other in terms of both the gain and the phase of transfer function (**Figure 3**).

As a result of trial runs with and without the new acoustic damper, it was shown that the new acoustic damper reduces combustion instability by 25%, increases the operating margin under rated operating conditions and enables stable operation (**Figure 4**). It was also confirmed that NOx emissions do not increase as a side effect. Currently, the new acoustic damper is being applied to long-term power supply operation and verification of the acoustic performance and structural reliability is also being carried out continuously for long periods.

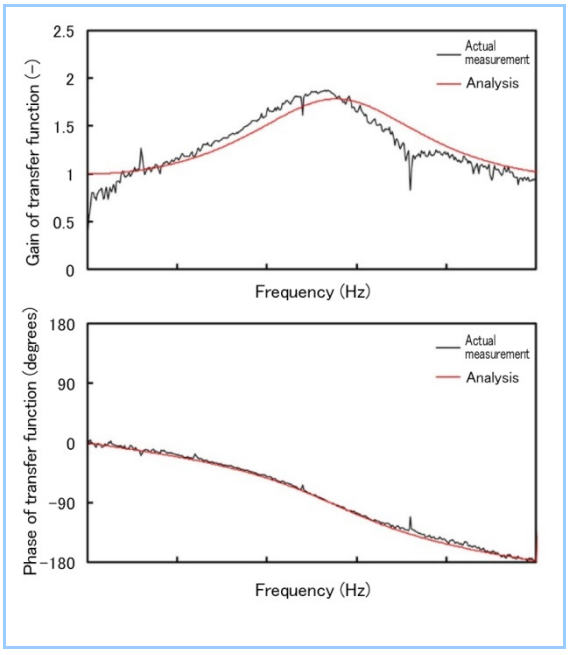

Figure 3 Transfer function of a new acoustic damper measured in an actual combustor

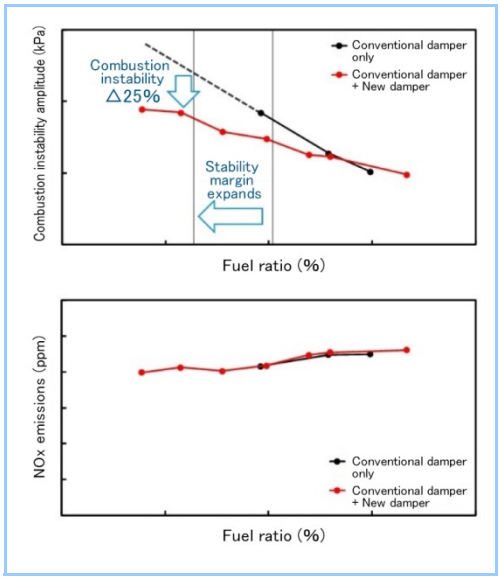

Figure 4 Actual combustor verification results of new acoustic damper

3. Short-term prediction technology of combustion instability that suddenly increases in amplitude

3.1 Combustion instability that suddenly increases in amplitude

The operating conditions of gas turbines are becoming stricter as the efficiency and output increase, and the operating state is likely to change suddenly or become unstable. **Figure 5** shows the pressure fluctuation time history waveform, sonargraph and combustor circumferential acoustic mode during intentional unstable-region gas turbine operation to grasp the stability margin of combustion instability at a turbine inlet temperature of 1650°C in the power plant validation facility. It is shown that the pressure fluctuation amplitude increases sharply around 0 sec and the pressure fluctuation is increased to nearly 10 times larger than its normal state. Fluctuation with strong randomness in the 100-300 Hz band during normal operation changes to fluctuation in which a sine vibration consisting of 100 Hz basic frequency and harmonics is predominant after a sudden change in state. In the process of sudden state change, the pressure fluctuation mode shape changes from a distorted mode shape in which the phases of the combustors are not aligned to a mode shape with the same phase and same amplitude. Once an abnormal state occurs even for a short time, the combustor can be damaged, so the output of the gas turbine must be reduced immediately and rapidly or the turbine must be stopped in order to recover the normal state. For stable operation, a technology that can predictively detect a sudden state change in order to detect and avoid a high-risk abnormal state during operation, in addition to the robust hardware design to which damping is added using an acoustic damper, etc., is required.

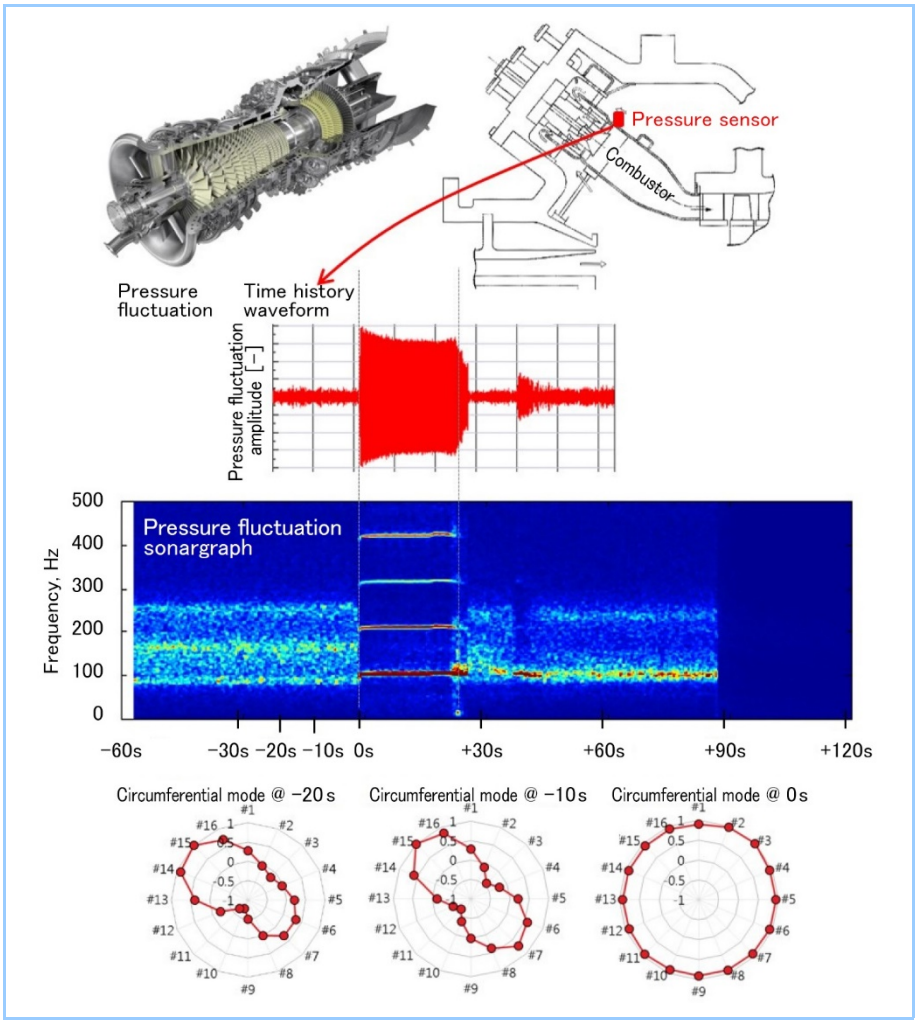

Figure 5 Example of combustion instability that suddenly changes in state (gas turbine combustor)

3.2 Development of short-term prediction technology of abnormal vibration applying complex system science

In recent years, the application of complex system science, which expresses complex nonlinear phenomena with mathematical equations and solves the structure of the solution, to nonlinear problems in the field of combustion has been advancing. For example, there are several reports of research that was incorporated into the advance detection of combustion instability (blow off) of gas turbine combustors[(2)].

The combustion instability of a gas turbine combustor that suddenly changes in state as shown in Figure 5 is a self-excited vibration phenomenon due to the coupling between the acoustic mode and the combustion in which sixteen combustors are coupled in the circumferential direction. From the viewpoint of complex system science, the combustion instability can be regarded as a collective synchronization phenomenon of a group consisting of a large number of vibrators. Therefore, we extended the concept of phase synchronization parameter, which is a parameter indicating the instantaneous phase synchronization state between two points proposed by R. Gutierrez et al.[(2)], to define the frequency at which the sixteen combustors synchronize per unit time as the synchronization probability and we developed a technology to detect the transition from the normal state to an abnormal state based on the time change of the synchronization probability (**Figure 6**).

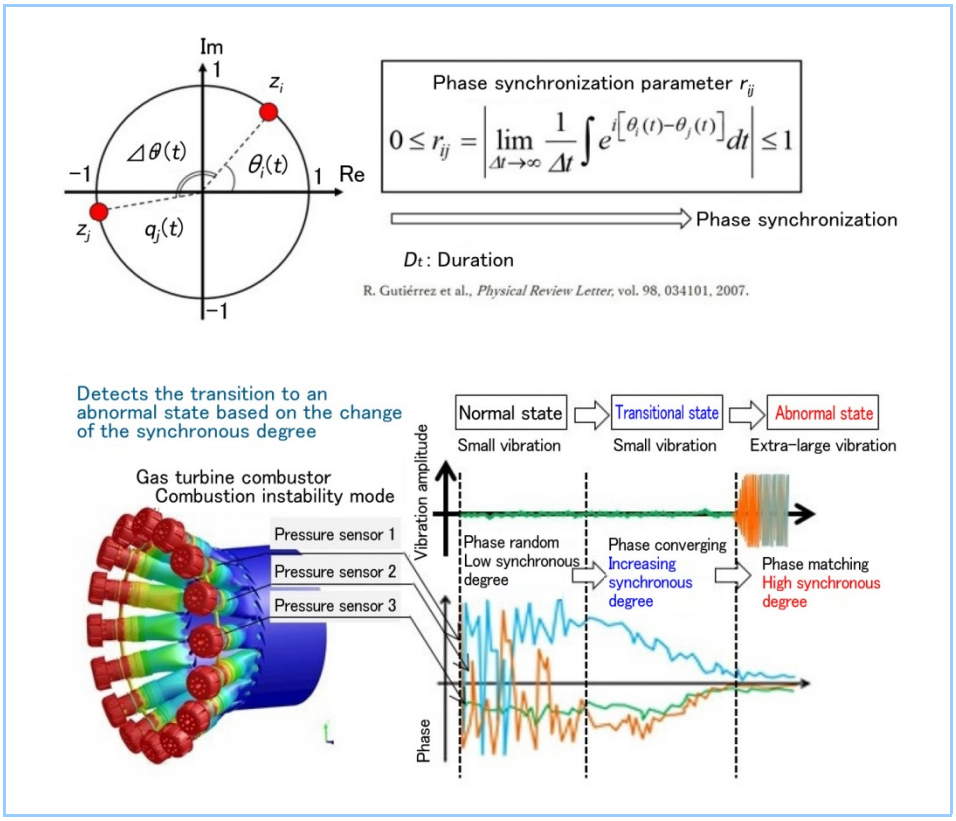

Figure 6 Short-term prediction technology of abnormal vibration applying complex system science

3.3 Actual combustor verification

Figure 7 shows the result of applying the short-term prediction technology to the data of actual combustor verification in the power plant validation facility. The conventional monitoring method could not avoid a sudden state change of the pressure fluctuation of combustion instability. However, the developed method can avoid an abnormal state during operation by monitoring the synchronization probability of the pressure fluctuations calculated from multiple sensors to detect a transition to the abnormal state 40 seconds before the sudden state change. We will continue to verify the usefulness of this technology over the long term.

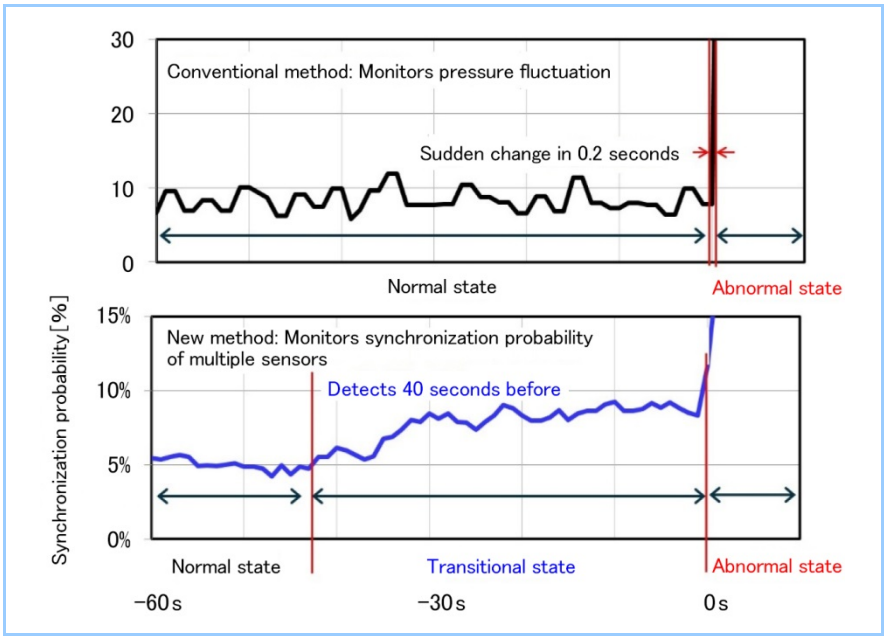

Figure 7 Actual combustor verification results of short-term prediction technology

4. Conclusion

In order to realize stable gas turbine operation, we developed a device that stabilizes combustion instability and a short-term prediction technology for advance detection of a sudden state change and avoiding vibration risks. Then we verified these developed technologies in the power plant validation facility to contribute to the realization of stable operation.

The development of the new acoustic damper that was described in this report was carried out as a part of the "High-efficiency Gas Turbine Technology Demonstration Project (the development of ultra-high efficiency 1700°C-class gas turbines)," which is underway as a project with a subsidy from the New Energy and Industrial Technology Development Organization (NEDO).

References

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