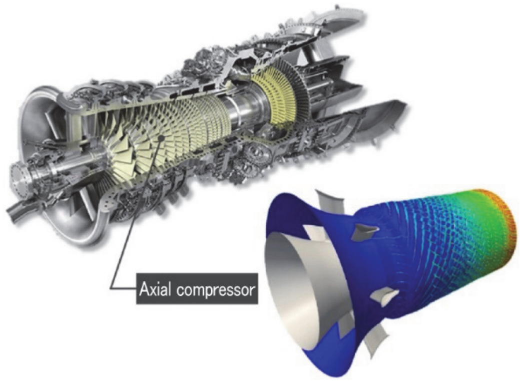
Prediction Technology for Blade Interference Sound in Axial Compressor of Industrial Gas Turbine



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In recent years, there has been a concern about increased intake noise levels of gas turbines as their flow rates increase, and the cost of noise control measures has tended to increase accordingly. On the other hand, gas turbine intake noise is dominated by a blade-passing frequency component of first-stage rotor blades of the axial-flow compressor, and some literature points out the relationship between the internal flow (shock waves generated in the transonic region) and the blade-passing frequency component of the noise, which was not considered in the conventional noise prediction method. Therefore, Mitsubishi Heavy Industries, Ltd. have developed a new prediction method that takes into account the mechanism of intake noise generation using our high-precision numerical analysis technology to improve the prediction accuracy of intake noise and optimize the noise control measures.

1. Introduction

Recently, due to the high importance of reducing CO_2 emissions, the electricity supply from renewable energy sources such as wind power generation and solar power generation has been planned and implemented. However, these are unstable power sources and their electricity supply amount fluctuates depending on weather conditions, and there are concerns that they may cause sudden frequency fluctuations and load fluctuations in the power grid. In this context, gas turbine combined cycle power generation (hereinafter referred to as GTCC), which is more efficient and easier to operate than conventional thermal power generation, is becoming more important in terms of global environmental conservation and stable energy supply. In addition, due to the effects of fuel conversion projects, such as the shift away from oil in the Middle East, and of the demand for electricity for data centers in the U.S., the global demand for new GTCC plants of 40-50 GW per year is expected to continue for the next 3-4 years, which will require gas turbines with even higher flow rates and capacities.

As gas turbines become larger in flow rate, the predicted intake noise value based on the conventional noise prediction method (1), which employs a correction using the flow rate and pressure ratio, increases due to the increase in the flow rate, causing the cost of noise control measures to increase significantly. However, as shown in **Figure 1** (symbols A to K in the figure are plant identification), the intake noise prediction accuracy of the conventional prediction method is poor. Improving the prediction accuracy may reduce the excessive cost of noise control measures in GTCC plants. As shown in **Figure 2**, the measurement results indicate that the intake noise of a gas turbine is dominated by the blade passing frequency (hereinafter referred to as BPF) component of first-stage rotor blades of the axial-flow compressor and its harmonics. Some published literature (2) has pointed out the relationship between the BPF component and shock waves generated in the transonic region, which was not considered in the conventional noise prediction method.

This report clarifies the mechanism of intake noise generation in the transonic region using

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numerical analysis technology, and describes a case in which a noise prediction method with higher accuracy than the conventional prediction method was developed.

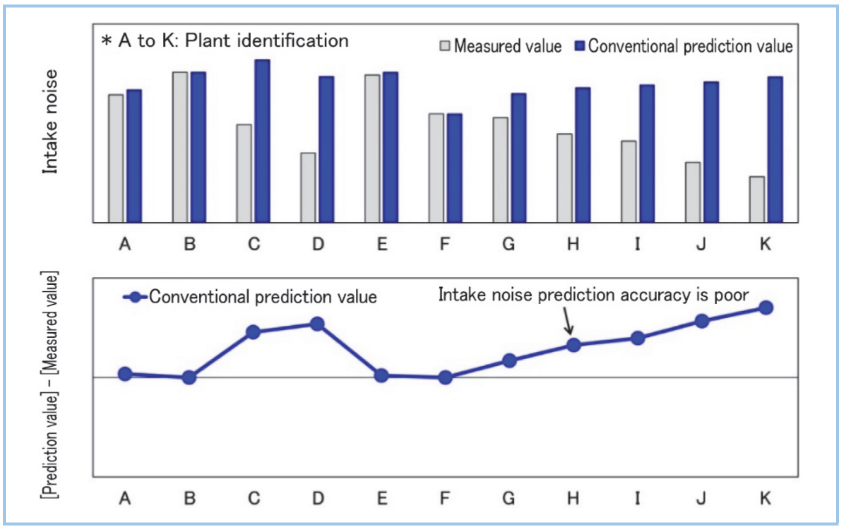

Figure 1 Comparison of intake noise between measured value and conventional prediction value

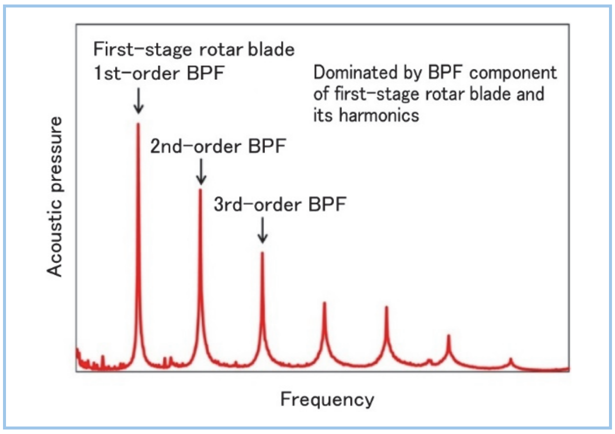

Figure 2 Frequency spectrum of intake noise

2. Clarification of intake noise generation mechanism

2.1 Numerical analysis method

To clarify the mechanism of intake noise generation in gas turbines, we evaluated the internal flow of a gas turbine intake section using computational fluid dynamics (CFD). As shown in **Figure 3**, the analysis targeted the gas turbine intake manifold, strut, and area from the inlet guide vane (hereinafter referred to as IGV) to the second-stage stator vane of the axial-flow compressor, and used a computational grid of about 120 million nodes. To evaluate changes in the internal flow and pressure fluctuation level with increasing or decreasing intake flow, several cases of computational grids with different IGV openings were prepared and analyzed. Numerical analysis was performed with unsteady Reynolds-Averaged Navier-Stokes (RANS), and the Spalart-Allmaras (SA) model was used as the turbulence model.

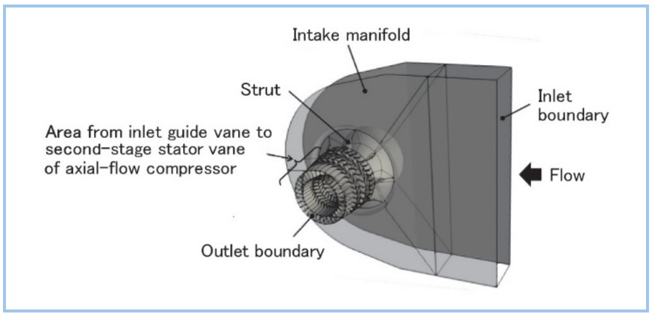

Figure 3 Analysis model

2.2 Internal flow and intake noise generation mechanism

Figure 4 shows the static pressure distribution on the outer diameter side of the area from the strut to the first-stage rotor blade when the intake flow rate was varied by changing the IGV opening. As shown in this figure, shock waves occurred at the first-stage rotor blade, and the position in the flow direction where the shock waves occurred changed as the intake flow rate was increased or decreased. **Figure 5** shows the pressure fluctuation spectra at the positions in front of the strut to in front of the first-stage rotor blade when the intake flow rate was varied. In both cases, the BPF component of the first-stage rotor blade was the main component of the noise, but the pressure fluctuation levels in front of the IGV and in front of the strut differ.

It is seen that under flow conditions where the shock wave is at a certain position relative to the first-stage rotor blade, the interference between the shock wave and the IGV is strong and the pressure fluctuation level of the BPF component is also large. Under the larger flow rate condition, the shock wave is sucked back into the flow path of the first-stage rotor blade, which weakens the interference between the shock wave and IGV, and the pressure fluctuation level of the BPF component is also significantly reduced. On the other hand, under low flow conditions, the shock wave moves forward and becomes largely detached from the leading edge of the first-stage rotor blade, indicating that the interference with the IGV is strong to some extent. However, as shown in **Figure 6**, since the IGV is closed and interference noise with the shock wave propagates upstream while being dampened in the IGV flow path, the pressure fluctuation level in front of the IGV decreases.

From the above, it was discovered that the main cause of intake noise is the interference between the shock wave generated by the first-stage rotor blade and the IGV, and that the intake noise level changes as the shock wave position changes with an increase or decrease in the intake flow rate and as the damping of the pressure fluctuation in the IGV flow path changes with the opening or closing of the IGV.

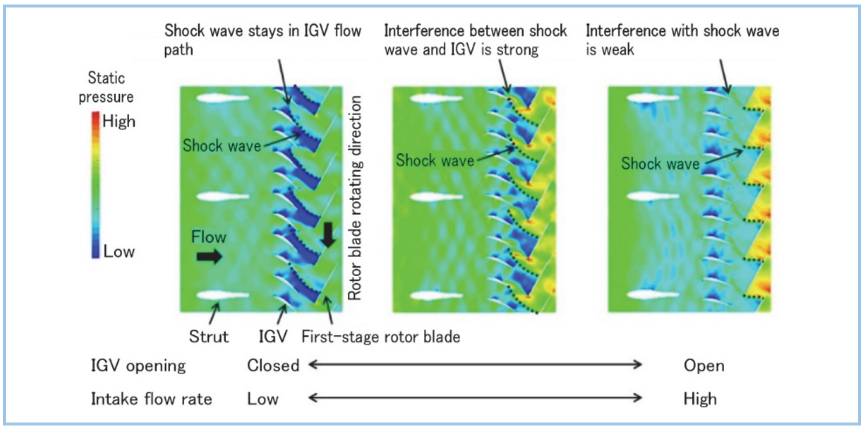

Figure 4 Comparison of static pressure distribution

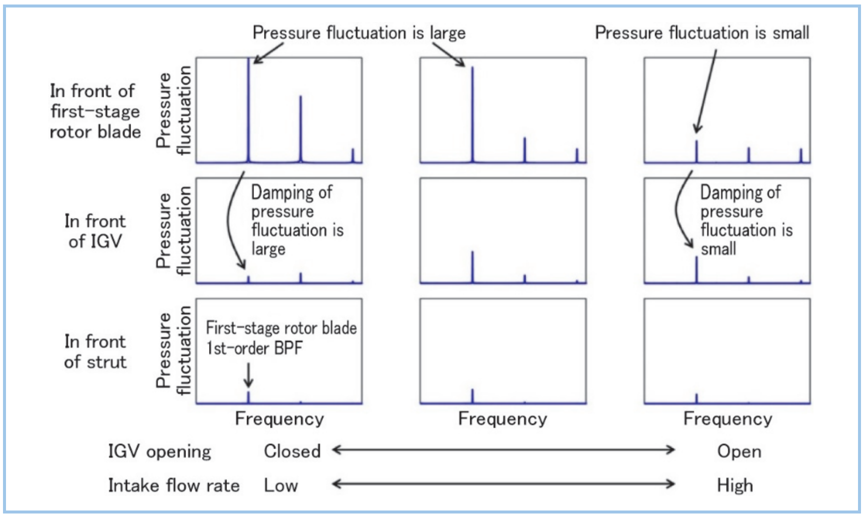

Figure 5 Comparison of pressure fluctuation spectra

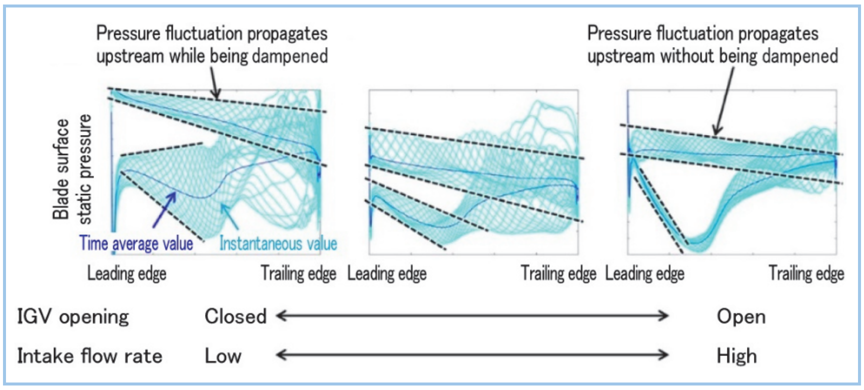

Figure 6 Comparison of IGV blade surface static pressure distribution

3. Establishment of intake noise prediction method

From the results of the numerical analysis shown in **Figure 7**, it is estimated that intake noise peaks at a certain flow rate condition, decreases at higher flow rates as the shock wave retracts and the interference with the IGV weakens, and also decreases at lower flow rates as the IGV closes and the pressure fluctuation is dampened in the IGV flow path. On the other hand, the conventional intake noise prediction method uses a model in which noise increases monotonically with increasing flow rate, resulting in an overestimation of noise at the design stage and possibly excessive noise control measures.

Based on the mechanism of intake noise generation, we calculated a correction curve for obtaining the amount of correction to the conventional prediction value, and added it to the conventional prediction value to derive a new prediction value. This new intake noise prediction method is expected to improve the prediction accuracy of intake noise for all plants used in the evaluation as shown in **Figure 8**.

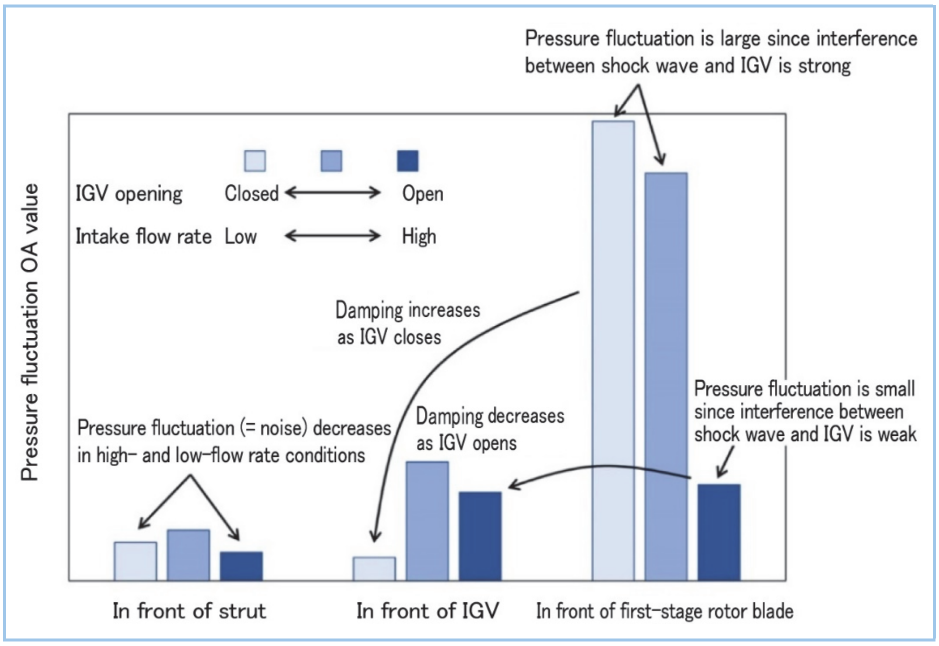

Figure 7 Comparison of pressure fluctuation OA values

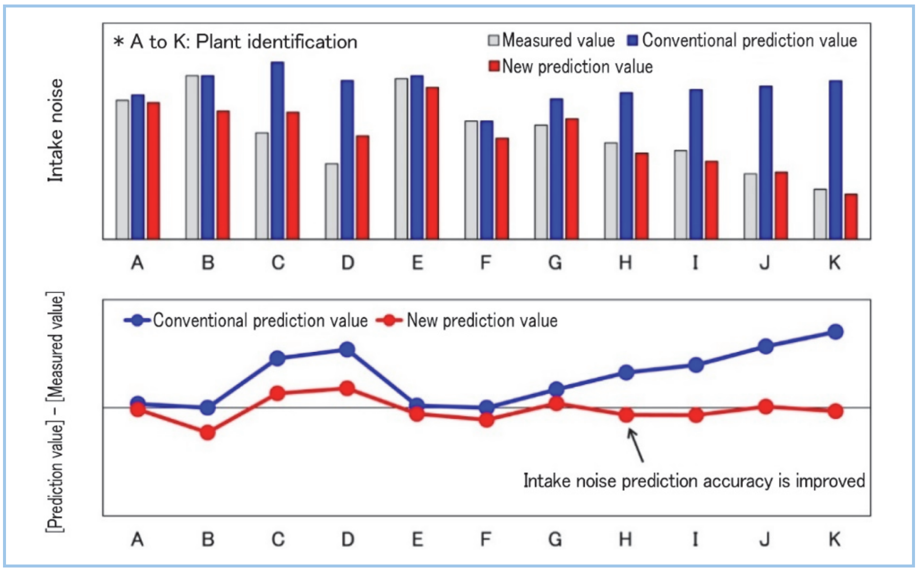

Figure 8 Improvement of intake noise prediction accuracy with new method

4. Conclusion

This report clarified the mechanism of intake noise generation in the transonic region using numerical analysis technology, and presented the development of a noise prediction method that is more accurate than the conventional one. Through this development, we were able to explain the trend of intake noise with respect to the intake flow rate and IGV opening, which could not be known by the conventional prediction method, and have achieved the prospect of a significant improvement in prediction accuracy and reducing the excessive cost of noise control measures.

References

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(2) Liping Xu, SHOCKWAVE AND NOISE ABATEMENT OF TRANSONIC FANS, ASME Turbo Expo, GT2004-53545