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Advanced Monitoring System for Combustor Pressure Fluctuation

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ABSTRACT

Stable combustion of gas turbines is essential to insure reliability, availability and achieve maximum component life capability. Combustor instabilities can trigger high-pressure fluctuations that are generally due to sudden changes in fuel calorific value or fuel quality, large ambient temperature swings, or sudden changes in operating load conditions. In order to protect against combustor instabilities, Mitsubishi developed an advanced monitoring and protection system known as the Advanced Combustor Pressure Fluctuation Monitoring (advanced CPFM) system. This on-line monitoring and protection system automatically tunes the air by-pass valve, main and pilot fuel flows to maintain appropriate fuel / air ratio depending on the combustion chamber flame instability condition. The response to such actions successfully prevents flame out occurrence, combustion oscillation, and flame flash back under various modes as well as unexpected disturbances during the combustion process.

This paper describes the operation and functionalities of the advanced CPFM system that has been tested at Mitsubishi's in-house combined cycle power plant under real operating conditions.

INTRODUCTION

Emission limits from industrial gas turbines have become increasingly stricter during the past decade. The overall low emissions emphasis has made combustor design even more challenging at the higher firing temperatures of 1400 deg. C to 1500 deg. C in modern industrial gas turbines such as the M501F, M501G and M501H. Knowledge of the physics in the combustion chamber, and effective control of the key parameters that influence combustion stability are essential in order to achieve a proper balance between combustor performance, and overall operating reliability, availability and gas parts service life durability. The abovementioned knowledge and control are required not only for certain operating conditions, but for the entire expected operating profile of the power plant. This challenge of achieving stable combustion applies to the gas turbine industry as a whole.

Mitsubishi Heavy Industries first introduced pre-mix Dry Low NOx (DLN) combustion in commercial gas turbines in 1984. Since that time, the basic design of the MHI DLN combustor system has been applied at many power plants located around the world. An early version of pressure fluctuation monitoring was developed and applied in 1984. This pressure fluctuation monitoring system known as CPFM (combustion pressure fluctuation monitoring) was commercially introduced on MHI gas turbines in 2000. Since its introduction, the CPFM system has been improved by increasing its system functionalities to benefit overall reliability and availability. The latest improved system, known as the advanced CPFM, is able to perform on-line combustion tuning adjustments, thereby improving system availability and reliability even further.

BACKGROUND

Fig. 1 presents an emission/stability comparison between pre-mix DLN combustion system and conventional diffusion combustion. The flame stability is inherently greater in conventional diffusion type combustion over a wider range of fuel to air ratio. On the other hand, the NOx emissions are much greater compared to pre-mix DLN combustion.

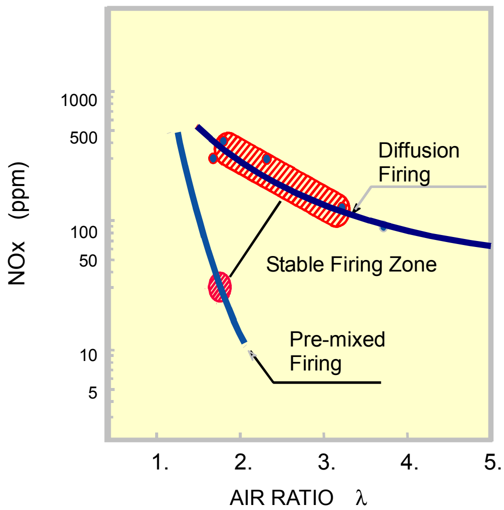

Fig. 1 Diffusion and pre-mixed firing

Fundamentally, stable combustion in DLN combustion systems requires more accurate control of Fuel and Air (i.e. fuel to air ratio) quantities in the combustion chamber at all load levels. Examples of factors that can upset the combustor flame stability are changes in fuel composition (and fuel quality), calorific content, grid frequency, ambient conditions, operating load transients, or even operator influenced conditions etc.

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DLN SYSTEM DESCRIPTION AND PARAMETER CONTROL

The MHI DLN combustion system consists of a pilot nozzle and 8 main fuel nozzles in each combustion chamber. The primary function of the pilot nozzle is to produce a stable diffusion flame that can maintain high flammability in the pre-mixed flame.

An air by-pass-valve is installed downstream at the transition piece for maintaining almost constant Fuel/Air ratio at the combustion chamber. (See Fig. 2.) The air by-pass valves of all combustion chambers are integral part of a common linkage actuated by a hydraulic piston. The by-pass valve modulates during transient conditions, ignition, acceleration and partial load operation, and it moves toward the close position with increasing load. The air by-pass valve is also used to prevent flame out, combustion oscillations and flash backs that can be induced by changes in the GT total airflow resulting from IGV position changes. Fig. 3 shows a typical interaction between the IGV position and the by-pass valve opening.

MHI DLN combustion system does not require fuel staging for maintaining fuel to air ratio, as in the case of some alternate combustor design systems.

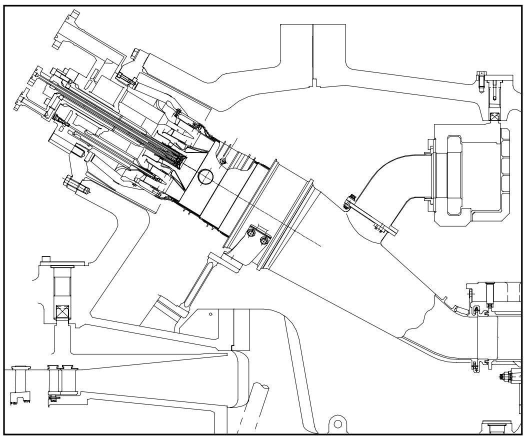

Fig. 2 Pre-mix DLN combustor in MHI F-series gas turbines

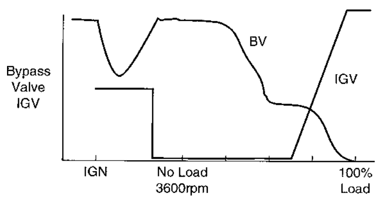

Fig. 3 IGV and air by-pass valve sequence

Since a constant Fuel/Air ratio is maintained with the air by-pass valve, the overall combustion control is quite simple, as shown in Fig. 4.

The fuel to each combustor is supplied through one single pilot port and one single main fuel port. The pilot and main ports of all combustion chambers are connected to one pilot and one main manifold respectively. The fuel flow to each manifold is controlled by the pilot and main control valves

In addition to controlling the fuel to air ratio as described above, the DLN system manipulates the pilot to main fuel ratio (also known as Pilot Control Signal Output PLCSO) for emissions and combustion stability control.

Fig. 5 shows the typical pilot and main fuel flow characteristics from ignition to full load. The pilot to main fuel ratio is set higher at ignition, acceleration, and lower load, and it is progressively reduced with increasing load conditions in order to reduce NOx emission.

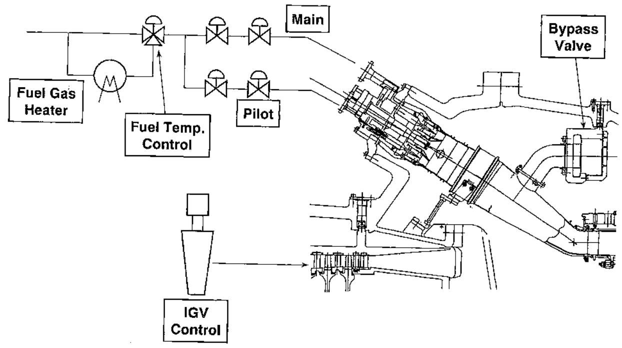

Fig. 4 MHI gas turbine control

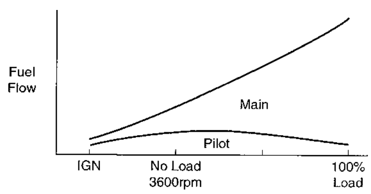

Fig. 5 Pilot and main fuel nozzle sequencing

CPFM (COMBUSTOR PRESSURE FLUCTUATION MONITORING) SYSTEM

The purpose of the CPFM system is to provide early detection and protection of hardware distress caused by combustor pressure fluctuations. The original CPFM control logic takes appropriate interlock measures such as alarm annunciation, load runback to a safe intermediate load level, or trip the unit depending on the amplitude of the combustor pressure fluctuation. Under such circumstance, sometimes further combustor tuning at site is necessary.

ADVANCED CPFM

The functionality of the CPFM system has now been enhanced so that the fine-tuning adjustments of the combustor (i.e. adjustment of fuel air ratio, by-pass air flow, etc) described above can be executed on-line, thereby maintaining continued combustion stability over longer intervals and benefiting gas turbine availability. This improved CPFM system is referred to as the advanced CPFM system as shown in Figure 6.

The advanced CPFM has several basic functions as follows.

- Increased data acquisition and analysis speed.
- Real-time evaluation of combustion pressure fluctuations and estimation of necessary firing stability margin.
- Automated adjustments for control parameters by calculating optimal correction based on the estimation.
- Detect defective sensors.

To realize the above functions, the advanced CPFM utilizes a dedicated computer system linked to the gas turbine main controller.

The system periodically receives and stores the measured data, and calculates parameters from the data in order to be able to create mathematical models of the combustion characteristics. These models evaluate pressure fluctuation and NOx emissions as well as the necessary adjustments of parameters such as fuel/air ratio, temperature of inlet air, etc. required to improve the combustion stability margin. Because the characteristics of the pressure fluctuation can vary according to combustors and oscillation modes, the mathematical modeling is done for every combustor and every mode. The models are linear or nonlinear functions (e.g. polynominal approximate expression) of combustion parameters such as fuel/air ratio, fuel gas temperature, etc.

After the modeling, combustion stability estimation is done. The stability margin can vary according to the changes of fuel composition, surrounding climate condition, or aging, even if the control parameters are the same. In addition, since each plant or each combustor has its own combustion characteristics the control parameters should be individually considered for determining the corrective tuning action. The system estimates stable region for control parameters and determines a combustion stability map by using the obtained models as shown in Fig. 7. The stable region is surrounded by several border lines which are derived from different oscillation characteristics. For example, higher PLCSO leads to the leaner main fuel, and the lower PLCSO brings the less diffusion flame. Both can cause unstable firing.

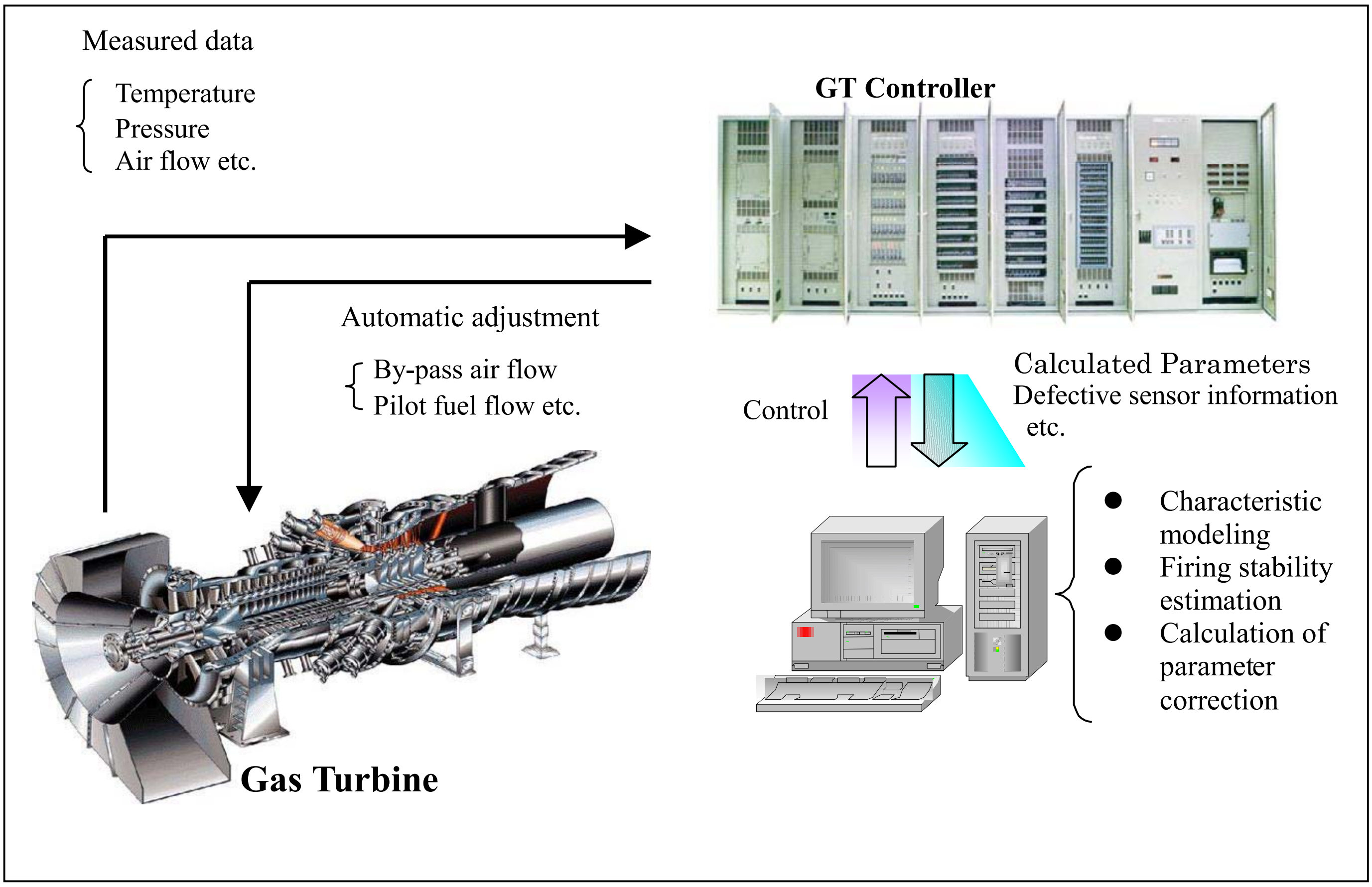

Fig. 6 The structure of the advanced CPFM system

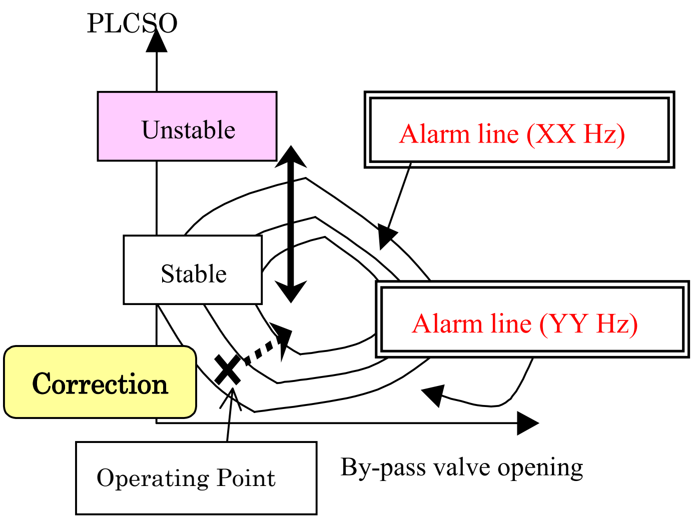

Fig. 7 Combustion stability map and control parameter Correction

The next step is the calculation of correction for the by-pass valve opening and pilot control signal output (PLCSO). If the pressure fluctuation amplitude exceeds predetermined level, the system calculates a correction according to the stability estimation. This step is omitted if the combustion is stable.

Periodic modeling, stability estimation and adjustment cycle makes it possible to realize immediate responses to condition changes and individual characters.

VERIFICATION OF THE ADVANCED CPFM AT IN-HOUSE POWER PLANT

The advanced CPFM system was verified at Mitsubishi's combined cycle power plant. The plant controls were intentionally deviated from the tuned condition to increase pressure fluctuations, and the system automatically established appropriate combustion models, estimated firing stability margins, and adjusted the control parameters on-line. The pressure fluctuation amplitude decreased in response to the adjustments. The actions established by the advanced CPFM system agreed well with what an experienced operator would have undertaken.

Fig. 8 shows an example of automatic test performed in our in-house plant. During the test, the pilot nozzle setting was reduced intentionally, so as to increase the pressure fluctuation levels intentionally. The response of the advanced CPFM system was to set the correction signal, so as to increase of Pilot nozzle setting. This action was also consistent with any manual course of corrective actions by experienced operators. By the adjustment, pressure fluctuation level successfully decreased.

Fig. 9 shows stability estimations, and corresponding maps for the stable and induced unstable combustion, and the results of the FFT analysis. In the stable case, the operating point is inside the stable area on the map. On the other hand, when the combustion pressure fluctuation level increases at a frequency, the operating point is outside the stable area and located near the alarm line.

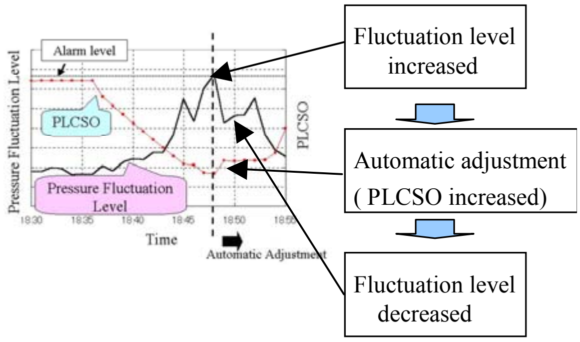

Fig. 8 Example of automatic adjustment

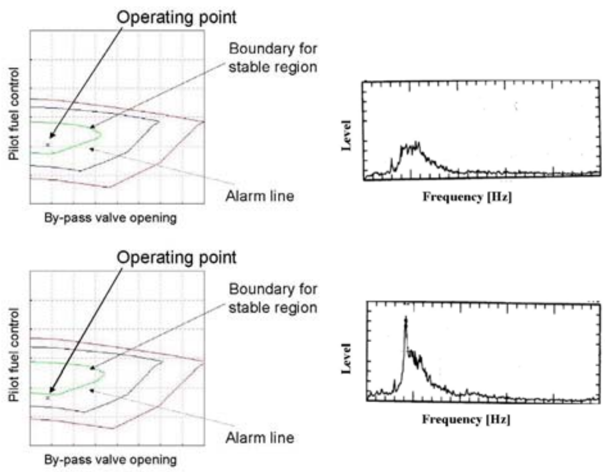

Fig. 9 Stability estimation and maps on the test case (Top: stable case, Bottom: unstable case)

SUMMARY

The advanced CPFM system functionality vastly improves the availability and reliability of modern low NOx pre-mix combustors. The features of the advanced CPFM system are;

- Quick acquisition, recording and evaluation of measured data
- On-line modeling of the characteristics of combustion pressure fluctuation
- Estimation of firing stability
- Automated adjustments of control parameters

The execution of the advanced CPFM system was verified in actual operation of a combined cycle power plant. The automated responses taken by the advanced CPFM system were appropriate. The test verified that the system successfully reduced the level of the combustion pressure fluctuation.

The advanced CPFM system will be available for commercial applications shortly. Future improvements will continue to focus on establishing faster calculations, and validating further against operating error anomalies.