PCB PIEZOTRONICS
AN AMPHENOL COMPANY

Taking the Pulse of Combustion

Obstacles in Reducing NOx Emissions with Lean Fuel Technology

In the last thirty years, there has been significant regulatory pressure for gas turbine manufacturers and users to reduce nitrogen oxide (NOx) emissions. In response to these regulatory initiatives, gas turbine manufacturers initially turned to water and steam injections (Wet Low Emission technology) during the combustion process as the methodology for achieving the necessary reductions. However, as low emission requirements continue to increase, manufacturers have had to turn to alternative reduction methodologies, the two most popular of which have been lean-burn and dry low NOx designs.

While lean fuel technology leads to single digit NOx emissions, the low fuel-to-air ratio also leaves these turbines more prone to coupled acoustic/heat release pressure oscillations as a result of minor operational instabilities. While the magnitude of these oscillations may be low, even small fluctuations less than 1 psi (0.069 bar) can cause structural vibrations that result in high cycle fatigue in metal parts downstream of the combustors such as nozzles, baskets, transition pieces and blades.

Systems for Monitoring Pressure Oscillations

The solution to this challenge is to continuously monitor and detect the presence of pressure pulsations while modifying the combustion process via techniques such as adjusting the fuel mixture. The presence of undesirable pressure pulsations causes combustion resonances in the range of 1 to 1200 Hz. Early detection of resonances is important, so that corrective measures can be taken proactively before there is damage to the compressor.

This detection relies on combustion instability monitoring systems that employ combustion chamber pressure sensors. The output of these sensors is monitored by a dedicated data acquisition system. The system records pressure fluctuations for turbine tuning and alarms either the operator or the turbine controller of out-of-limits pressure fluctuations. Digital systems use a frequency windowing technique (see figure 1) where user-selected frequency bands are defined. If the spectral amplitude exceeds any of the selected windows, the system will provide an alarm, allowing the operator to make required corrections.

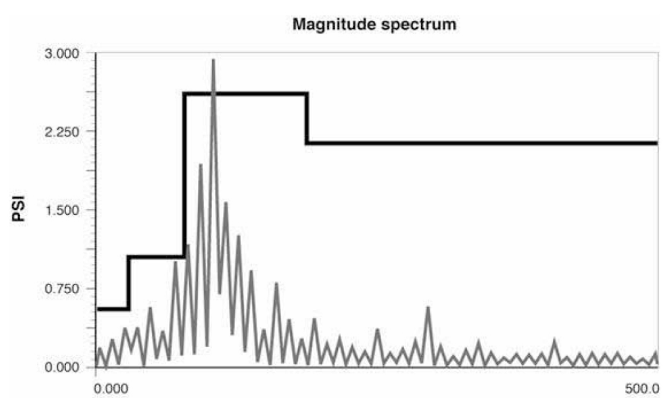


Figure 1: Example of a dynamic pressure plot in the frequency domain. Frequency bands are defined by the four windows. If the amplitude level is exceeded in any of the bands, an alarm alerts the operator of a pending problem.

To conduct required measurements and collect accurate real-time data within gas turbine generating sets, a pressure transducer is typically placed within each turbine combustor. Typically, there are approximately 14 combustors per turbine. Selection of pressure transducer type within this application environment is critical to ensuring high-reliability measurements within extreme environments. As the pressure sensor is providing the input signal to the data system, it is also extremely important that clean, reliable and undistorted signals be generated.

Design Considerations in Choosing a Pressure Transducer

Once a decision is made to implement electronic control and monitoring strategies for ongoing assessments of the combustor stage, generator operators are challenged with finding a pressure transducer technology type that will provide consistent 24/7 performance within a number of extreme environmental conditions, including:

- Continuous operation in temperatures of up to +1400°F (+760°C)
- Seamless integration with high-temperature cables
- Wide frequency response range
- Reliable operation in high vibration conditions

- Convenient mounting configurations

Unlike static pressure transducers, this monitoring application requires use of a dynamic sensor. The sensor should have a frequency response of at least 20 kHz. In general, excellent data can be obtained with an error margin of < 5% within up to 1/5 of the transducer's resonance frequency. This frequency range is generally more than adequate, since combustor resonances are typically 1200 Hz or less.

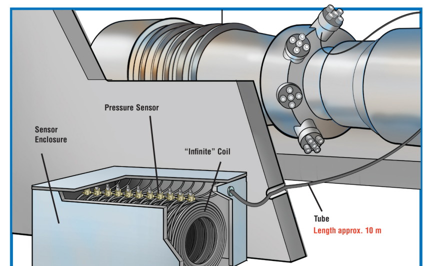
Pressure sensors have an inherent mass on the diaphragm end of the sensing crystals, making the sensing system also act like an accelerometer in the presence of high vibration levels. An accelerometer is a device used to detect vibration, a measurement parameter that is undesirable in this application. If some type of acceleration compensation or isolation is not included, the ambient vibration will distort the pressure signal.

Piezoelectric pressure sensors are AC-coupled gauges that measure only dynamic pressure and have come to be widely used for this application. Piezoelectric devices also have excellent high frequency characteristics. Since they are insensitive to static pressure, the sensor only measures dynamic pulsations, while ambient static pressure has no effect on the transducer's output signal.

Development of PCB Model 176A31 with UHT-12™ Technology

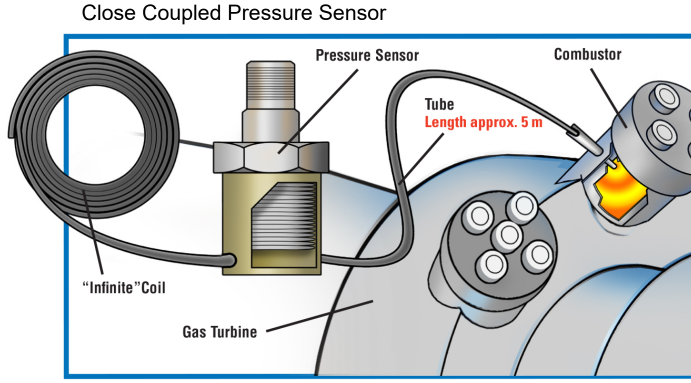
Initially, ground-isolated integrated electronic piezoelectric (ICP™) pressure sensors were installed in hundreds of turbines. While the integrated electronics allowed for amplification of the signal, the remote sensor (PCB Models 102M205 and 121A44) had a distinct disadvantage of only having a temperature tolerance of 250 °F (121 °C). As a result, the sensors had to be mounted in an ambient temperature environment external to the turbine containment area. Given the large acoustic volume between the sensor and the combustion chamber, the sensors were employed in "semi-infinite" coil systems that attenuated standing waves, but also limited the frequency range of the system. In addition, the standing waves in the gas volume between the sensor face and the combustion process caused both attenuation and amplification at various acoustic frequencies.

Remote Pressure Sensor

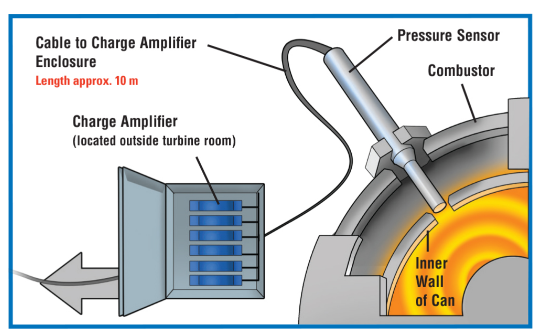


The performance trade-off of the ICP™ sensor drove the industry to develop a pressure sensor that could be moved closer to the combustion process in order to expand the frequency range of the sensor. The first embodiment of the effort was a close coupled pressure sensor (PCB Model EX171M01) that had a temperature tolerance of 500°F (260°C) and a charge mode output. The sensor could be mounted inline on an "infinite" coil system. This system achieved substantial improvements in the measurement bandwidth.

Close Coupled Pressure Sensor



The most recent effort has resulted in the development of on-turbine pressure sensors (PCB Model 176A31) in order to further reduce the acoustic volume between the sensor and combustor. Built to withstand temperatures up to 1400 °F (760 °C) with advanced crystal technology, the sensor can now be mounted directly on the combustor basket to provide 24/7, consistent, reliable combustion dynamics data so that tuning changes can be made at any time. The sensors have been specially designed with case isolation and differential output, to reduce electromagnetic interference (EMI) issues to an absolute minimum. This on-turbine mounting has led to the sensors requiring hazardous area certification as they are now operating in potentially-explosive environments.



Single, natural crystals, such as quartz and ferroelectric ceramics, are inherently piezoelectric. Most naturally-occurring single crystals that are used for sensors are grown in laboratories rather than mined, resulting in consistent quality with reduced risk of supply shortages. In addition, the man-made aspect of a natural crystal has enabled development of new, higher performance variations. In the case of PCB Piezotronics Model 176A31, the new crystal technology, UHT-12™, features:

- Absence of pyroelectric noise spikes up to 1400 °F (760 °C).
- Sensitivity that remains more consistent over a wide temperature change.
- Shear mode crystals isolated from base strain and transverse measurement errors.
- Proprietary crystal technology comes sealed in a hermetic package and has proven reliable performance in hundreds of gas turbine installations for research and monitoring.

Summary

The PCB Piezotronics Model 176A31 was expressly designed to meet the aforementioned performance requirements, and others, within power generation applications. The series incorporates a built-in accelerometer which detects interference produced by vibration, and which generates an electrical output opposite in polarity to the pressure signal. When the out-of-phase vibration signal is combined with the pressure signal, undesirable vibration effects are virtually eliminated.

The development of these pressure sensors is enabling turbine manufacturers to continue reducing NOx emissions without jeopardizing the integrity of the components downstream of the combustors. This technology is being utilized by not only turbine manufacturers, but also power plants, aftermarket service companies and system integrators that specialize in monitoring systems.

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