Endevco® high-temperature piezoelectric pressure transducers for combustor pulsation monitoring

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Bruce Lent

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Gas turbine generating sets have become increasingly prevalent within large industrial power generation plants and electric power utilities. These generating sets can be delivered in fully assembled packages and quickly installed. Unlike a large steam turbine system, they can also be quickly put online as required during high power demand.

While conventional monitoring equipment is typically employed for physical parameter measurements (e.g., temperature, static pressure, vibration) within these installation environments, generating sets also require the ability to effectively monitor combustion dynamics. Acoustic monitoring is also required to detect oscillations, such as those caused when an unstable flame front causes small waves. When the frequency of the low amplitude waves equals the resonant frequency of the combustor geometry, extremely high amplitude waves are formed. This condition is often called “humming” or “pulsations.”

Evolving environmental regulations now require that power generation plants lower their NOx emissions. To meet these regulations, newer systems burn a leaner mixture of fuel and air. While lean fuel technology leads to single digit NOx emissions, combustors operate on the edge of instability. As a result of using the leaner fuel mix, plants have experienced frequent problems with combustion resonances. This condition can cause reductions in performance and sometimes cause significant structural damage to the turbine package.

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 easily identifiable resonances in the range of 1 to 1200 Hz. Actual acceptable frequencies vary and are determined by combustor design. Early detection of resonances is important, so that corrective measures can be taken proactively before there is damage to the compressor.

Since specific frequencies must be monitored, a system of filters is often used to monitor each of the frequency bands. Newer systems use digital Fast Fourier Transform (FFT) control systems that are also capable of storing historical information and provide a real-time display of the turbine frequency spectrum. Digital systems use a 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.

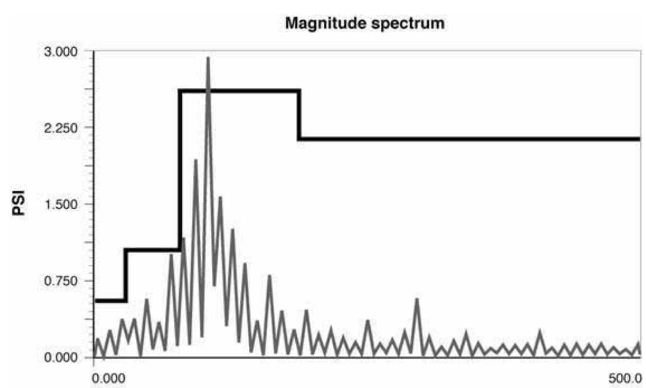

Figure 1: Example of a dynamic pressure plot in the frequency domain. Frequency bands are defined by the four windows. If the amplitude level is exceeded in any of the bands, an alarm alerts the operator of a pending problem.

Pressure transducer selection considerations

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.

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 +540°C (+1000°F)
- Seamless integration with high-temperature cables
- Wide frequency response range
- Reliable operation in high vibration conditions
- Offered in a wide range of mounting configurations

Unlike static pressure transducers, this monitoring application requires use of a dynamic sensor. The sensor should have a resonance frequency 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 generally 1200 Hz or less. To meet these specific requirements, use of piezoelectric pressure sensing technologies is recommended. Piezoelectric devices also have excellent high frequency characteristics. Since piezoelectric devices are insensitive to static pressure, the sensor only measures dynamic pulsations, while ambient static pressure has no effect on the transducer's output signal.

Different piezoelectric materials are used for pressure transduction. For example, tourmaline crystals provide the least sensitivity to thermal transients, though they exhibit a low output signal level. Ferroelectric material exhibits some response to temperature transients, though provides a higher output signal. Thermal transient effects can be minimized through the use of thermally contoured diaphragm designs.

Maximum temperature ranges of pressure sensors can go as high as +540°C (+1000°F) under continuous operating conditions and intermittently to +649°C (+1200°F) and higher with design enhancements. Certain types of piezoelectric sensing material available from Meggitt Sensing Systems has a long and successful track record within high-temperature monitoring applications, and can be seamlessly incorporated into accelerometers, allowing them to reliably perform in temperatures up to +760°C (+1400°F).

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.

The Endevco® 522 series from Meggitt Sensing Systems 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.

It is important to note that not all installations have the same mounting requirements. Due to the wide variety of turbine designs, it is also necessary to have pressure transducers available in different case diameters. As a result, Endevco® pressure sensors are available with diameters from 3/8" to 1" and with many mounting options, from threaded mounts to cases, designed to be welded into place.

The need for very high-temperature cabling within these applications is satisfied with the use of hardline cables (see figure 2), such as those available from Meggitt Sensing Systems. Within this family of sensors, a high-temperature hardline cable is directly built into the accelerometer and the temperature rating is at least that of the sensor. Most users will opt to use softline cable, connected to the integral hardline cable.

These cables are welded to the transducer with a hermetic connector supplied at the opposite end. Cables can be provided in a coaxial configuration terminating in a 10-32 connector. Many cables are furnished with a multi-pin connector and a two-conductor hardline cable.

Figure 2: A few examples of Endevco® pressure sensor packages and cables to accommodate a variety of mounting configurations. Both use hardline cable while the top sensor has a protective shield over the cable.

Use of a two-wire hardline cable is preferable in an environment where there are high levels of EMI. In this case, the two inner wires provide a signal lead and a signal ground lead. The outer shield of the cable provides protection from EMI pick-up. It is noteworthy that piezoelectric devices generally tend to be insensitive to EMI; however, associated electronics tend to be more EMI sensitive. If a differential charge amplifier is used, compatible pressure sensors are offered with a differential output providing optimum common mode rejection.