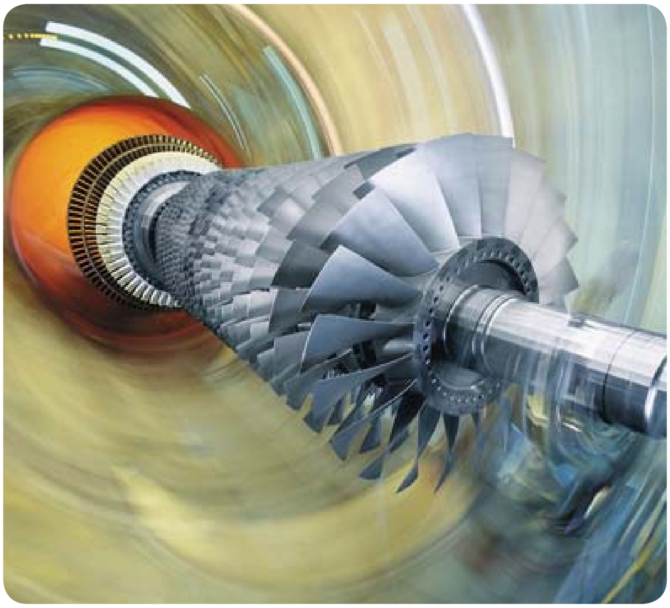
Dynamic Pressure Monitoring Gas Turbines

Industrial gas turbines

This application note discusses the techniques and equipment used in dynamic pressure monitoring and combustion control systems using piezoelectric dynamic pressure sensors. Sensor selection, installation, cabling and signal processing issues are considered in order to obtain a high performance and reliable dynamic pressure monitoring system.



Dynamic pressure monitoring

One of the challenges of the 21st century is the reduction of emissions. In the gas turbine industry, this means the reduction of Nitrogen Oxide (NOx) emissions. Turbine manufacturers are working towards combustors that operate at dry NOx levels approaching only a few parts per million (ppm). Stable combustion is vital to maintaining low emissions.

Furthermore, a failure in the combustion control can lead to hardware failure caused by "flashback" or serious oscillating dynamics in the combustion chamber. Such hardware failure is very costly to repair, as well as leading to lost availability and increased emissions. A method of controlling the combustion process is the measurement of ***dynamic pressure*** at different locations at the combustor.

In industrial gas turbines, compressed air from the compressor section flows continuously through a combustion chamber (often annular in shape) where it is mixed with fuel and ignited. This flow and burn occurs at a static pressure defined by the thermodynamics of the engine. However, there is also a small dynamic component in this pressure.

When the combustion is stable, the fluctuating pressure shows a low RMS value. When the combustion oscillates, the RMS value increases. The turbine manufacturer may use the magnitude of this RMS signal to control combustion parameters such as fuel injection. The dynamic pressure becomes the feedback measurement in a closed-loop control system, which is then used to achieve and maintain stable combustion. The use of the dynamic pressure measurement as a control parameter means it is of more critical importance than other vibration protection and condition monitoring signals. The reliability of the dynamic pressure measurement system is paramount.

The greatest obstacle in actually measuring the dynamic pressure is achieving stable characteristics over the entire temperature range present within the combustion chamber, typically up to 700 °C *(1 292 °F)*. Solutions involving location of the sensor in a cooler environment than that of the combustor itself have been tested across the globe.

Some systems involve fitting small "bleed tubes", which allow the combustion pressure to be "routed" to a cooler location and measured by a more general purpose pressure transducer. However, the drawbacks of this method are well known: sensitivity to dynamic pressure is lowered owing to the additional length of tube required. Also, the signal spectrum can be distorted by possible acoustic resonance. Some phase lag can also occur and introduce a new, difficult parameter in the active control system.

Other systems use water-cooled devices, and are therefore less reliable and more costly to implement. In all instances, as the complexity of the system increases, the reliability decreases, but the cost still remains high.

A superior solution is to place the sensor directly in the combustion chamber. To date, only a ***piezoelectric crystal device*** has been proven to withstand the high temperatures of the combustion process and provide a reliable measurement system.

Piezoelectric pressure transducers

Piezoelectric pressure transducers are a logical extension of the use of piezoelectric quartz crystals to measure acceleration. A piezoelectric crystal produces an electrical charge proportional to the mechanical force exerted upon it. Hence, in an accelerometer, Newton's Second Law is simply exploited:

- Force (N) = Mass (Kg) × Acceleration (g)

The crystal will provide a measure of the force it sees in picocoulombs (pC). Thus, if a known mass is placed upon the crystal, it exerts a force upon the crystal proportional to the acceleration of that mass. This simple equation produces a pC/g output. The dynamic pressure sensor utilizes equally simple principles:

- Pressure = Force / Area

Expose the crystal over a known surface area, then the force the crystal sees is proportional to the pressure and we have a pC/mbar output. As with an accelerometer, the technique is capable of measuring small dynamic components.

The end design is a sensor consisting of only a quartz crystal and high temperature metal alloys – no moving parts, no joints and very robust. A very reliable and accurate solution. **Fig. 1** illustrates a typical piezoelectric dynamic pressure sensor.

Fig. 1. Dynamic pressure sensor.

The effect of vibration

Some designs of piezoelectric pressure sensor are susceptible to the effect of vibration of the combustion chamber itself, which may be significant. Thus, in these cases, a model capable of compensating for this vibration should be considered. Such devices comprise of an internal acceleration-sensitive piezoelectric stack, which is subtracted from the pressure and vibration sensitive stack.

For example, a non-compensated model (e.g., the Vibro-Meter model CP 211) used in a dynamic pressure application with a dynamic range of 300 mbar can lead to erroneous data representing 10% of the full scale value due to a spurious acceleration signal of just 10 g. The same application with a vibration compensating sensor (e.g., the Vibro-Meter model CP 103) would show only 1% full scale error.

Because the typical dynamic pressure signal is very low, an acceleration-compensating sensor should always be used in high-vibration combustor locations.

Transducers, signal conditioning and transmission

The choice of transducer is dictated by the factors discussed above. **Table 1** is a specification comparison of three high temperature dynamic pressure sensor models. The remaining considerations lie with the choice of cabling and signal conditioners that are required to implement a complete system. **Fig. 2** illustrates the measurement chains required for the sensors listed in **table 1**.

Great care must be taken in the selection and harnessing of the transmission cables used for the low level signals encountered in the dynamic pressure monitoring application.

Firstly, the sensor's hard-line cable needs to be well harnessed. This precaution will avoid tribo-electric noise pickup in the mineral insulated cable. This problem should not be neglected after the charge amplifier either, although it is of less importance here. For example, a badly harnessed cable can generate 10 pC of tribo-electric noise, which in the case of the Vibro-Meter model CP 103 (0.2 pC/mbar) represents 0.625 PSI of pressure signal. The tribo-electric noise often occurs at low frequency (< 50 Hz), which may be within the measurement range of dynamic pressure monitoring system.

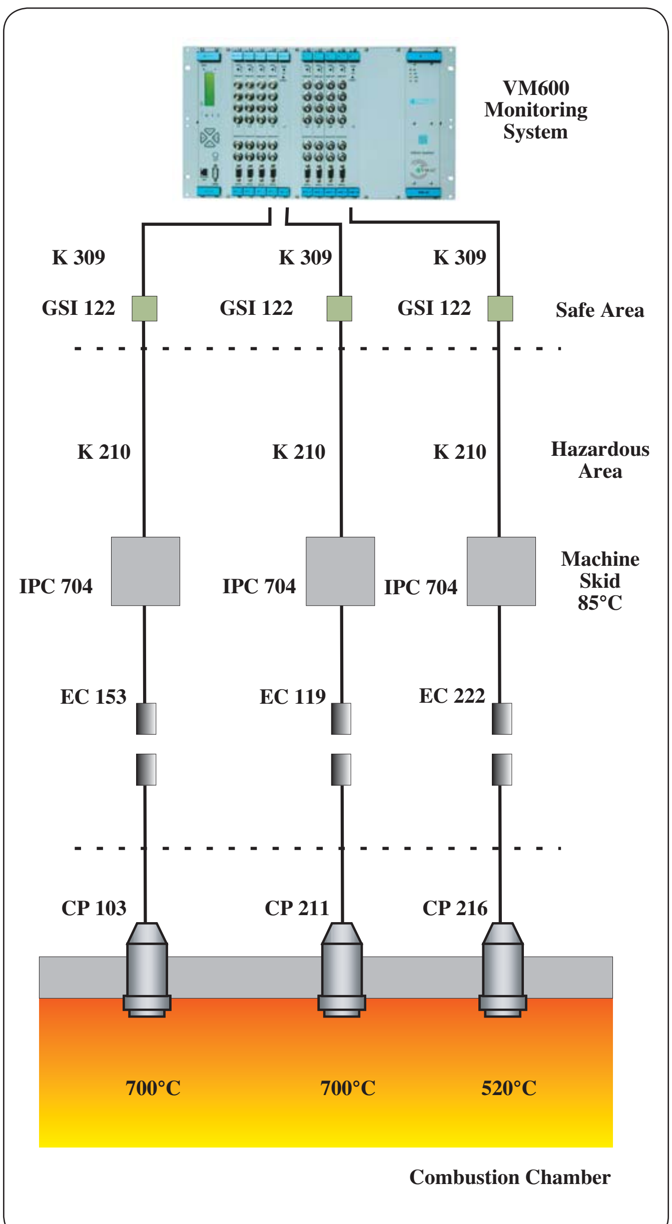


Fig. 2. Overview of Vibro-Meter dynamic pressure sensor system.

Table 1

Comparison of dynamic pressure sensor specifications

	CP103	CP211	CP216
Maximum continuous temperature	700 °C *(1 292 °F)*	700 °C *(1 292 °F)*	520 °C *(968 °F)*
Nominal sensitivity	0,232 pC/mbar *(16.00 pC/PSI)*	0,025 pC/mbar *(1.72 pC/PSI)*	0,200 pC/mbar *(13.78 pC/PSI)*
Acceleration sensitivity	< 0,2 mbar/g *(< 0.003 PSI/g)* Compensated	< 2,0 mbar/g *(< 0.030 PSI/g)* Not compensated	< 2,5 mbar/g *(< 0.036 PSI/g)* Not compensated
Sensitivity deviation from nominal	Outstanding < ±5%	< Outstanding < ±5%	Fair < ±10%
Temperature sensitivity deviation	Outstanding < ±6%	< Outstanding < ±6%	Fair < ±15%
Crystal aging	Outstanding < ±1%	< Outstanding < ±1%	Fair < ±3%
Piezoelectric crystal	Natural monocrystalline	Natural monocrystalline	Ceramic

The extension cable between the pressure sensor (e.g., CP 103) and the charge amplifier (e.g., IPC 704) must be designed for piezoelectric devices. It needs to be a low noise, low capacitance, shielded, twisted pair cable with high insulation impedance. Furthermore, it should be able to withstand the surrounding temperature, which is still high in the vicinity of the combustion chambers. The Vibro-Meter sensors all include 7/16" high temperature connector and MI cable assemblies that have been proven over many industrial applications. There are no special requirements for the cable between the charge amplifier and monitoring system – a shielded, twisted pair cable suffices.

A low noise, differential (i.e., symmetrical) charge amplifier is always recommended. Most charge amplifiers available on the market are single-ended (asymmetrical) and not optimized for high temperature sensors. For this reason, the Vibro-Meter model IPC 704 is recommended. Moreover, these sensors need a differential input to avoid noise pickup that can occur in single-ended charge amplifiers. The following four parameters have to be defined for a Vibro-Meter IPC 704 type conditioner:

- Input sensitivity: Sensitivity of the pressure sensor
- Output sensitivity: Value in µA/mbar
- High pass filter: Value in Hertz
- Low pass filter: Value in Hertz

The galvanic separation unit allows two-wire isolated signal transmission and avoids the use of Zener barriers for Ex i applications. It allows the transmission of AC signals up to 10 kHz over very long distances. The unit rejects up to 2 kV RMS of ground noise and avoids AC noise pickup that can occur between the sensor case and the poles of the sensor. Because of the very low signal levels encountered, the use of galvanic separation units in the dynamic pressure monitoring system is recommended.

Monitoring system

The evaluation takes place in a monitoring system such as the VM600 System illustrated in **fig. 2**. The VM600 is a multi-channel digital monitoring system, with a single monitor card (the MPC-4) fully programmable for virtually all applications. Each MPC-4 card supports four dynamic channels and two speed channels and provides state of the art machinery monitoring and protection. When selecting a digital system for monitoring of dynamic pressure, a data acquisition time of tens of milliseconds is necessary in order to accommodate the fluctuations in the combustor and provide a fast enough reaction time. The VM600 is specifically designed for dynamic pressure measurements in the most stringent of applications.

A dedicated system is required to provide the necessary signal conditioning for the dynamic pressure signal. **Fig. 3** shows the VM600 input setup required for a piezoelectric dynamic pressure sensor. Note units are in millibar (mbar). A band pass filter is required to ensure only relevant pressure fluctuations are measured; **fig. 4** shows the configurable band pass filter instructed on the MPC-4 card of the VM600. The VM600 system assigns a single filter or function per channel, and allows two subsequent processing paths within that filter or function. In this case, only one processing path is employed to calculate the true RMS value of the incoming signal. VM600 programming for this is shown in **fig. 5**.

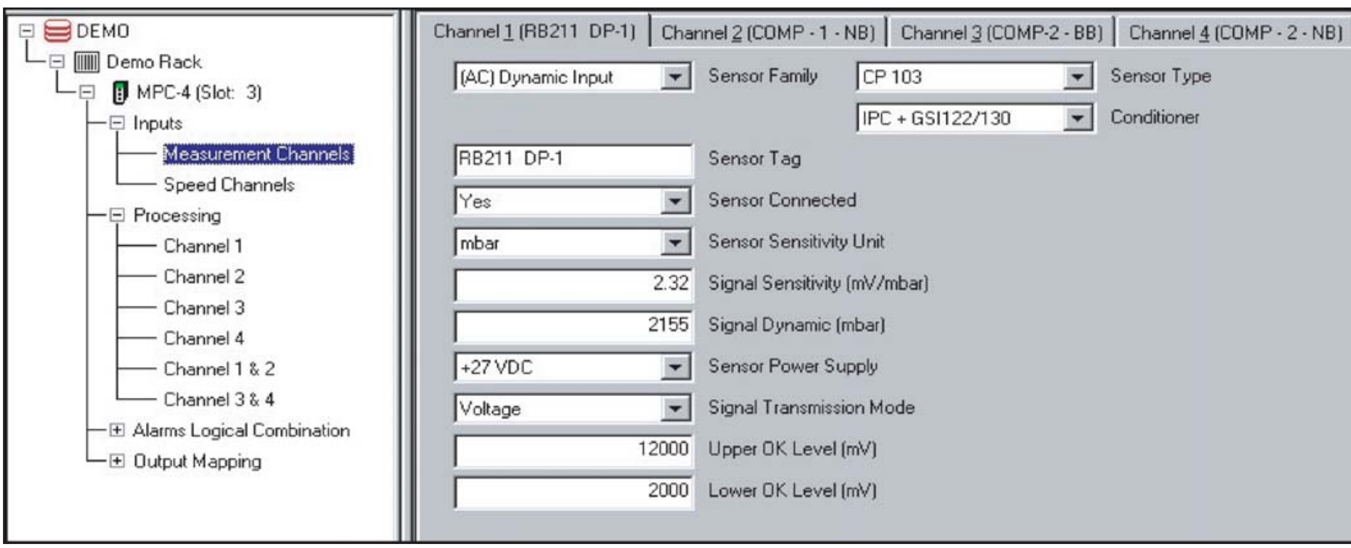


Fig. 3. VM600 input programming for dynamic pressure.

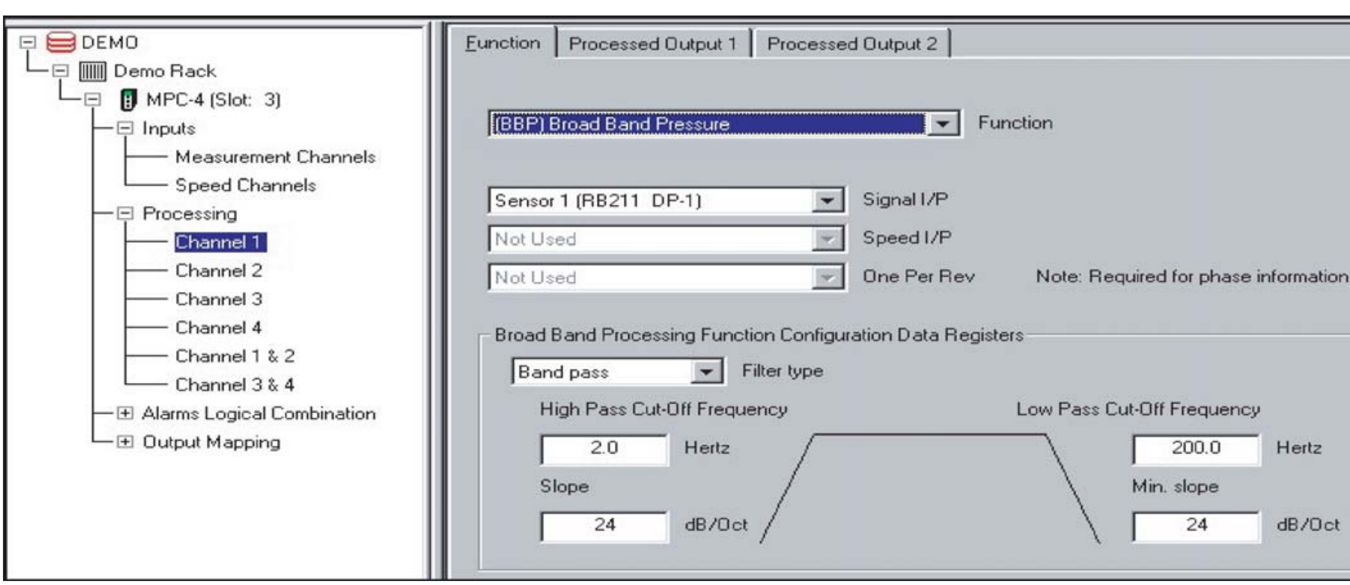


Fig. 4. VM600 processing programming for dynamic pressure.

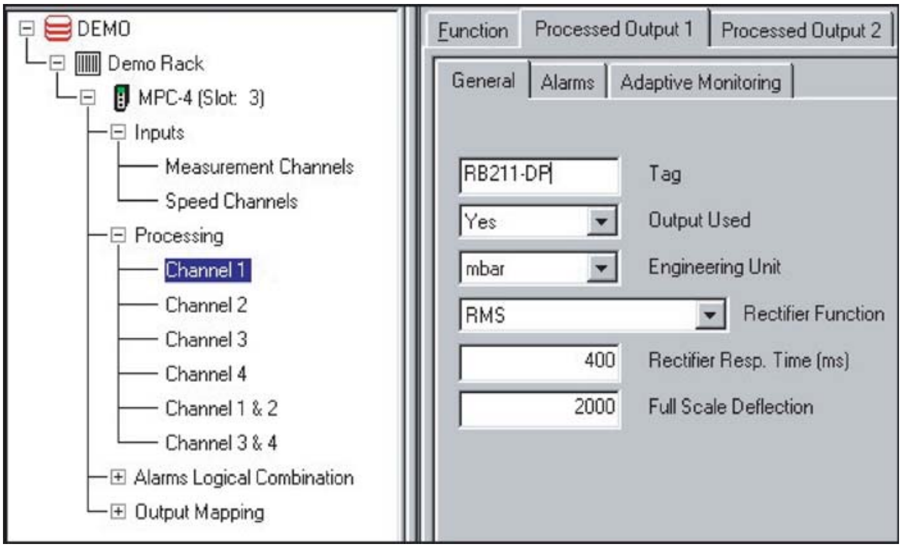


Fig. 5. VM600 processing programming for RMS pressure.

Output from the VM600 channel to the combustion control system may take any of three forms:

- Discrete output
- DC proportional output
- Software output

The discrete output takes the form of up to two relay contact closures per channel – typically an ALERT and DANGER output. These are based on RMS values and used by the control system to recognize when a particular pressure threshold has been passed.

The DC proportional output is a 4 to 20 mA or a 0 to 10 V DC level proportional to the RMS value (full scale values being definable in the VM600 software). These provide a constant, simple value the control system can utilize for feedback into a closed-loop system.

Finally, the RMS value is made available over a "soft-link" that will either be a serial communication or TCP/IP network connection. The protocol may be a common one such as Modbus, but for best integrity and reliability in this application, a proprietary protocol – tailored to the specific needs of the manufacturer's combustor control system – will bring better performance.

The piezoelectric dynamic pressure sensor has gained widespread acceptance, and **table 2** illustrates some of the gas turbine types on which it has been employed.

Table 2

Gas turbine types using dynamic pressure sensors

Manufacturer	Turbine	Sensor model
ABB	GT 8/11/13/24/26	CP 103*
Alstom	GT	CP 103
Allison	601	CP 103
Fiat Avio		CP 103
GE (General Electric)	LM 1600/2500/6000 Frames	CP 103*
Hitachi		Proprietary information
KHI (Kawasaki)	M7 A	CP 211
MHI (Mitsubishi)	501/507	Proprietary information
Nuovo Pignone	PGT-5/PGT-10	CP 216
Pratt and Whitney	FT8-2	CP 103*
Rolls Royce	RB 211/Avon	CM 103
Rolls Royce	Trent	CP 211
Siemens	V 94.2/84.3	CP 104 / CP 216
Toshiba		CP 103
Westinghouse	501	CP 103 / CMP 216

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