Fibre optical sensors for harsh gas turbine environments

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Abstract. Four selected applications of fibre optical sensors in industrial gas turbines will be reviewed. The measurement challenges, the operating principle of the corresponding fibre optical sensing solution and associated test results will be described.

1. Introduction
Gas turbines (GT) have been widely employed for decades in large quantities for electrical power generation and aircraft propulsion. Over recent years there has been an increasing demand for sophisticated instrumentation to put onto GT. GT in the power generating industry facing a number of challenges, including the need to optimize gas turbine operation to reduce pollution, coping with an increasing flexibility in fuel supply and enabling greater loads and ramp rate conditions. Combustion concepts that are being introduced to address above challenges such as lean combustion are generally prone to combustion instabilities [1]. Monitoring of combustion dynamics is therefore becoming an indispensable part of future engine development and operation.

In the aircraft industry, there is a drive to move from scheduled to predictive maintenance with the aim to reduce maintenance costs and minimize service disruption. Real-time monitoring of critical engine health parameters is being used to check that the engine is operating within the expected tolerances and that any developing potential problems can be detected at an earlier stage and corrective actions being put in place. For a robust assessment a number of critical parameters are being monitored, including turbine gas temperature, pressure, vibration and shaft speed [2].

In addition, pressure and temperature sensors are being employed upstream and downstream of the combustor. The applications include monitoring performance and stability of the compressor and temperature measurements in the exhaust and turbine regions.

Instrumentation currently used to monitor combustion processes are mainly piezo-resistive or piezoelectrical pressure sensors with a limited maximum operating temperature. They are typically used in conjunction with a stand-off tube to reduce the operating temperature of the sensor, thus resulting in an increased lifetime. This mode of operation has an adverse effect on the frequency characteristics of the sensor as the stand-off tube acts as a low pass filter [3]. This leads to a dampening effect at higher frequencies and therefore limits the potential to detect the onset of combustion instabilities. There are also practical issues associated with the tubes as they can accumulate condensation, leading to potential signal distortions.

Temperature measurements in the exhaust and turbine areas of a GT can provide invaluable information about potential combustor fault conditions. Depending on the engine type, temperatures can well exceed 1000°C, a region where common thermocouples are showing significant drift over time [4] and may suffer from reliability problems.

Regardless of the specific application, these sensors have to operate under very harsh conditions and are expected to function reliably over prolonged periods of time. Optical sensor technology is now becoming more mature and could provide a number of advantages to solve these challenging...
measurement tasks, including enhanced reliability in excess of 10,000hrs with minimal change in calibration [5].

2. Selected application examples of fibre optical sensors (FOS) to GT measurement challenges
In the talk we will discuss four selected application of FOS in industrial GT that we have been working on over the last few years. The measurement challenges, the operating principle of the corresponding FOS solution and associated test results will be described.

The first application is a single channel dynamic pressure sensor that is now available as an off-the-shelf product. The sensor is based on a Fabry-Perot sensing element employing a sapphire diaphragm that responds linearly with applied pressure. The diaphragm is part of a vacuum cavity and the occurring interference gives rise to a variation in light intensity with pressure. Due to its simplicity this scheme facilitates a very high signal bandwidth if required. In practice a dual wavelength scheme is being used to minimise measurement errors induced by fibre bend losses. Potential combustion instabilities manifest themselves as pressure fluctuations in a known frequency band. The usual practice is to use an FFT and monitor the height of the corresponding peak. The optical sensor offers a dynamic resolution of 2x10^{-5} FS in the FFT domain with the standard bandwidth set to 5Hz to 10kHz. It is now being implemented by Centrax Ltd. via a New Product Introduction process to monitor combustion instabilities in a Siemens 501-KB7S 5MW aero-derivative GT for which Centrax provides the packaging.

This type of sensor has also been used to demonstrate that compressor active stability management is possible using a high-bandwidth version of the sensor, monitoring the variation in pressure due to blade passing and comparing pressure signatures between consecutive rotations. Using this method, impending compressor stalls have been detected [6].

The third application is a multi-parameter sensor system for the simultaneous measurement of pressure and temperature. It is based on a dual-cavity sapphire sensing element and provides temperature as an additional parameter. The temperature is also used to compensate for the temperature cross-sensitivity of the pressure measuring cavity caused by thermal expansion. Two interrogation schemes have been developed for interrogating a multi-cavity sensing element. The first one is a 4 channel hybrid solution, combining the dual wavelength approach with a spectral measurement of the sapphire base cavity to extract temperature information [7]. This enables to maintain the high bandwidth for dynamic pressure measurements whilst a lower update rate of the temperature readings is sufficient, taking into account the relatively large thermal mass of a mounted sensor. Simultaneous measurements of pressure and temperature can provide added value and confidence in detecting various combustion events like flame-out and flashback. To increase accuracy a spectral readout has been developed that is used for both pressure and temperature sensing cavities. Excellent linearity with pressure < ±0.1% FS and low temperature cross-sensitivity to pressure < ±0.03% FS have been demonstrated up to 700°C and 60 bar [8]. Engine tests using the sensor with a spectral readout are planned for later this year, but this type of sensor has already been successfully installed in a SAGD installation that has its own set of environmental challenges [9].

The fourth application is a 1300°C sensor prototype for potential exhaust and turbine temperature measurements. Here the sapphire sensing element is spatially separated from the lead fibre via a long alumina tube and addressed via a collimated light beam [10]. Excellent stability of < ±1°C over 42 days at 1100°C has been demonstrated [11], and the sensor was stable to within 3°C over 47 days at 1300°C. A resolution of better than 0.5°C at 1300°C was achieved. Being able to place the sensor closer to the combustion region is expected to enable a more direct measurement with the ability to identify annular combustor can-by-can temperature variations directly.
3. References

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