

Optical Sensors for Harsh Environments

Harpin/Arnold
Oxsensis Ltd
Rutherford Appleton Laboratory
Didcot OX11 0QX UK

1. Introduction

Oxsensis produces a range of High temperature pressure sensors for use in Gas turbine and Jet engine monitoring and diagnostics. Such sensors are able to withstand higher temperatures than electronic sensors and can deliver both static and dynamic pressure measurements and we collaborate with a number of manufacturers in this area.

These sensors have been described elsewhere [1][2] and it is not the purpose of this paper to describe them further, but we have mentioned them as we have applied the same technology to temperature sensing in response to interest from the Gas turbine community.

Initially the desire to measure temperature came from the need to maintain the calibration over temperature of our pressure sensors. Initially this was estimated from the expected temperature of the engine and used to give a limit on accuracy of the static pressure reading. We will describe the limitations of this approach and the benefit of measuring the temperature of the sensor whilst it is measuring pressure. We will describe an interrogation scheme to measure multiple parameters in an optical sensor and present some simulated and actual results.

Further interest lead to the development of temperature sensors to read the temperature of the gas flow they are in. We will describe some developments we have made in this direction.

2. Effect of temperature compensation on accuracy

The following graph shows the sensitivity to temperature of a 1Bar sensor

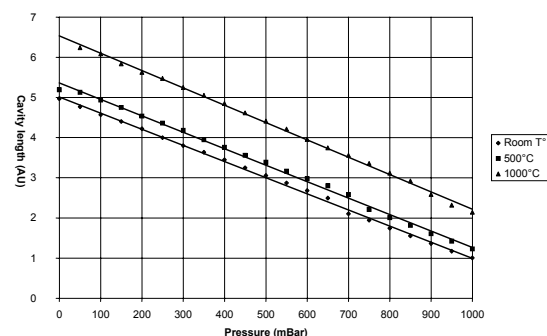


Fig.1

The cross sensitivity to temperature is 0.2mBar/°C, which means that to keep the error due to temperature 0.1% we need to know the temperature to better than 0.5°C. This requires being able to monitor the temperature of the very sensor itself in real time, and not infer the temperature from the engine or casing temperature or some nearby thermocouple.

3. Simultaneous Temperature and Pressure measurement

If we examine the structure of a sapphire optical temperature sensor one will see that it provides several optical cavities one of which is sensitive to pressure.

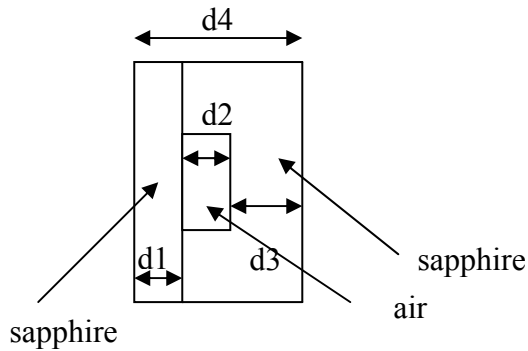


Fig.2

In the figure above, as we have described elsewhere the layer labelled d_1 is in fact thin enough to respond to variations in pressure that the sensor pill is exposed to. It may be scaled appropriately depending on the pressure sensitivity and movement required. This has been developed extensively in our pressure sensor. Conventional interrogation techniques can then decode the length of cavity d_2 , whilst ignoring the effects of d_1 and d_3 , for example by having a source with limited coherence length.

It is also possible to use a tunable filter such as a Mach Zehnder interferometer to interrogate such a cavity, but what we have also demonstrated is the fact that such a Mach Zehnder can interrogate multiple cavities or that the movements of other cavities can be ignored or taken into account as necessary. The schematic figure below shows the optical set up.

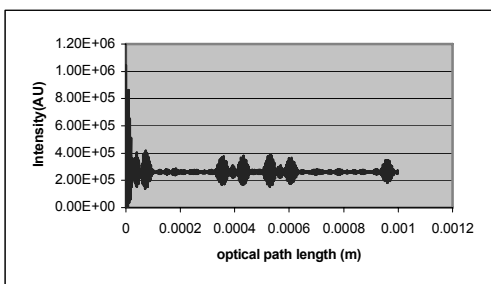
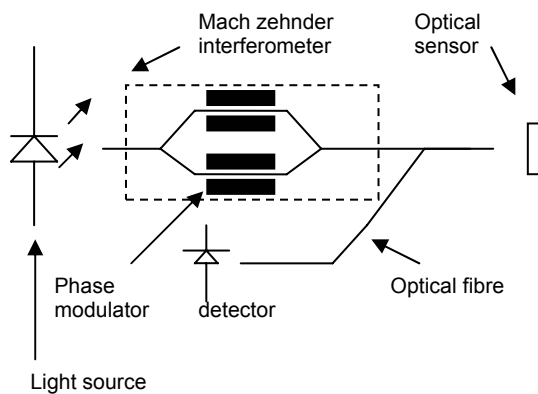


Fig.3

The graph in Fig. 3 above shows the simulated response of the system as the effective path length difference of the Mach Zehnder is scanned over the range of path lengths presented by the sensor. Should one cavity change it will not affect the other peaks. In practice this can be extended to use as many Mach Zehnders as necessary as it is not always convenient to modulate them more than a few microns effective path length and so each Mach Zehnder can independently be matched to its own cavity and track it as necessary. Below we show an expanded version of the graph so we can get more insight into how the measurements are carried out.

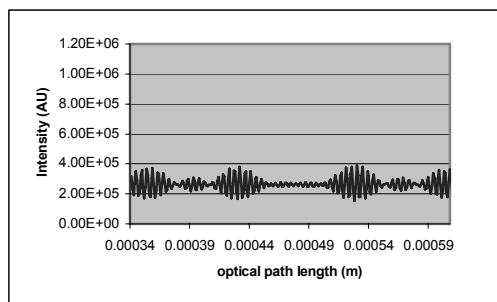


Fig. 4

We can see that for a certain cavity there is a fringe pattern with a central maximum or minimum (depends on reflections being considered) and that to determine the exact length of the cavity one needs to locate accurately the maximum (or minimum)

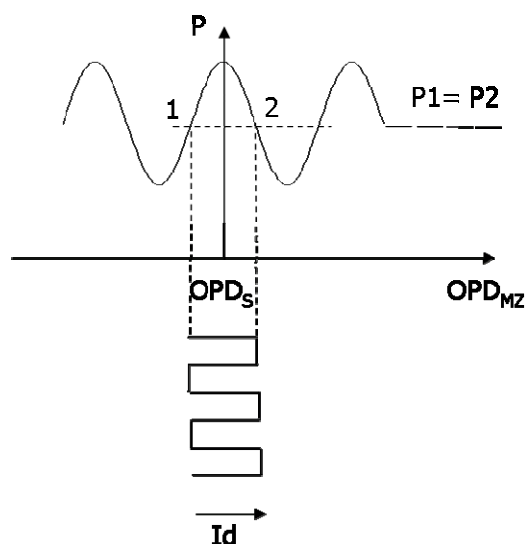


Fig.5

In fig. 5 we can see that if the optical path length of the Mach Zehnder (MZ) is dithered either side of the path length of the sensor then a symmetrical signal is produced, whereas if it is not matched the result in fig. 6 shows that the signal is asymmetrical

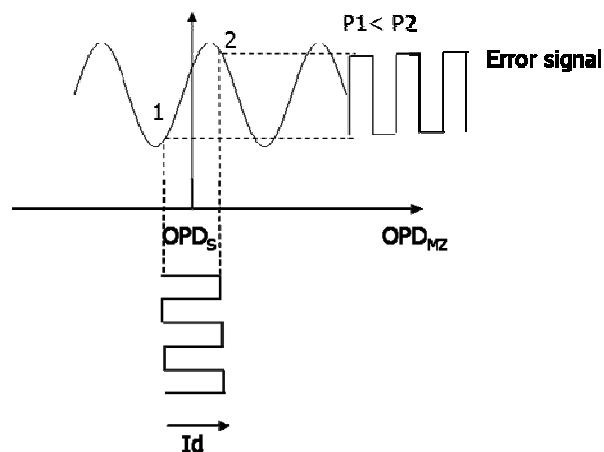


Fig. 6

The schematic in figure 7 shows one method of processing the signal. The error signal is multiplied by the driving or 'clock' signal, and this will result in a signal whose average is zero when in balance. This technique can be used effectively to provide feedback to the mach Zehnder interferometer to keep its path length matched to that of the sensor, so the output signal depends on the repeatability of the MZ interferometer, which being a solid state device should be very good. Also because the set up matches interference patterns, one is looking for spectral rather than intensity based features, and as such the set up is potentially more immune to intensity fluctuations due to for example, ageing, or fibre bending. Work is on going to confirm the accuracy of this method, but simulations show that accuracies of better than 0.1% should be possible.

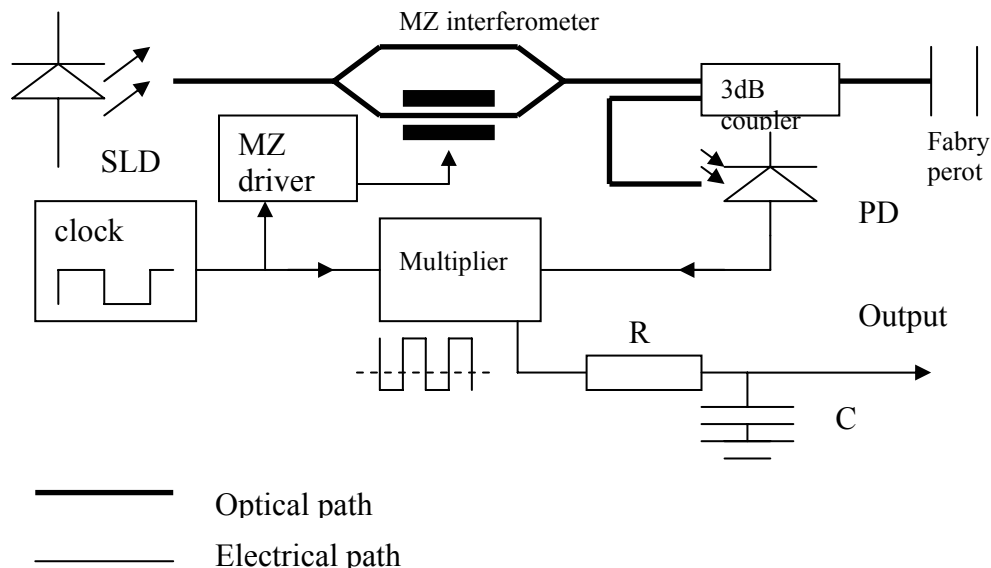


Fig.7

We have simulated this method of interrogation in software using a sapphire cavity of the form shown in figure 2. The sensor was packaged using Oxsensis proprietary packaging techniques for harsh environments. We were able to measure the change in the front diaphragm d1, and the rear diaphragm d3. This demonstrates the ability to decode two cavities separately. The two graphs below (fig. 8, 9) show that each cavity varies with temperature but because they are different thicknesses they expand differently. A trendline has been superimposed on the graphs as have 1% error bars. The errors are due to the accuracies of the experiment.

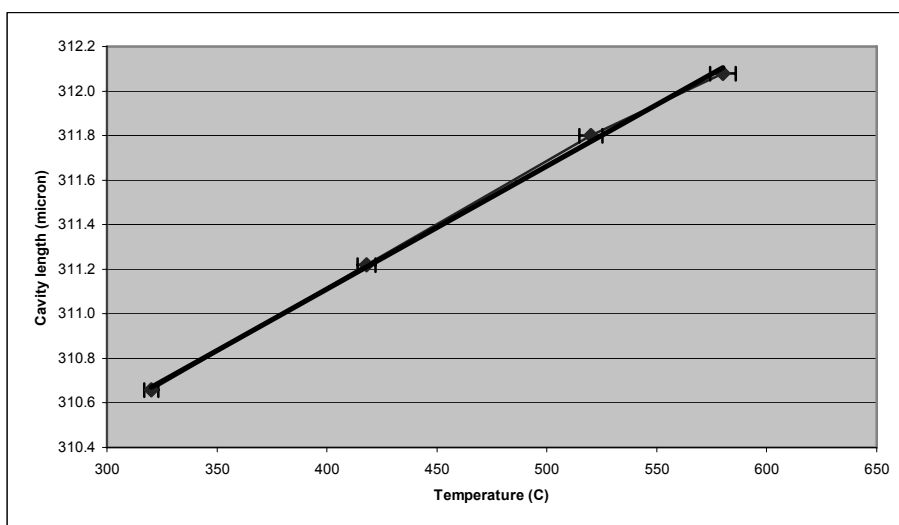


Fig. 8

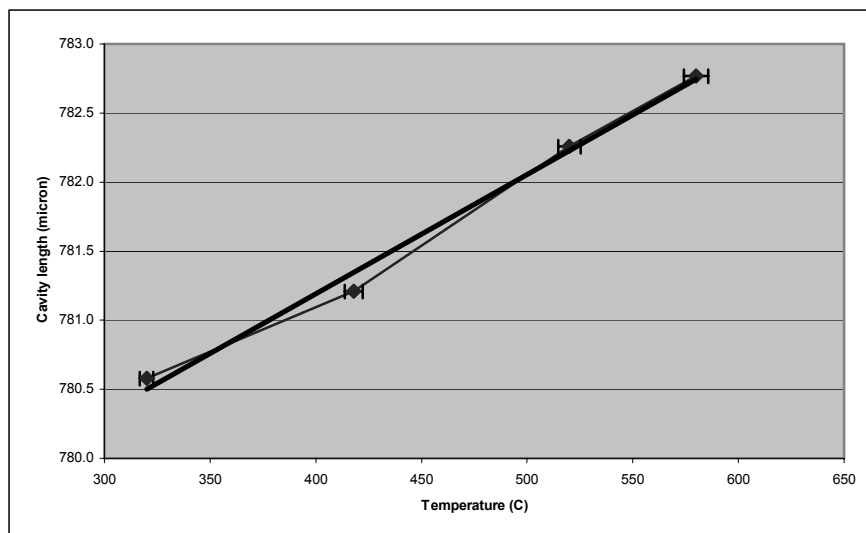


Fig. 9

These simulations show the effectiveness of the Mach Zehnder in interrogating multiple cavities, and if one of the cavities responded to pressure then we could independently measure temperature and pressure at the sensor simultaneously.

4. Fast Temperature Measurement

The section above describes the measurement of temperature on a fairly slow timescale; the time taken for a jet engine casing or the optical sensor embedded in it to change temperature. The interrogation scheme described should be able to go at speeds of several tens of kHz, but the actual temperature of the sensor that we are interested in will presumably be limited by the thermal mass of the system. If one is interested in the temperature of the gas flowing past the sensor then a sensor is required that can be inserted into the gas stream whilst returning the gas temperature independently of the mounting surface the sensor is mounted in.

Thermal modelling shows that a thin diaphragm of sapphire mounted with a very small contact area to a ceramic of poor thermal conductivity can produce a rugged sensor as shown in fig.10 below with a speed of response to a gas temperature change of better than 0.1 second.

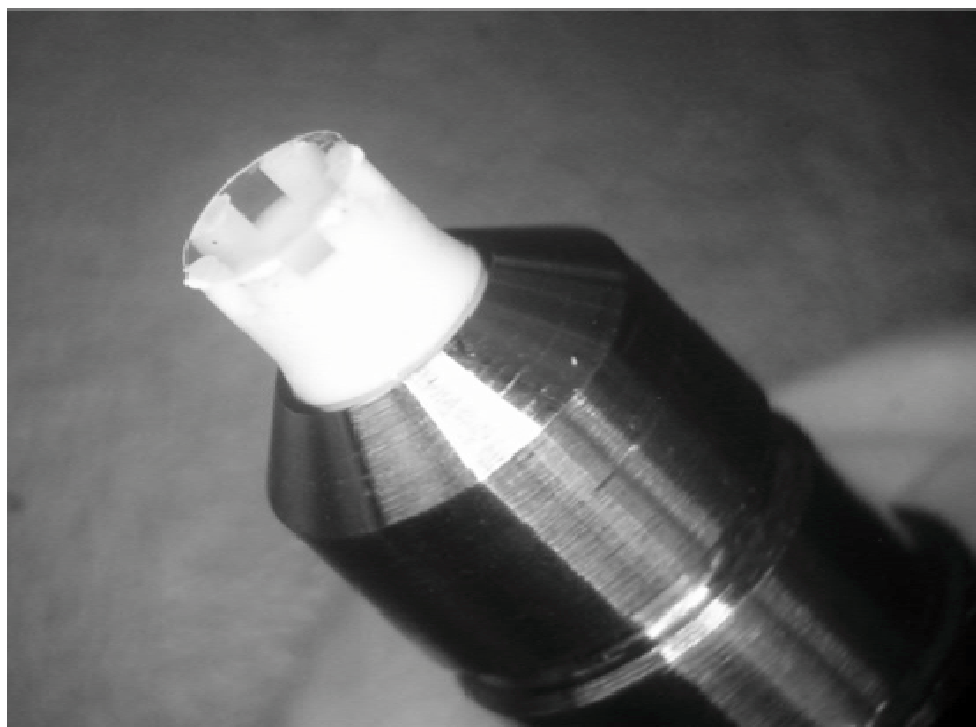


Fig.10

Whereas this approach has been demonstrated for moderate temperatures (350°C) we have also modelled a different approach. For maximum thermal survivability one needs to make the hot part of the sensor out of one material, say sapphire. To this end we modelled how long a rod would be required to give fast response independent of the mounting surface of the sensor. As we can see from fig. 11 below a very long thin rod is required- of the order of 2mm for a 10 μ m diameter rod!

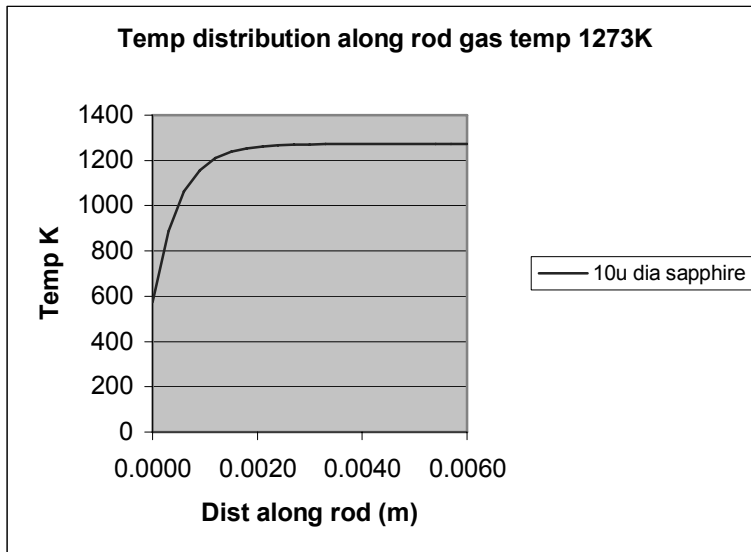


Fig. 11

5. Summary

We have developed an interrogation method that is potentially low cost and is rugged and compact which can interrogate multiple optical cavities in real time and at high speed (10's of kHz), and are in the process of fully characterising its performance. It is particularly suited to interrogating our harsh environment sensors for static and dynamic pressure and also simultaneously measuring their temperature. Similarly it can be used for high speed temperature measurements for example in surge detection.

We are also working on variants of our existing sensors optimised for temperature measurement.

[1] "High Speed, High Dynamic Range Pressure and Temperature Sensor Results in High Temperature Environment", A. Harpin 3rd EVI GTI International Conference on Gas Turbine Instrumentation 28/29th Sept.2006, Rome, Italy

[2] "Ultra High Temperature Sensor Systems for Static and Dynamic Pressure, and Temperature" I. Evans et al. ISA International Society for Automation May 2008