

Recent Advances in Distributed Optical Fibre Temperature Sensing using the Landau-Placzek Ratio

Gareth P. Lees^a, Peter C. Wait^b, Arthur H. Hartog^b and Trevor P. Newson^a

^a Optoelectronics Research Centre, University of Southampton,

^b York Sensors, York House,
Abbey Park Ind. Est., Romsey, SO51 3AQ, UK

Abstract

Distributed optical fibre temperature sensing (DTS) provides an elegant way of monitoring the temperature at many points without necessitating the accurate positioning of individual discrete sensors. This paper demonstrates recent advances in distributed temperature sensing based on spontaneous Brillouin scattering. A high spatial and temperature resolution is achieved by exploiting a novel low cost detection system. The experimental configuration consists of two key components; a Q-switched laser source to generate the backscattered signal and the low cost detection system which comprises an in-fibre double pass Mach-Zehnder interferometer and a sensitive InGaAs APD connected to a computer based averaging system. It is the relative low cost of these components which has made the Brillouin based temperature sensor so attractive for commercial exploitation. A spatial resolution of 3.0 metres with a Brillouin temperature resolution of 0.9°C at a range of 16km has been achieved.

Introduction

Optical fibre distributed temperature sensors (DTS) is a rapidly expanding field which has applications as diverse as fire detection in underground storage tanks to monitoring of temperature profiles of power cables. These applications rely on the immunity of fibre optic sensors to electro-magnetic interference and the ability of fibre sensors to be operated in environments where electrical signals are hazardous. The use of optical fibre sensors for temperature sensing is an elegant way of monitoring, quasi-simultaneously, thousands of points avoiding the requirement of optimum positioning of discrete sensors.

DTS systems operate on the powerful optical time domain reflectometry (OTDR) technique where a pulse of light is transmitted down the sensing fibre and the intensity of the light which is backscattered within the numerical aperture of the fibre is measured. The time between sending the pulse of light into the fibre and detecting the backscattered signal provides a measure of the distance along the fibre whilst the physical characteristics of the backscattered light provides valuable information on fibre parameters such as optical attenuation, temperature and strain. The current commercially available distributed temperature sensors function by detecting the Raman backscattered light, the intensity of which provides information on the

temperature profile of the fibre under test. This paper demonstrates recent advances in distributed temperature sensing based on the detection of spontaneous Brillouin backscattered light which offer increased versatility (strain and temperature sensing) and the possibility of increased range over the Raman based systems.

Experiment

The experiment consists of two basic components; a laser source to generate the Brillouin backscattered signal and a low cost detection system which comprises an in-fibre Mach-Zehnder interferometer and a sensitive InGaAs APD connected to a computer based averaging system. It is the relative low cost of these two principal components which has enabled the Brillouin based temperature sensor to be constructed for commercial exploitation.

Q-switched fibre laser: Recent advances in the field of optical fibre Bragg gratings have made it possible to produce a Q-switched Erbium doped fibre laser source which satisfies the narrow linewidth requirements for Brillouin distributed sensing¹. The Brillouin backscattered signal is separated by 0.08nm from the Rayleigh signal when operating at a wavelength of 1.53µm. Therefore a laser with a linewidth of less than 0.08nm is required in order to be able to spectrally

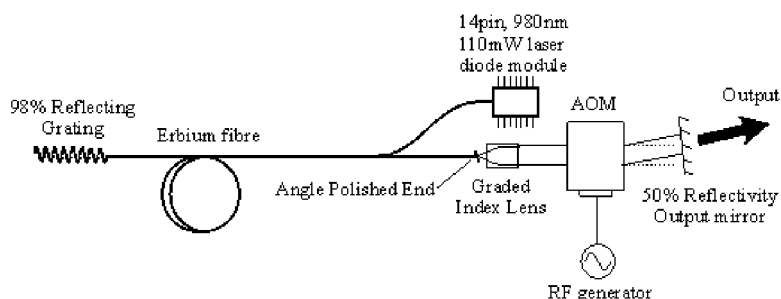


Figure 1 - Schematic of the narrow linewidth Q-switched fibre laser used for Brillouin temperature sensing

resolve the two signals at the detection system. A schematic of the Q-switched fibre laser is shown in figure 1.

The laser consists of a length of Erbium doped fibre which is pumped with a fibre pigtailed 980nm laser diode. The cavity is defined by a broadband dichroic output mirror with a reflectivity of 50% and a high reflectivity (98%), narrow linewidth fibre grating. The laser is Q-switched using a bulk acousto-optic modulator and the laser output is taken from the first order beam. Operating the laser in this configuration allows the ASE which is generated from the Erbium doped fibre, between the Q-switched pulses, to be gated out. In this configuration high power (10W), short duration (30ns) pulses at a repetition rate of 1kHz were produced. The laser wavelength which is determined by the grating wavelength is 1532nm, which lies in the low-loss window of single-mode silica fibre, a necessary criterion for a long range sensor. The linewidth of the laser is also determined by the in-fibre Bragg grating and is measured to be 16pm (2GHz) using a Fabry-Perot interferometer. A source linewidth of 0.08nm (10GHz at 1.53 μ m) is required in order to spectrally resolve the Rayleigh and Brillouin backscattered light.

The pulses from the Q-switched laser are coupled into the sensing fibre using an appropriate coupler or circulator, the returning backscattered light is then passed into the Mach-Zehnder interferometer to separate the temperature sensitive Brillouin

component from the much larger Rayleigh component.

Mach-Zehnder Interferometer:

The detection systems used in recent distributed Brillouin temperature sensors operate on heterodyne detection or the use of expensive, high loss bulk Fabry-Perot interferometers. In this paper we report on the use of a double pass configured in-fibre Mach-Zehnder interferometer consisting of two 3dB couplers as shown in figure 2 with a path imbalance in one of the interferometer arms². In order to spectrally separate the Brillouin signals from the Rayleigh the interferometer should have a free spectral range of 22GHz which is twice the Brillouin separation from the Rayleigh. A 22GHz FSR corresponds to a path imbalance of 8.8mm.

This double pass device, provides in excess of 27dB extinction of the Rayleigh signal from the Brillouin and is stabilised using a Peltier heat pump on one arm of the device. This provides a control of the path imbalance in the interferometer. The feedback for the control is provided from a 5% tap in the Rayleigh arm which the controller aims to maximise. In maximising this Rayleigh, the counter-propagating Brillouin signal is then maximised and can be detected at the output of the filter. The control circuit is used to match the peak of the transfer function of the Mach-Zehnder to the wavelength of the laser generating the

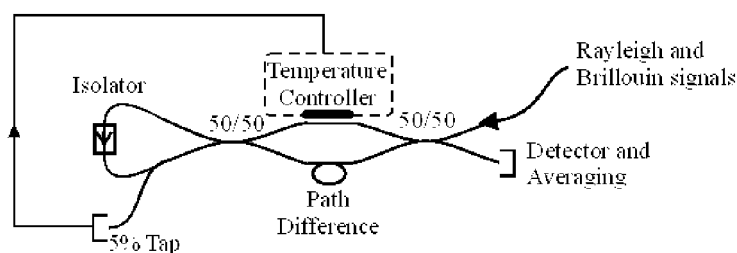


Figure 2 - Schematic of a double pass Mach-Zehnder Interferometer used to separate the Brillouin signal from the Rayleigh

backscattered light. The laser wavelength drifts slowly with time because of the dependence of the grating wavelength on temperature ($1.25\text{GHz}/^\circ\text{C}$

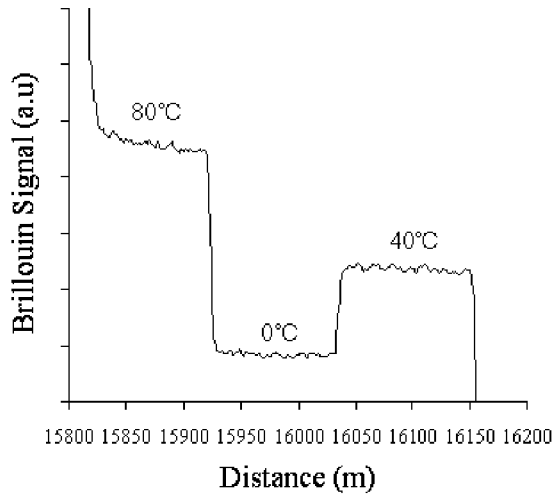


Figure 3 - Spontaneous Brillouin Signal for fibre at three different temperatures

@ $1.53\mu\text{m}$). The time response of the control circuit is selected to track this temperature shift.

Results

The Brillouin results obtained are shown in Figures 3 and 4. These plots show the spontaneous Brillouin backscattered signal for a test section of fibre which has a temperature profile of 80°C , 0°C and 40°C in equal 100 metre sections. These results are taken at a distance of 16km down the sensing fibre.

The RMS temperature resolution of the Brillouin signal was measured to be 0.9°C with a spatial resolution of 3.0metres (Figure 4). This Brillouin signal cannot be used to measure absolute temperature due to the dependence of the signal on fibre attenuation and localised splice/bend losses. In order to take absolute measurements, the Brillouin signal has to be referenced to the Rayleigh backscattered signal which is independent of temperature. The ratio of the Brillouin and Rayleigh signals is known as the Landau-Placzek ratio and provides a temperature dependent signal which is corrected for splice/bend losses and fibre attenuation (Figure 5)³.

Figure 5 shows the Landau-Placzek ratio for the same three 100 metres lengths of test fibre. The RMS noise on the Landau-Placzek ratio was measured to be 1.4°C , which is higher than that on the Brillouin signal. This observed increase in

noise is due to the presence of coherent Rayleigh noise (CRN) on the Rayleigh signal. Coherent

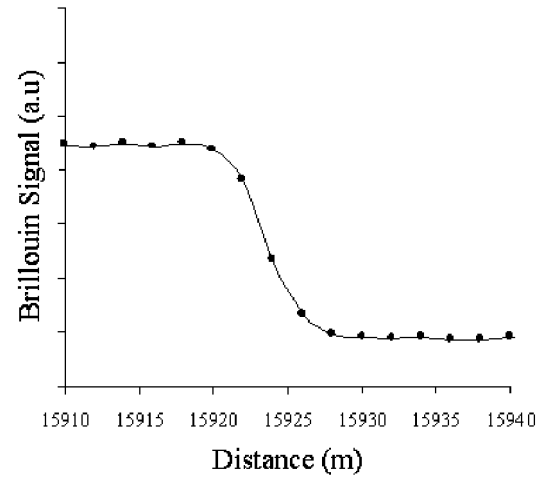


Figure 4 - Results showing the step between the 80°C and 0°C sections of fibre to illustrate the 3metres resolution

Rayleigh noise is generated from the coherent interference between light backscattered from different scatter elements (density fluctuations, variations in fibre composition) to generate random intensity fluctuations⁴. CRN can be reduced by a technique of frequency shift averaging. This can be carried out by either using a broadband laser diode or by scanning the wavelength of the Q-switched fibre laser over a number of nanometers⁵. In this experiment a broadband source with a linewidth of 2.9nm was used to generate the Rayleigh signal.

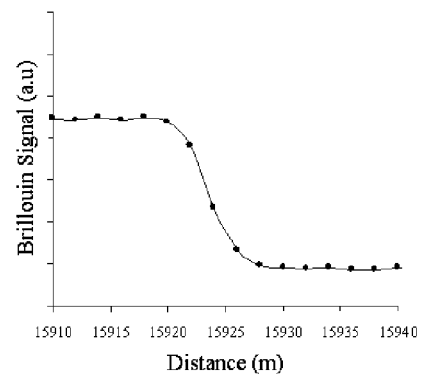


Figure 5 - A plot of the Landau-Placzek ratio which is the ratio of the Brillouin signal to the Rayleigh

Conclusions

A spontaneous Brillouin based temperature sensors has been demonstrated with a temperature resolution of 1.4°C and a spatial resolution of 3.0metres at a range of 16km. By further implementation of techniques to reduce coherent Rayleigh noise a temperature resolution of 0.9°C on the Landau-Placzek ratio is possible. We believe the reduced cost of the detection system demonstrated in this paper could significantly improve the attractiveness of Brillouin scattering for temperature sensing.

Acknowledgements

This work has been carried out in collaboration with York Sensors Ltd and Pirelli Cables as part of the NOMADS LINK programme.

References

1. G.P.Lees, M.J.Cole and T.P.Newson: "A Narrow linewidth Q-switched Erbium doped fibre laser", *Electronics Letters*, Vol.32, No.14, pp.1299-1300, (1996)
2. K. De Souza, G.P.Lees, P.C.Wait and T.P.Newson: "Diode-pumped Landau-Placzek based Distributed Temperature Sensor utilising an all-fibre Mach-Zehnder Interferometer", *Electronics Letters*, Vol.32, No.23, pp.2174-2175, (1996)
3. P.C.Wait and T.P.Newson: "Landau-Placzek ratio applied to distributed fibre sensing", *Optics Communications*, Vol. 122, pp. 141-146 (1996)
4. K.Shimizu, T.Horiguchi and Y.Koyamada: "Characteristics and Reduction of Coherent Fading Noise in Rayleigh backscatter measurements for optical fibres and components", *Journal of Lightwave Technology*, Vol.10, No.7, pp.982-987, (1992)
5. G.P.Lees, P.C.Wait, M.J.Cole and T.P.Newson: "Advances in Optical Fibre Distributed Temperature Sensing using the Landau-Placzek ratio", *IEEE Photonics Technology Letters*, Vol.10, No.1, pp.126-128, (1998)