

Development of distributed fibre optic temperature sensor with sub-metre resolution

Fibre-optic distributed temperature monitoring offers special advantages for remote measurements in hazardous environment or in a situation where there is a large amount of electromagnetic noise and possibility of data corruption. It also offers particular advantage in places where there is risk of sparking due to atmospheric volatility, such as oil refineries.

Distributed anti-Stokes Raman thermometry (DART) is becoming a major technology for measurement of temperature along optical fibres. The distributed temperature sensing (DTS) method, based on optical time domain reflectometry (OTDR) using Raman effect, represents a powerful breakthrough in temperature measurements by providing fast, accurate and high-resolution information.

In the DTS technique, a pulse laser is coupled to an optical fibre through a directional coupler. The light is backscattered through the fibre due to changes in density and composition as well as due to molecular and bulk vibrations. The back-scattered light consists of a Rayleigh component, a Brillouin component and a Raman component.

Thermally influenced molecular vibrations cause the Raman backscattered component to change and therefore it is

sensitive to temperature. The anti-Stokes component is strongly dependent upon temperature, while the Stokes component is weakly dependent on temperature. Therefore, the ratio of anti-Stokes to Stokes signal provides an absolute value of temperature irrespective of laser power, launch conditions and fibre geometry¹. Combining the temperature measurement technique of Raman backscatter with distance measurement through time-of-flight of light, DTS provides temperature measurements along the length of the fibre.

One of the most important features of the DART sensor is its spatial resolution. Standard DART sensors can achieve a best spatial resolution of 1 m. Although this resolution is adequate in some applications, it may not suffice in cases like monitoring of transformers and steam pipes in power plants for accurate detection of hot zones. Here we report the development of a DART-based system with sub-metre spatial resolution. In many respects, it is comparable to commercially available systems and on some counts it is even superior to them.

The basic scheme of our DART system reported earlier¹ has been substantially modified to demonstrate the spatial resolution aspect (Figure 1). The excita-

tion source in the present scheme is a compact 2 ns, 10 nJ adjustable repetition rate diode laser working at 850 nm. The monochromator has been replaced with interference filters to increase light throughput. Special optics has been developed to reduce losses and improve light collection. The Raman anti-Stokes is recorded near 820 nm using a fast photomultiplier as detector.

Its negative output is connected directly to a 500 MHz Tektronix digital storage oscilloscope (DSO), which has storage and PC interface capability. Special heating tapes have been used to heat selective portions of the fibre rather than use of a hot chamber.

In order to demonstrate the capability of the system, a two-step approach was adopted. First, two heating tapes were wound on two small fibre sections located at about 40 m from the far end of a 120 m long sensor fibre in such a way that about 2.3 m of the fibre portion between them is maintained at room temperature, while short lengths of the fibre on both sides are heated.

The oscilloscope has been adjusted such that it clearly shows the signal/information from relevant zones only. This is done by monitoring high reflection peaks (trace not

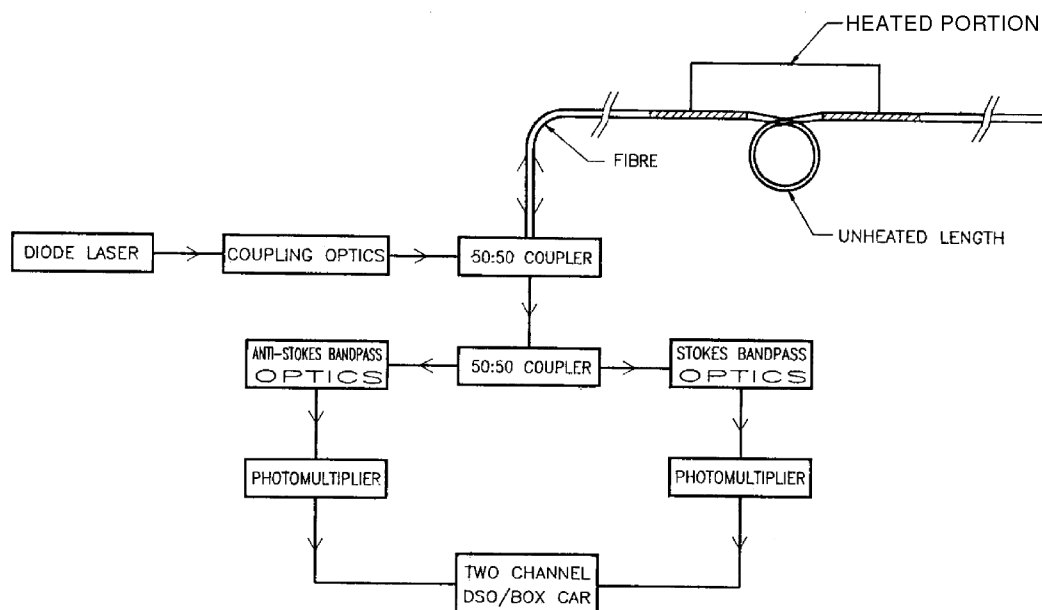


Figure 1. Schematic diagram of fibre optic Raman distributed temperature sensor.

shown) from the two fibre ends according to normal practice in standard OTDR and then suitable zones are selected by trigger delay in DSO. Figure 2 with curves 1, 2 and 3 shows the anti-Stokes signals recorded on DSO under different fibre conditions and with slight trace shift in vertical axis. This is the negative output of our detector. On the horizontal axis, time information conveys spatial location of the fibre (10 ns = 1 m) and the vertical axis provides the intensity of the Raman signal from the corresponding locations. Normally, in a homogenous fibre, the intensity of backscattered light decays exponentially with time. However, as the total fibre length is small with low net loss and the anti-Stokes signal from a part of this fibre is selected to view on the CRO screen, we observe a flat signal with time.

Curve 1 is the anti-Stokes signal when the entire fibre is maintained at room temperature. Curve 2 shows the anti-Stokes signal when only one fibre section/coil of 2 m length is heated (the baseline is shifted to clearly see the trace). The peak (increase in negative signal) shows the rise of Raman anti-Stokes signal from a fibre section which was heated. Curve 3 shows the signal when two fibre sections (not equal in length) are heated, while about 2 m fibre loop in between is maintained at room temperature (note baseline shift). The two peaks (increase in negative signals) riding on the normal anti-Stokes Raman backscatter distinctively represent two hot zones. One can also notice that these peaks do decay and reach the normal anti-Stokes signal level in the intervening zone, which indicates the presence of a cold zone between hot zones. This gave us the confidence that hot zones as small as 2 m can be precisely located in a long fibre. The challenge now was to prove that two hot zones separated by sub-metre cold zone are distinctively observed.

The usual Raman anti-Stokes exponentially decaying signal with time, arising from the entire full fibre length, has not been shown to maintain brevity in text. As a final step, to prove decisively sub-metre spatial resolution, a single heating tape is wound in such a way that only 90 cm fibre length (sub-metre) is maintained at room temperature, while on both sides, small fibre lengths are heated to about 90°C. For this purpose, from a long fibre at a distance of about 40 m from the far end, a loop of 90 cm length was

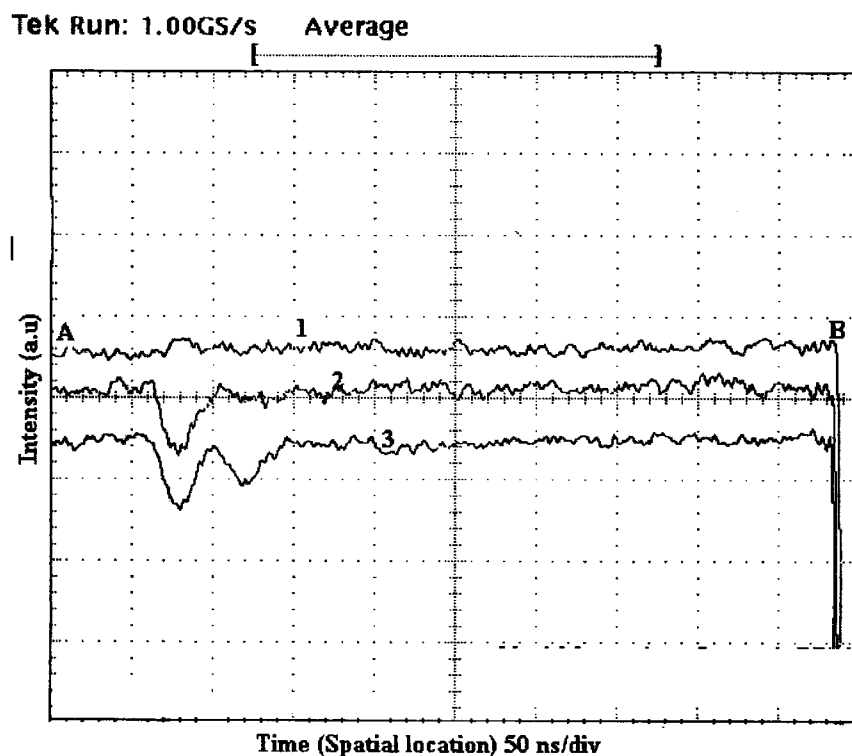


Figure 2. Raman anti-Stokes signals. Curve 1, DSO trace when the entire fibre is at room temperature. Curve 2, DSO trace when a small section of the fibre is kept at an elevated temperature. Curve 3, DSO trace when two fibre sections are heated, while about 2 m of fibre at the intervening zone is kept at room temperature.

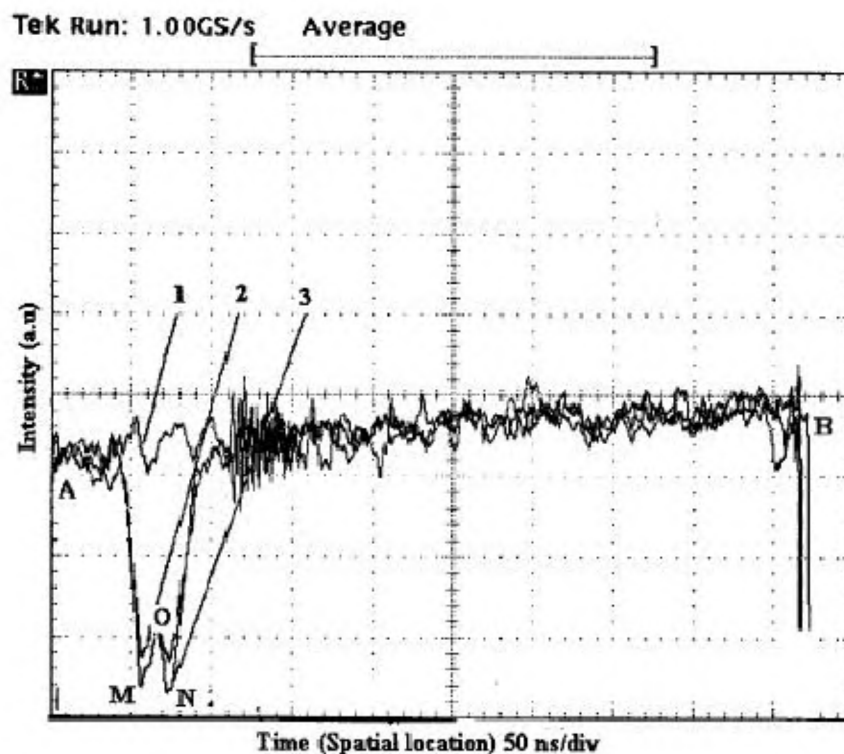


Figure 3. Raman anti-Stokes signals. Curve 1, DSO trace when the entire fibre is at room temperature. Curve 2, DSO trace when two fibre sections of about 1 m length are heated, while about 90 cm of fibre at the intervening zone is kept at room temperature. Curve 3, Recorded when the heated fibre sections were at slightly higher temperature.

prepared, positioned and isolated in such a way that it does not get heated, whereas about 1 m fibre lengths are heated on both sides of this loop.

The DSO horizontal and vertical sensitivities, trace and trigger delays are adjusted such that the anti-Stokes Raman signal from the relevant heated zones is seen clearly on the screen. Since the laser pulses are stable with low pulse-to-pulse fluctuations, the signal recorded only at anti-Stokes wavelength represents true temperature information.

Each DSO trace is recorded with 2000 pulse average to improve S/N ratio, stored and printed using a PC. In this setting, on the horizontal axis, information from 5 m spatial zone per big division and (50 ns/div) and 1 m per small division is obtained. On the vertical scale, the intensity of Raman anti-Stokes signal from the selected fibre section is obtained. Figure 3 clearly shows the capability of our DART system. Two peaks over the normal signal (prominent rise of negative signal) recorded at anti-Stokes wavelength of 820 nm represent

hot zones, whereas the dip (fall in negative signal) between two peaks represents the fibre zone not being heated. The clear observation of a dip between two hot zones in the fibre, which are separated along a measured fibre length of 90 cm, proves that it is possible to achieve sub-metre resolution without using complex instruments such as boxcar-integrator.

It may be noted that all intensity signals are recorded at a fixed wavelength (Raman anti-Stokes) in OTDR mode and peaks represent increase in backscattered light of anti-Stokes component due to temperature changes. It is believed that the use of these instruments with gate scanning and gain facility will further improve spatial resolution, perhaps to the ultimate theoretical value of 20 cm for 2 ns laser pulse.

The commercially available DART systems with sub-metre resolution are expensive and utilize complex signal processing techniques such as time-correlated single-photon counting and/or use of expensive high-power pulsed lasers². Here we have

developed a sub-metre DART system with inexpensive diode laser and relatively straightforward signal processing technique.

-
1. Kher, S., Srikant, G., Chaube, S., Chakraborty, A. L., Nathan, T. P. S. and Bhawalkar, D. D., *Curr. Sci.*, 2002, **83**, 1365–1368.
 2. Feced, R., Farhadiroushan, M., Handorok, V. and Rogers, A. J., *Rev. Sci. Instrum.*, 1997, **68**, 3772–3775.

Received 20 December 2003; revised accepted 17 March 2004

SANJAY KHER*
SHRIKANT GURRAM
MANOJ KUMAR SAXENA
T. P. S. NATHAN

*Fibre Optics Laboratory,
Solid State Laser Division,
Centre for Advanced Technology,
Indore 452 013, India*

**For correspondence
e-mail: kher@cat.ernet.in*