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Multi-Mode Fibre and Few-Mode Fibre for Distributed Temperature Measurement System

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Abstract: The monitoring of temperature change can effectively avoid the occurrence of potential safety hazards of tunnels, pipelines and high temperature reaction furnaces, and assist in the formulation of rescue plans in case of accidents, the distributed optical fibre temperature measurement system satisfying both precision and continuous monitoring function requirements is developed. YOFC has released the multi-mode fibre and few-mode fibre for distributed temperature measurement system to improve the signal-to-noise ratio, temperature measurement accuracy and spatial resolution of long-distance temperature measurement.

Key words: distributed optical fibre temperature measurement system, long distance temperature measurement, high temperature measurement accuracy, high spatial resolution

1 Requirements of Distributed Optical Fibre Temperature Measurement System

Temperature is one of the most important physical quantities, in our production and life, temperature measurement is very important. The monitoring of temperature change can effectively avoid the occurrence of potential safety hazards of tunnels, pipelines and high temperature reaction furnaces, and assist in the formulation of rescue plans in case of accidents. However, the traditional temperature measurement technology cannot meet the requirements due to the poor temperature measurement accuracy and positioning accuracy of the temperature sensing cable; point thermometer or thermocouple with high precision cannot meet the needs of linear and continuous monitoring. Therefore, to address above challenges well, the distributed optical fibre temperature measurement system (DTS for short) satisfying both precision and continuous monitoring function requirements is developed.

For the high Raman gain and excited threshold of the multi-mode fibre, many mature distributed temperature measurement products use the multi-mode fibre as their sensing fibre. But the traditional communication multi-mode fibre only optimizes the attenuation at 850nm and 1300nm in wavelength, the higher C-band attenuation seriously affects the signal-to-noise ratio of long-distance measurement, on the other hand, the larger inter-modal dispersion will lead to the degradation of spatial resolution in long-distance measurement. In addition, the poor geometrical consistency of general multi-mode fibre will lead to the temperature-jump at the successive points.

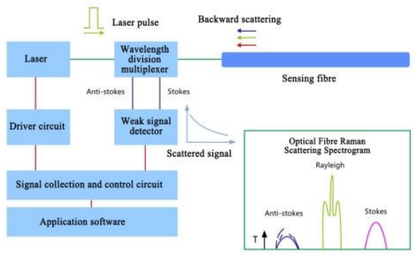

Figure 1 Raman Thermometry Schematic Diagram

2 Multi-Mode Fibre and Few-Mode Fibre for Distributed Temperature Measurement System

Aiming at the problems in practical application of multi-mode fibre in traditional temperature measurement system, YOFC has improved the multi-mode fibre by using its own experience and technical ability in optical fibre design and manufacture.

(1) The optimization for attenuation at the working wavelength of DTS has improved signal-to-noise ratio of long-distance temperature measurement;

(2) The optimization of C-band bandwidth has improved the spatial resolution of long-distance DTS and solved the spatial resolution degradation of DTS system in long-distance transmission;

(3) The optimization of geometrical consistency has improved the temperature measurement accuracy of the system and solved the temperature consistency problem of successive points of optical cables which is inevitable in practical engineering.

Table 1 Performance Parameters of multi-mode Fibre for DTS Temperature Measurement System

Type of optical fibre		GI50/125-20/250DTS
Product number		GI2012-B
Numerical aperture		0.195±0.01
Loss	@1300 (dB/km)	≤ 0. 50
	@1450nm(dB/km)	≤ 0. 45
	@1550nm(dB/km)	≤ 0.28
	@1650nm(dB/km)	≤ 0. 45
Splicing loss (dB)		≤0.1
Bandwidth	@1300nm(MHz.km)	≥200
	@1550nm(MHz.km)	≥1000

The test results for the optimized temperature measurement multi-mode fibre matching with the YOFC DTS host show that the temperature curve is smooth, the temperature resolution is higher than 2℃ and the spatial resolution is about 2-3 meters when the temperature measuring distance is 25 km. In addition, the optical fibre is coated with bending and high temperature resistant coating, which makes it more suitable for cabling and high temperature applications.

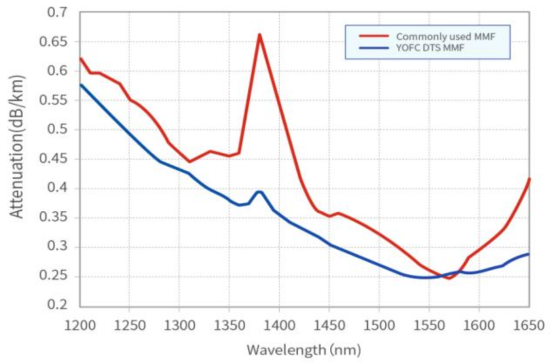

Figure 2 Attenuation Spectrum of Temperature Measurement Multi-Mode Fibre

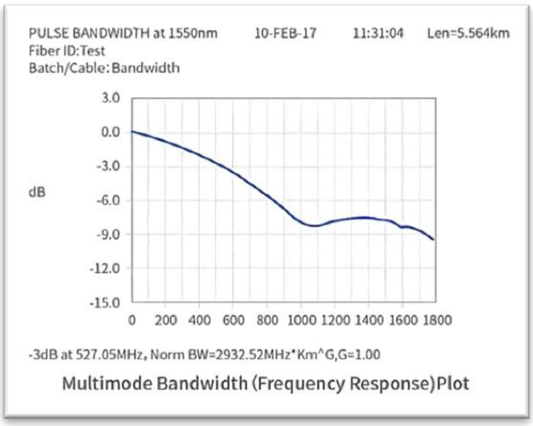

Figure 3 Bandwidth of Temperature Measurement Multi-Mode Fibre

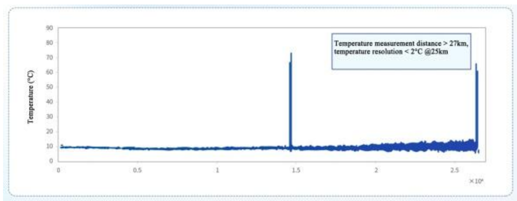

Figure 4 Temperature Curve of YOFC Temperature Measurement Multi-Mode Fibre

The advantage of the distributed Raman sensing system based on multi-mode fibre is that the multi-mode fibre has larger effective mode area and higher Raman gain coefficient, which makes it easy to obtain the temperature information along the fibre by spontaneous Raman scattering. The disadvantages are that the loss of the multi-mode fibre is large, and more importantly, the long-distance sensing spatial resolution is insufficient due to the pulse width broadening caused by the inter-modal dispersion (differential mode group delay) of the multi-mode fibre, which actually limits the sensing distance of optical fibre in temperature measurement scenarios requiring higher spatial resolution (usually the length of multi-mode system is limited to 8km ~ 10km). The advantages of the distributed Raman sensing system based on single-mode fibre are that the loss is small and there is no pulse broadening caused by inter-modal dispersion. The disadvantage is that the effective mode area is small. In order to avoid excited Raman scattering, the input optical power is limited and the detection range is limited. Therefore, the long-distance distributed optical fibre temperature sensor system based on single-mode fibre is more complex and costly (distributed amplification and complex signal processing need to be conducted). Compared with the single-mode fibre, the few-mode fibre has a larger mode field area when only the fundamental mode is excited, and compared with the multi-mode fibre, it has a much smaller inter-modal dispersion because of its special refractive index design. Using few-mode fibre as the sensing fibre, combined with the existing single-mode fibre Raman system, the sensing distance of the existing distributed temperature sensor can be effectively prolonged without increasing the complexity of the system while ensuring high spatial resolution.

Table 2 Performance Parameters of Few-Mode Fibre

Test item	LP01	LP11
Attenuation coefficient (@1550nm)	0.187dB/km	0.191dB/km
Dispersion coefficient (@1550nm)	20.483	19.303
Dispersion slope (@1550nm)	0.070	0.071
Differential group delay (@1550nm) (LP11 relative to LP01)	/	1.877ps/m

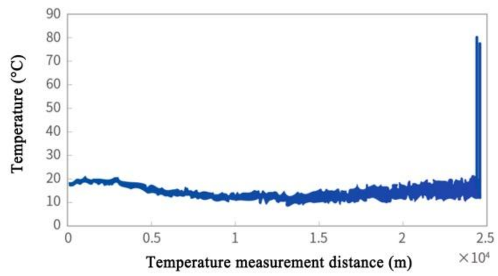

Figure 5 Temperature Curve of Distributed Temperature Measurement System Based on Few-Mode Temperature Measurement Optical Fibre

After coming up with the distributed optical fibre temperature measurement system based on few-mode fibre, YOFC, from the principle of Raman scattering, carried out theoretical analysis and calculation on Stokes Raman scattering and anti-Stokes Raman scattering in the few-mode fibre to find the optimized temperature demodulation algorithm. With the high efficient coupling equipment of few-mode fibre developed, YOFC developed the corresponding module for distributed Raman temperature measurement by combining the few-mode fibre with the existing single-mode fibre. In the single-mode DTS system, the quasi-fundamental mode operation avoids the pulse width broadening caused by the inter-modal dispersion, and the large effective area greatly increases the power of the input optical in the fibre, finally realizing a distributed optical fibre temperature measurement system based on the few-mode fibre of long distance and high spatial resolution. As shown in the figure below, in the test for YOFC few-mode optical fibre matching with the DTS host, the temperature resolution is higher than 4℃ and the spatial resolution is about 3m when the temperature measurement distance is more than 20km.

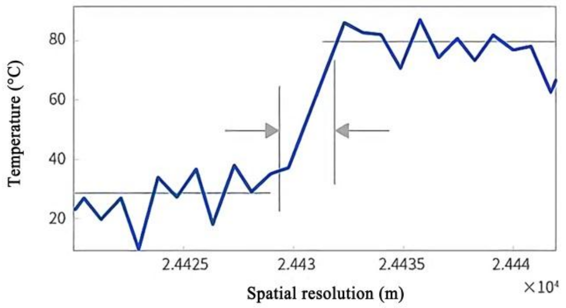

Figure 6 Spatial Resolution of Distributed Temperature Measurement System Based on Few-Mode Temperature Measurement Fibre

YOFC has devoted itself to specialty optical fibre technology for more than 20 years. With the advantages of specialty optical fibre research and development and manufacture, it has combined the specialty optical fibre technology with the sensing technology, efficiently promoting the performance optimization of the distributed optical fibre temperature measurement system. The product has been widely used in the monitoring of electric power, tunnels and pipe corridors at home and abroad, such as temperature monitoring in Changying Tunnel of Xinzheng Airport. YOFC will continue to promote the optimization of the multi-mode and few-mode fibres in the distributed optical fibre temperature measurement system and the industrial commercialization of the temperature measurement system. YOFC will act as a banner for the specialty optical fibre and specialty optical fibre sensing market and lead the quality development of the market.

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