A Fibre Optic Force Sensing Method Based on the S^2 Imaging Technique

Athithyan Srikanthan[1], Natasha Vukovic[1], Christophe A. Codemard[2], Michalis N. Zervas[1]

1. Optoelectronics Research Centre, University of Southampton, Southampton SO17 1BJ, U.K.

2. TRUMPF Lasers UK Ltd, Wellington Park, Tollbar Way, Hedge End, Southampton SO30 2QU, U.K.

Optical fibres are the ideal sensing platform to measure strain, pressure, temperature, displacement, vibration, torsion, and humidity [1], thanks to their extreme environmental robustness. Since they are made of dielectric material, optical fibres are immune to electromagnetic interference and corrosion, are highly sensitive, and have a very wide operating temperature range. In addition, optical fibre-based sensors can be lightweight while providing easy integration into a wide variety of structures, while being low cost compared to an alternative approach. In particular, fibre Bragg gratings, polarization-maintaining fibres, and multicore fibres [2] are used as force or strain sensors in a broad range of industrial, medical, and military applications.

In this paper, we present an implementation of a large-mode-area (LMA) optical fibre combined with a self - interferometric technique (S^2) for force sensing. Spatial and spectral (S^2) imaging has been established [3] to support the fast development of optical fibre technology for fibre lasers. Our method provides for simplicity of the design and is expected to have low-temperature sensitivity.

The schematic of the S^2 imaging method shown in Fig.1(a) highlights the concepts based on resolving the interference that arises at the fibre output due to different velocities of the various optical modes. We use an in-house-built low-cost tunable laser source that is scanned across the 1064 nm – 1084 nm wavelength span with a resolution of 7.2 pm. The 2D spatial intensity profile at the output of fibre under test (FUT) is collected by the charge-coupled-device (CCD) camera (Basler acA1920-155um) as a function of wavelength. The S^2 system typically completes the measurement in <1 minute. Here, the FUT is a 4 m long LMA fibre with 21/200 µm core/cladding diameter and 0.11 NA. We purposely make an offset splice (0.5µm offset) between the singlemode fibre from the laser and the LMA FUT, to excite some LP_{11} mode that will serve as a reference. A pressure device (PD) with a weight indicator display is used along the in-house built mechanical device, to measure the force applied to the FUT. The fibre length between the splice and the pressure device was 1.5 m. The proposed fibre optic force transducer converts a lateral force into a corresponding measurement of the multipath interference (MPI) of each mode as a function of group delay, as shown in Fig.1(b). The force applied on the FUT results in the coupling of LP_{01} into LP_{11} modes which creates peaks at different group delays. The first peak in the MPI plot (Fig.1(b)) corresponds to the excitation of the LP_{11} mode from the PD while the second LP_{11} peak corresponds to the splice. The differential delay between the peaks of the same mode gives the position of the PD along the fibre length. Experimentally, we found that we can achieve a spatial resolution of 15 cm with that fibre.

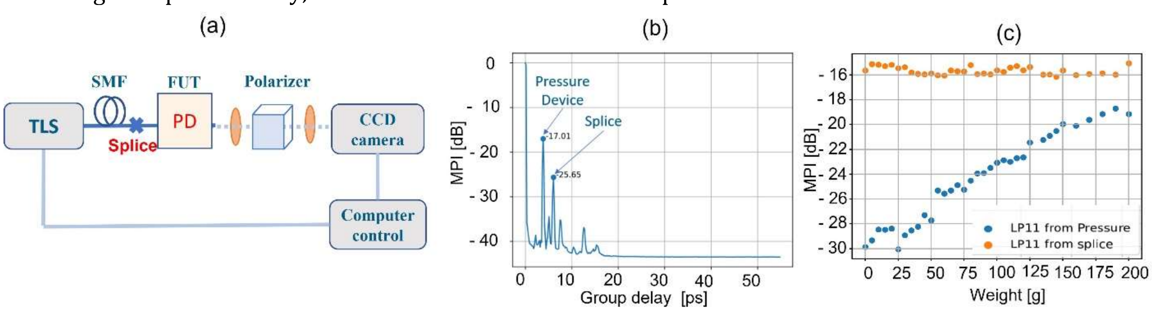

Fig. 1 (a) S^2 testing system with added pressure device (PD); TLS: tunable laser source, SMF: singlemode fibre, FUT: fibre under test. (b) An illustrative example of the relative intensity i.e. multipath interference (MPI) of each mode as a function of group delay. (c) S^2 measurement of LMA fibre as a function of different applied forces.

The S^2 measurement was performed for the force applied in the range of 0 – 200 g, with a 5 g step, as shown in Fig.1(c). The results indicate a linear trend (in log scale) for the relative intensity of LP_{11} mode at the PD as a function of applied force. In conclusion, we demonstrated proof of concept that the S^2 imaging method can be used in force-sensing applications. The advantage of the proposed method includes the simplicity of the design and the capability to discover multiple points of applied force on the FUT. Additional design parameters that enhance the measurement range and spatial resolution will be discussed at the conference.

References

[1] C. Cuadrado-Laborde, *Applications of Optical Fibers for Sensing*, (IntechOpen, 2019).

[2] J. Zhao, D. Jia, A. Nie, H. Zhang, and T. Liu, "Compact Vectorial Transverse Force Sensor Based on Two-Modal Interference in a Few-Mode Seven-Core Fiber," J. Lightw. Technol. **38**, 2052 (2020).

[3] J. W. Nicholson, A. D. Yablon, J. M. Fini, and M. D. Mermelstein, "Measuring the Modal Content of Large-Mode-Area Fibers," IEEE J. Sel. Top. Quantum Electron. **15**, 61 (2009).