Fast measurement of local PMD with high spatial resolution using stimulated Brillouin scattering

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Abstract *Local beat length with a 21.5cm spatial resolution is measured in one second along a single mode fibre using the polarisation dependence of stimulated Brillouin scattering, in a non-destructive and simple way.*

Introduction

It has been demonstrated over the past two decades that polarisation mode dispersion (PMD) may limit the ultimate data rate through an optical fibre. The basic reason for PMD is the presence of intrinsic or induced birefringence within the fibre. Measuring the local birefringence would thus provide key information to localize the fibre segments mainly contributing to PMD, so that an efficient action could be undertaken for cable upgrade. A simple solution based on Rayleigh reflectometry using polarized light, the so-called POTDR technique [1], has been proposed. It has demonstrated the potentiality to measure local PMD over long distances, but with moderate spatial resolution and long integration time [2,3]. Very high spatial resolution measurements of beat length were achieved using an OFDR technique [4], but over a short distance.

We report here a novel method for local birefringence measurements based on the polarisation dependence of the stimulated Brillouin interaction. This method offers the key advantage to provide a signal very immune to noise. It combines the advantages of a high spatial resolution, a long range and a very short integration time.

Principle

The experimental configuration of this method basically relies on an instrument providing a local analysis of the stimulated Brillouin interaction [5]. The instrument launches a CW lightwave (signal) into one end of the fibre while an intense light pulse (pump) with the proper optical frequency is launched into the other end of the fibre. This pulse interacts through stimulated Brillouin scattering (SBS) with the CW wave, this latter being amplified while crossing the pulse. The amount of amplification at any location depends on local features of the fibre, such as temperature and strain, but also, as explained below, on the relative polarisations of the waves crossing at this point. The time recording of the intensity of the amplified signal light gives the spatial distribution of the Brillouin gain along the fibre, that is directly related to the polarisation variations experienced by light during its propagation.

The differential Brillouin gain is given by the relation

$$d\vec{E}_s = \frac{1}{2} g(\nu) \left(\vec{E}_s \bullet \vec{E}_p^* \right) \vec{E}_p \, dz$$

where $\vec{E}_p$ and $\vec{E}_s$ are the pulse and CW fields respectively and $g(\nu)$ is the linear Brillouin gain coefficient. The product $\left(\vec{E}_s \bullet \vec{E}_p^* \right)$ indicates that the local gain is polarisation-dependent, being maximal for aligned fields and zero for crossed fields. The gain varies along the fibre as the relative polarisations of $\vec{E}_p$ and $\vec{E}_s$ are changed by birefringence, as shown in the measured gain distributions in Fig. 1.

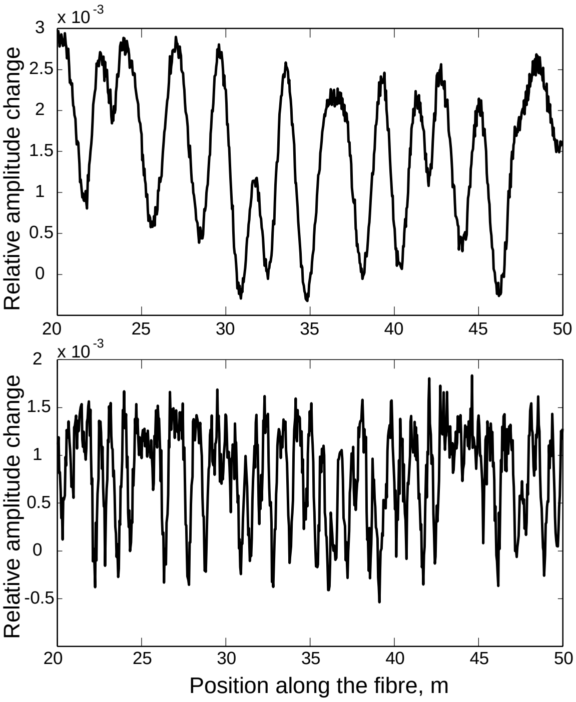

Fig.1: Brillouin gain distribution along a standard single mode fibre (top) and a specialty bending insensitive fibre (bottom) with a 3μm core radius. Fibres are wound on a 14cm diameter drum and measurement are performed using a 2.15ns pulse width and 256 times averaging.

The information about the birefringence beat length can be extracted from such gain longitudinal distributions, since the pulse and signal waves experience the same birefringence and have correlated, though not identical, polarisations. The distance between a maximum and the next minimum of the gain corresponds to a quarter of the local beat length.

Experiment

A special configuration of the Brillouin optical time-domain analyser was developed to make it very immune to optical noise. It was observed that optical noise results from the bidirectional propagation of optical waves showing the same frequency along the optical fibre. A fraction of any of these optical waves may propagate in the opposite direction through partial spurious reflections at splices and connections or simply through Rayleigh backscattering. These backreflected contributions superpose to the optical waves normally propagating in the reverse direction. The superposition with a wave showing the same optical frequency gives rise to interferences that turn into intensity noise since the fibre is usually much longer then the laser coherence length. Considering the small amplifications observed through Brillouin gain - in the permille range - the intensity noise on the detector may easily be comparable in amplitude with the gain contrast.

The optical noise could be drastically reduced by using distinct modulators for gating the pump pulses and for generating the CW signal using the suppressed carrier sideband technique [5]. In addition these modulators were specially selected to show an extinction ratio larger than 40dB, so that a minimal CW spurious signal at the pump frequency propagates bidirectionally through the fibre.
This massive noise reduction has made possible distributed Brillouin gain measurements with pump pulses as short as 2ns (20cm spatial resolution) with a limited averaging of 64 to 256 times. The acquisition time is thus reduced to a fraction of a second using a 1KHz pulse repetition time, as preset in our set-up.

The short pulse width results in a much broadened pump spectrum exceeding 200MHz. This effect is a penalty in a Brillouin sensing system, since it drastically decreases the accuracy on the determination of the Brillouin shift frequency. In the present case it is beneficial because it does not cause any gain fading due to local fluctuations of the Brillouin frequency that may for instance result from temperature changes or an applied residual strain. These fluctuations are in normal conditions much smaller than our broadened pump spectrum. It is therefore sufficient to adjust the frequency difference between signal and pump on the average Brillouin shift along the fibre to obtain a high contrast gain distribution with a single time trace.

Fig. 2 illustrates the potentialities of the technique. It shows that sections along the fibre where the fibre is loose are absent of a significant birefringence, while the winding induces a clearly observable birefringence with a beat length of about 3.6m for a 14cm diameter winding. This effect would be hardly observed using an instrument showing a spatial resolution larger than 1 meter.

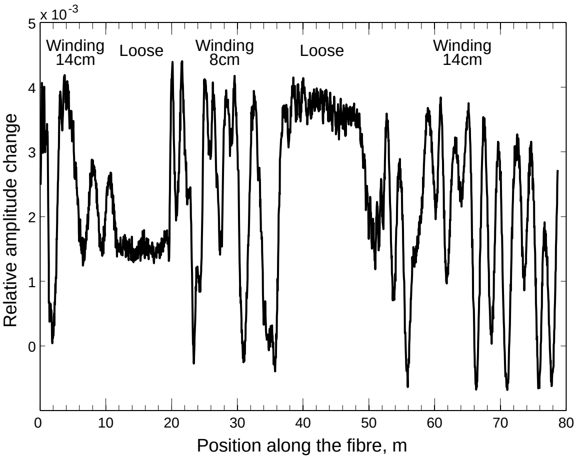

Fig.2: Brillouin gain distribution along a standard single mode fibre, which presents loose and wound sections, clearly showing the local birefringence induced by the winding. Measurement are performed using a 2.15ns pulse width and 256 times averaging.

The distance range is approximately 10km for a 25cm spatial resolution and extends to 50km for a 7m spatial resolution, all obtained with a 256 times averaging or less than 1 second acquisition time.

The local beat length can then be easily extracted from these high quality gain traces using the standard reported techniques [6].

Conclusions

This paper demonstrates that the Brillouin time-domain analysis can be an efficient tool to evaluate the distribution of polarization beat length along an optical fibre. It provides fast sub meter spatial resolution measurements over a range of several kilometres.

References

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