PARALLEL COHERENCE RECEIVER FOR QUASI-DISTRIBUTED OPTICAL SENSOR

P. SANSONETTI, J.J. GUERIN, M. LEQUIME, J. DEBRIE
BERTIN & CIE
BP 22000
13791 AIX EN PROVENCE CEDEX 3
FRANCE

ABSTRACT

We present the implementation of a coherence receiver that is able, in parallel, to demultiplex and measure the phase between up to seven interference signals generated in a "white light" polarimetric quasi-distributed sensing system. It is based on a Michelson interferometer, one mirror of which has seven reflecting facets with differing thicknesses in its aperture. It was further used to measure the phase variation, between two polarization couplers, versus three point bending loading for optical fibres either surface bonded or embedded in GRP composite.In both cases, the sensitivity to the composite elongation is found in close agreement with the sensitivity of the fibre itself.

1.INTRODUCTION

Intrinsic optical fibre sensors, where the optical fibre is itself the transducer, offer low invasiveness (outer diameter of the order of 100 µm) and the potential capability for distributed measurement along a single fibre. Both properties are of high interest and find applications for mapping, for instance, strain and/or temperature fields of various structures. Such sensing system can even be embedded in composite material due to the excellent compatibility between the optical fibre and the reinforcing matrix.Techniques based on OTDR[1] have been derived to allow distributed measurement, but cannot provide a real time measurement with high accuracy.

A quasi-distributed technique which has the potential for real time measurement and high accuracy, based on "white light" coherence multiplexing in two modes fibre, was recently reported[2,3,4]. A polarimetric configuration uses the two polarization modes of a Highly-Birefringent (Hi-Bi) fibre[5]. Light from a short coherence length source is polarized and launched into one polarization mode of a fibre possessing polarization mode couplers spaced along it. An analyzer, placed at the end of the sensing zone and axes of which are orientated at 45° from those of the fibre, then creates a set of polarimetric interference signals, all with different Optical Path length Differences (OPD). If the spacing between OPDs is greater than the source coherence length, each polarimetric signal can then be demultiplexed by coherence technique.The phase difference between each successive signals then yields the polarimetric information between each couple of polarization couplers.

First developments used, for instance, a Michelson interferometer Optical Path-length Difference (OPD) of which was successively locked on each incoming signal by using a motor. Such solution clearly cannot provide with real time operation of the system. Another technique is based on the wave front tilting in the receiving interferometer[6], the autocorrelation function being therefore spatially accessible as well as the coherence demultiplexed signals. Detection with a CCD further provides with the required signals. However, in such a system, the number of pixels is directly proportional to the inverse of the required accuracy , the spacing between each sensing signals and their number, which renders coherence multiplexing difficult to implement.

Here, we shall present the implementation of a Michelson based receiving system able to coherence demultiplex, with high accuracy, up to seven sensing signals. These signals can be generated by quasi-distributed, discrete intrinsic or bulk extrinsic sensing systems.

2. PARALLEL COHERENCE RECEIVER

The scheme of the whole quasi-distributed system with the parallel receiver is represented in Figure 1.

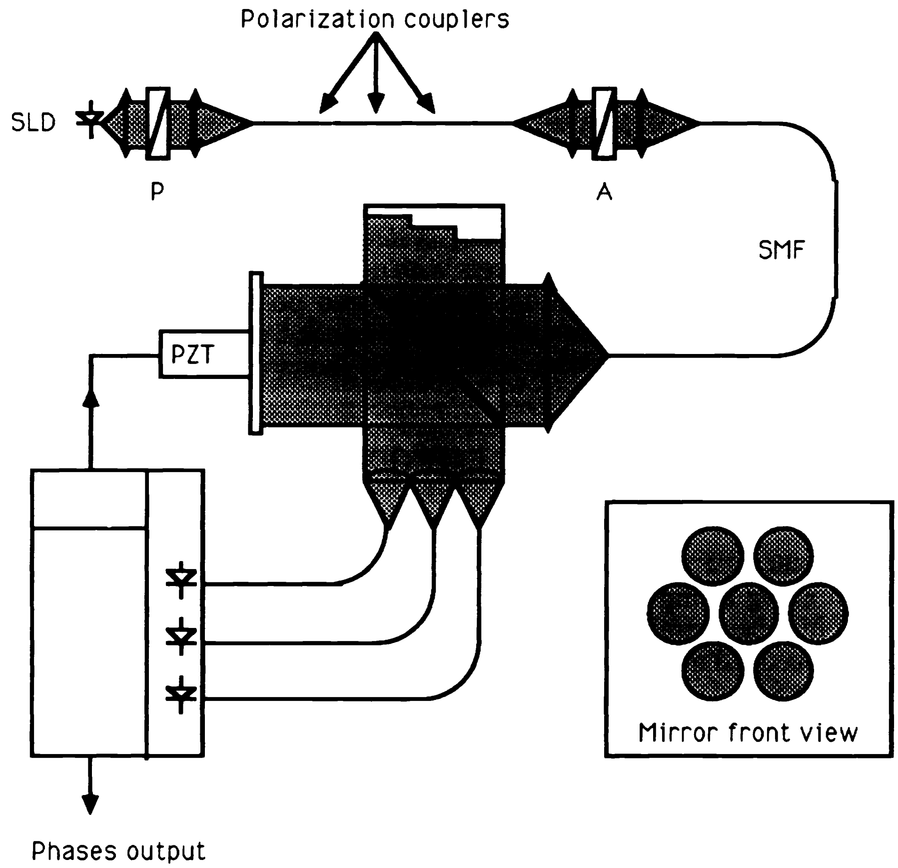

Figure 1-Scheme of the white-light polarimetric quasi-distributed sytem with parallel receiver

The beam from a SLD emitting at 830 nm is polarized and launched into one polarization mode of the sensing fibre. An analyzer, with axes at 45° from those of the fibre, then generates the polarimetric signals. The beam is afterward launched into a classical single mode fibre that assures the link to the receiver.

One "mirror" of the Michelson has seven reflecting facets with different thicknesses with a bundle distribution; this generates seven different OPDs in the interferometer aperture. The various thicknesses are such that each Michelson OPD Δ_r^i corresponds to each OPD $\Delta n\, l_i$ created in the Hi-Bi sensing fibre, where Δn is the fibre birefringence and l_i is the fibre length from the i^{th} polarization coupler to the end of the fibre. Therefore, all the OPDs required to coherence demultiplex the OPD comb coming from the fibre are present in the interferometer aperture. A bundle of lenses then allows the parallel detection of the seven signals. The phase difference between signals i and i-1 is then proportional to $\Delta_r^i - \Delta_r^{i-1} - \Delta n\, (l_i - l_{i-1})$ and therefore yields the polarimetric information between the two corresponding polarization coupling points.

3. EXPERIMENTAL PARALLEL COHERENCE DEMULTIPLEXING

The characteristics of the receiver itself were first studied by successively working at zero OPD for each facet. It was found that the intrinsic loss of power due to the illumination of all mirrors was estimated to be 12 dB. This compares well with techniques using couplers and as many receivers as sensors.

It was also found, when PZT ramping the plane mirror of the receiver, that the index of modulation of each signal at zero OPD, was better than 95%.

Possible crosstalk effect among the facets was also considered. For that, the OPD of each facet was scanned and no signal was found apart the one at zero OPD. With the system properties, this means that crosstalk is lower than -30 dB.

All these points indicate the receiver excellent ability to demultiplex, in parallel, the seven incoming interference signals.

Then, two polarization couplers, each coupling 1% of energy in the other polarization, were put on the Hi-Bi fibre, their spacing corresponding to the OPD difference between two elementary mirrors of the receiver. The oscilloscope traces of the two coherence demultiplexed signals , obtained in parallel on the corresponding mirrors, when PZT ramping the plane mirror of the Michelson, are given in Figure 2.

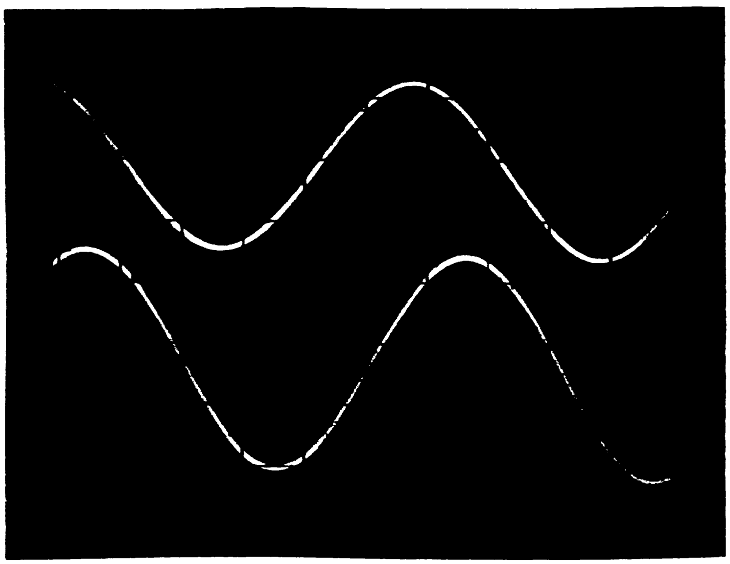

Figure 2-Parallely coherence demultiplexed signals generated by two polarization couplers along a single fibre (scales are the same for both signals: 100 mV per division)

It can be seen they exhibit equivalent index of modulation which indicates the parallel locking of the receiver on the center of the source coherence function. The spacing between the two polarization couplers was 27 cm.

4. PHASE MEASUREMENT BETWEEN POLARIZATION COUPLING POINTS

Using a PZT driven sawtooth translation of the plane mirror of the Michelson, the phase between each two successive signals is measured. Let us now consider the two signals, generated by the two polarization couplers, represented in Figure 2. We have represented, in Figure 3, the variation of phase between them when the optical fibre is elongated.

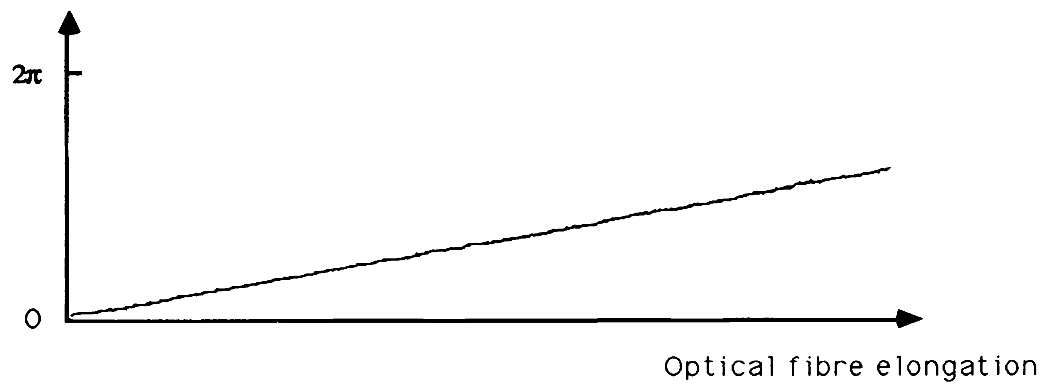

Figure 3-Phase variation between the two signals when the optical fibre is elongated between the polarization couplers.

On the other hand, when the perturbation occurs outside the region comprized between the two polarization couplers (in this case between the last polarization coupler and the 45° analyzer), the corresponding phase should not vary. This is represented in Figure 4 where the perturbation was produced by heating of the fibre by 10 °C on a 10 cm length. This produces a phase shift of around 4 rd on each signal. However, we see there is no influence on their phase difference, which confirms the quasi-distributed operation of the system.

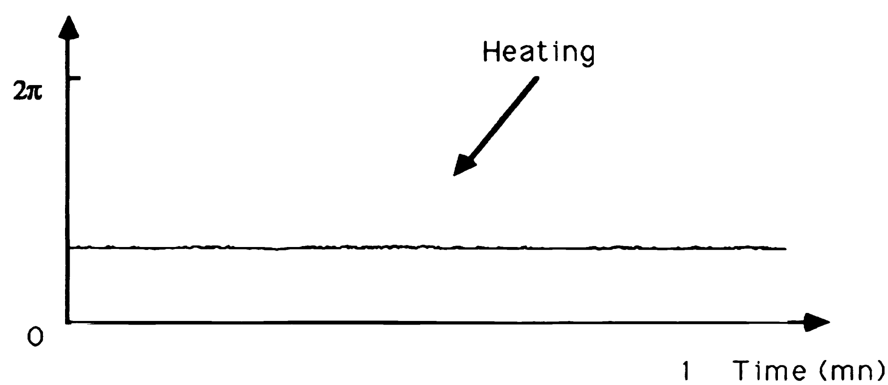

Figure 4-Phase measurement between the two signals when heating is produced outside the region comprized between the polarization couplers

5.TESTING WITH COMPOSITE MATERIAL

This quasi-distributed system was used to make measurement with optical fibre either surface bonded or embedded in GRP composite made by BERTIN. These fibres had, in each case, two polarization couplers spaced as to be parallely interrogated by the system. The scheme of the experiment is represented in Figure 5. To take advantage of an all-fibre configuration, the source was a Hi-Bi pigtailed SLD. It was further polarized by a fibre polarizer and linked to the sensing fibre by a polarization maintaining connector allowing to align the polarizer axes with those of the fibre. The latter one is also interfaced to the Michelson receiver by a connector. The analyzer, with axes at 45° from those of the fibre was this time located in the receiver, before the Michelson beam splitter.It must be noted that, in that case, the system is still not sensitive to the length of fibre after the last polarization coupler, since this is the phase difference between each signal which is measured and not the absolute phase of each signal. This scheme has the advantage of simplicity. However, in some applications with harsh environment, high thermal drift in this last length of fibre could cause the signals to fade due to too high a mismatch between the sensing signals and the receiver. The choice for the location of the analyzer, e.g. after the sensing zone or in the receiver will depend, for each application, on a trade-off between the simplicity and the environment.

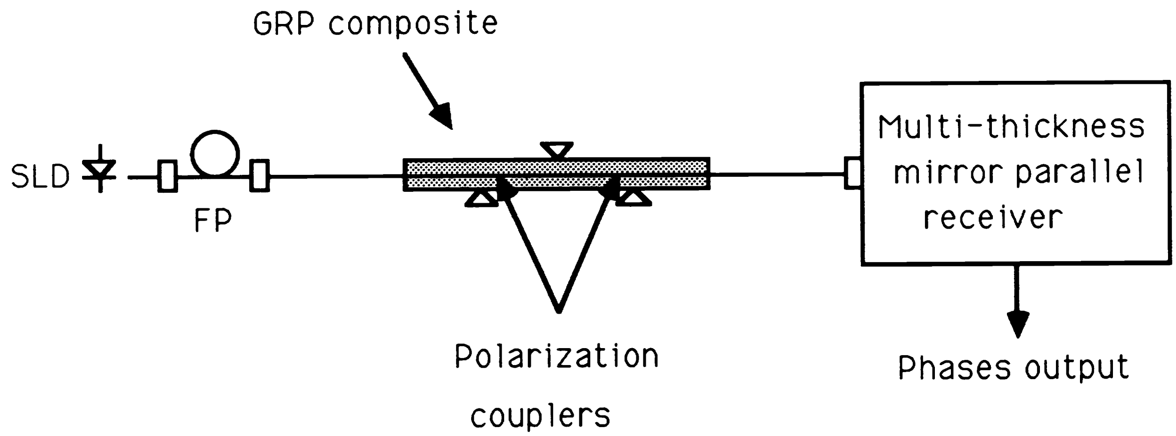

Figure 5- All fibre configuration for composite testing

The receiver is exactly the same as the one represented in Figure 1 except that the 45° analyzer is located in the receiver

We have respectively represented in Figure 6a and 6b the phase variation vs the loading point displacement for a fibre bonded on the bottom surface and embedded in a three points bent GRP composite. The optical fibre is extended in both cases. Composite samples and loading are different in each case.

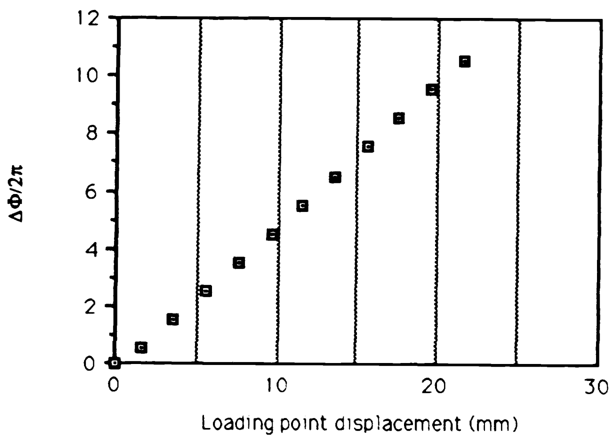

Figure 6a-Optical fibre bonded on the bottom surface

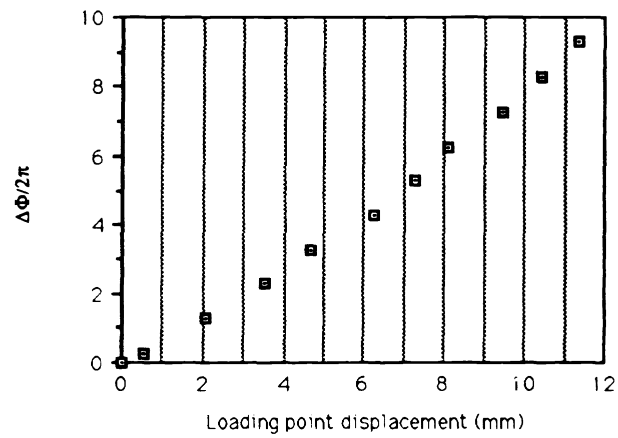

Figure 6b-Optical fibre embedded in GRP composite

Phase variation between two polarization couplers vs the loading point displacement for three points bending of GRP composite
Composite samples and loading are different in each case

From the composite characteristics and the location of the optical fibre, the composite elongation between the two polarization couplers can then be calculated from the measured displacement of the loading point. Sensitivities to elongation of 91 mrd/µm and 83 mrd/µm were then further respectively calculated for the bonded and embedded fibre. Taking into account the uncertainty on calculating the composite elongation from the loading point displacement (errors can come from the measurement of the fibre location, the position of the polarization couplers w.r.t. three points location, etc...), these sensitivities are in close agreement. They are also in close agreement with the sensitivity to elongation of the fibre itself which is of the order of 80 mrd/µm[7].

6. CONCLUSION

We have presented the implementation of a coherence receiver that is able, in parallel, to demultiplex and measure the phase between up to seven interference signals generated in a "white light" polarimetric quasi-distributed sensing system. It is based on the use of a multi-thickness mirror in the aperture of a Michelson interferometer. Measurements have shown that no crosstalk is present and that index of modulation of each channel is greater than 95% at zero OPD. No measurable crosstalk between all channels was detected.The two signals generated by two polarization couplers were demultiplexed in parallel, their phase variation being also measured. This was used to measure the phase variation, between two polarization couplers, versus three points bending loading for optical fibres either surface bonded or embedded in a GRP composite. The sensitivity to elongation of the composite is found in close agreement with the sensitivity of the fibre itself.

7. ACKNOWLEDMENTS

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8. REFERENCES

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