A Distributed Optical Fibre Sensor for Offshore Applications

B. P. Ludden, J. E. Carroll and C. J. Burgoyne

1. Introduction

The idea of 'smart structures' emerged some eight years ago from America. Since then there has been increasing interest and research in incorporating sensors in a variety of structures in the aerospace and civil engineering industries[1].

One of the most promising candidates as a sensor is the optical fibre[2,3]. The advantages of using an optical fibre as the sensing element have been well discussed. Amongst these advantages their immunity to electromagnetic interference, their electrical passivity, high sensitivity and high bandwidth are probably the most attractive. However, their ability to measure a diverse range of measurands and robustness also makes them adaptable to many applications even in the most hostile of environments.

Here we propose a distributed optical fibre sensor to measure the structural damage of Parafil ropes used in the offshore industry. It is envisaged that such ropes will play an important part in the realisation of ambitious structural projects in the marine environment such as deep-sea oil platforms and submerged-tube bridges.

2. Parafil Ropes

Parafil ropes[4] made from synthetic fibres were developed in the 1960's by Linear Composites.

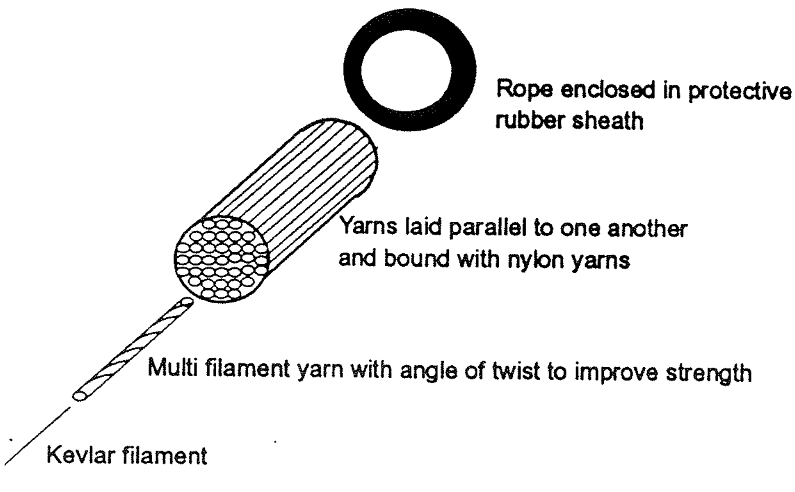

Figure 2.1 Architecture of Parafil ropes

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They are basically a parallel array of 'yarns' bundled together and encased in a polymeric sheath. Each yarn consists of about a thousand micron diameter fibres laid together and then slightly twisted to acheive optimum strength. They have very attractive properties for the construction industry including high tensile strength, high elastic modulus, low weight and high corrosion resistance. A variety of yarns can be used, but for structural applications polyester or aramid yarns are the most common.

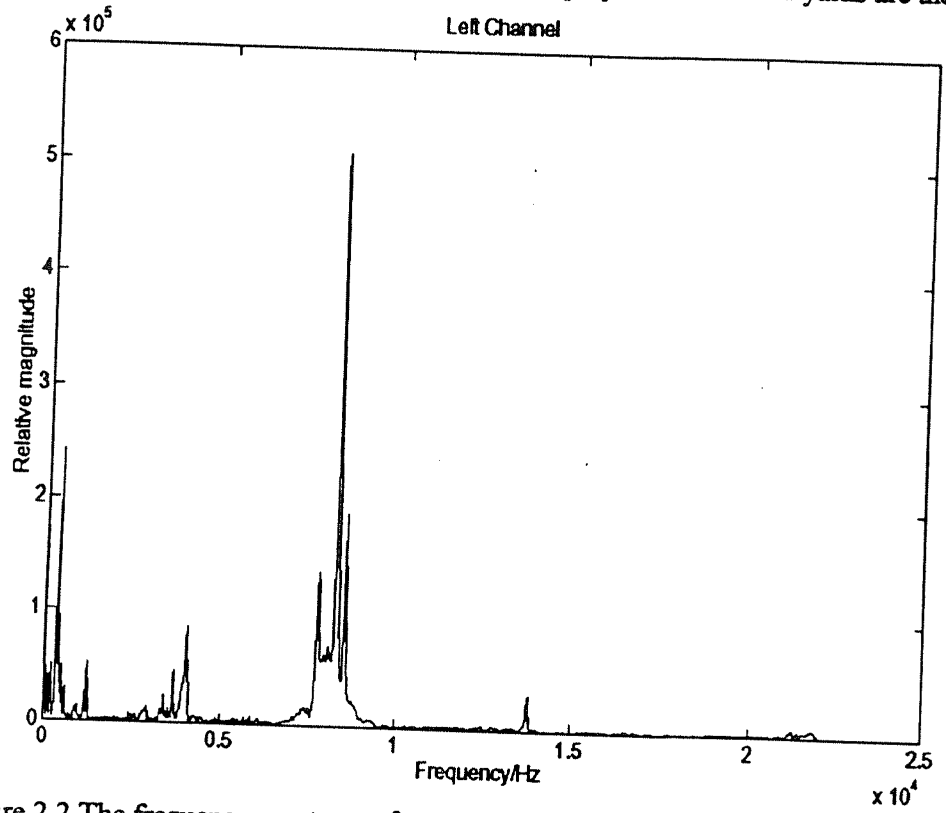

Figure 2.2 The frequency spectrum of snapping yarns in aramid Parafil ropes. The peak centred at 8kHz is characteristic of the snapping yarn. The other two peaks represent the resonant frequencies of the test equipment and the rope itself ('guitar string' effect) respectively.

Research into the failure of Parafil ropes has yielded some important facts for any attempt to develop a sensor to monitor their integrity. When a Parafil rope sustains damage it occurs as complete individual yarns snapping. The failure of the yarns is characterised by clearly audible acoustic signal (figure 2.2). A yarn which has failed will recoil back into the rope in both directions until the friction forces between it and its neighbours cause it to take up the load again. The length that the yarn recoils along the rope is called the characteristic length and is typically a few metres. Thus, the damage that a rope accumulates will be local and will only weaken the rope in a region equal to twice the characteristic length.

It is therefore desirable to be able to detect yarn snapping as it occurs and to locate where each yarn has snapped. A histogram could then be generated giving a simple display of the condition of the rope along its entire length.

3. Principles of Sensor Operation

3.1. Detection of Rope Damage

It is widely known that the properties of light propagating along a fibre, such as polarisation, mode or intensity, can be affected by external fields[5,6,7]. For example, we have demonstrated that a small acoustic signal will cause light to be coupled between modes in a two moded fibre at the frequency of the acoustic field (figure 3.1.1).

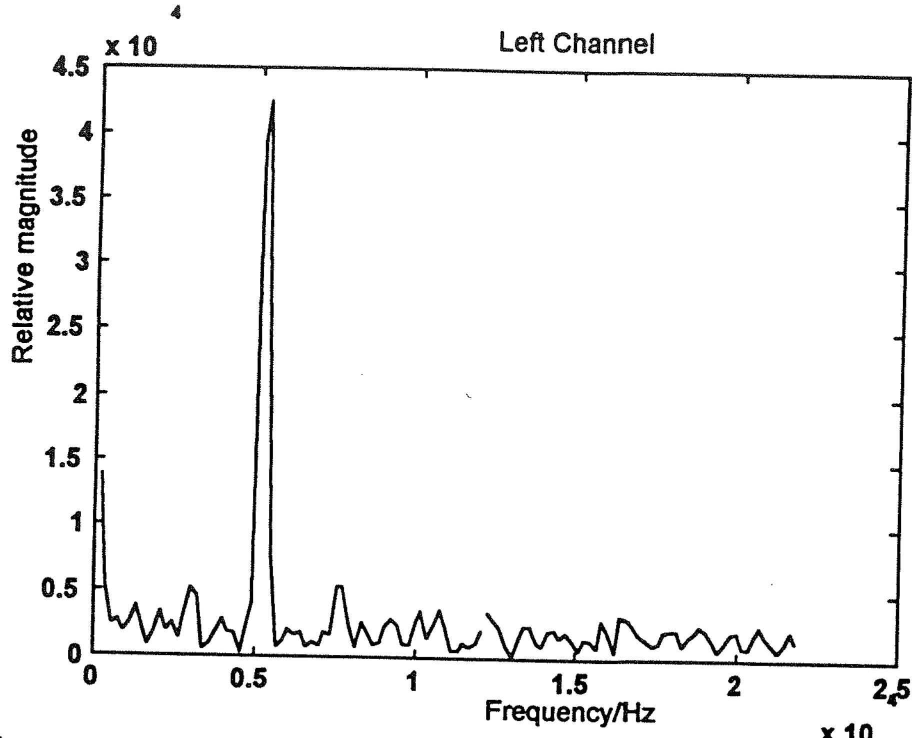

Figure 3.1.1 Response of a 'modal coupling' optical fibre sensor to a 5kHz acoustic wave

If an optical fibre is incorporated into a Parafil rope then a snapping yarn will change the properties of the light propagating along the optical fibre. The changes in, say, the amount of light in the zero order mode will carry information about the frequency of the detected signal. It is therefore possible to detect yarns snapping, and to distinguish the snaps from other noise in the sensing environment.

The principles of using this technique have been demonstrated by helically winding a small length of an 800m long standard telecommunications fibre around a 'bare' (polymeric sheath removed) six ton Parafil rope of 3m length and loading the rope to failure.

The laser source was a He-Ne 633nm laser and light was launched into the communications fibre (which is multimoded at 633nm) from a single moded fibre. The light was reflected by a mercury mirror at the end of the sensing fibre and the returning signal was mode stripped before detection, to monitor the amplitude modulation of the light in the zero order mode. The signal was then amplified and recorded on a dat-recorder.

The signals from the breaking yarns were easily distinguishable from other noise in the workshop environment, but were dominated by the 'guitar string' effect of the 3m long rope vibrating (this would not be a factor in the large area, long ropes employed in offshore anchoring) making frequency analysis difficult. However, the robustness of the optical fibre

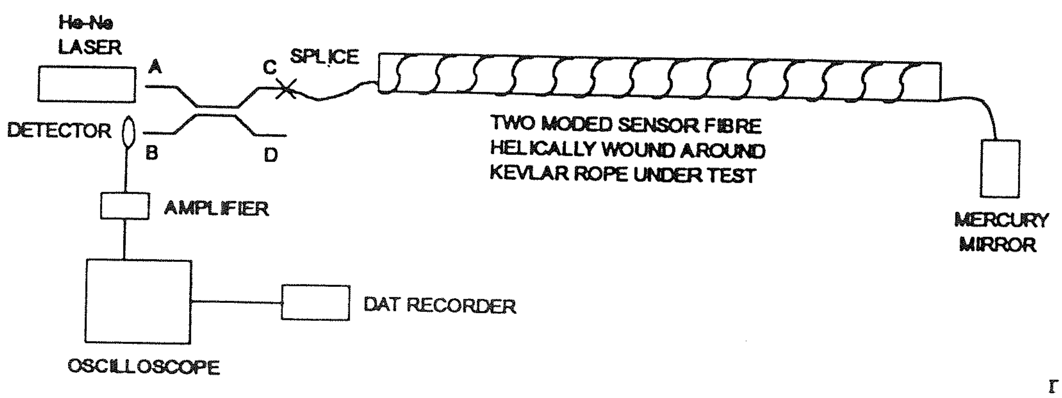

Figure 3.2.2 Detection of yarns snapping in an aramid Parafil rope using an optical fibre sensor

was highlighted by this experiment. The unprotected optical fibre remained undamaged by the snapping yarns in all tests except one, where the fibre only broke after complete failure of the Parafil rope. This is an important indication of the compatibility of the optical fibre with this sensing environment.

3.2. Location of Rope Damage

A modification to the above techniques enables distributed sensing. If a number of broad band partial reflectors are distributed along the length of the optical fibre, it would be possible to locate the position of snapping yarns with a resolution dependent on the reflector spacing.

A narrow pulse of light (typically 10-100ns) is launched into the optical fibre. The small percentage of reflected light sent to the detector from each reflector will carry information about the properties of the light passing that point. By analysis of the pulse signals arriving from each reflector it is possible to determine between which two reflectors a signal has occurred.

We have demonstrated the principles of this technique by launching 100ns pulses of highly polarised 1300nm laser light into a sensor fibre with 5 partial reflectors spaced at 100m intervals. The returning pulses of light were passed through a polariser before detection at a photo diode. An oscilloscope was used to display the pulses and it was possible to locate along which 100m section of the sensing fibre a test signal occurred.

An example of a distributed sensor for monitoring large Parafil ropes is shown in figure 3.2. The details of the laser source, fibre type, detector technology, signal processing and light property to be measured have been omitted. It is the subject of further work to determine the optimum configuration of the system.

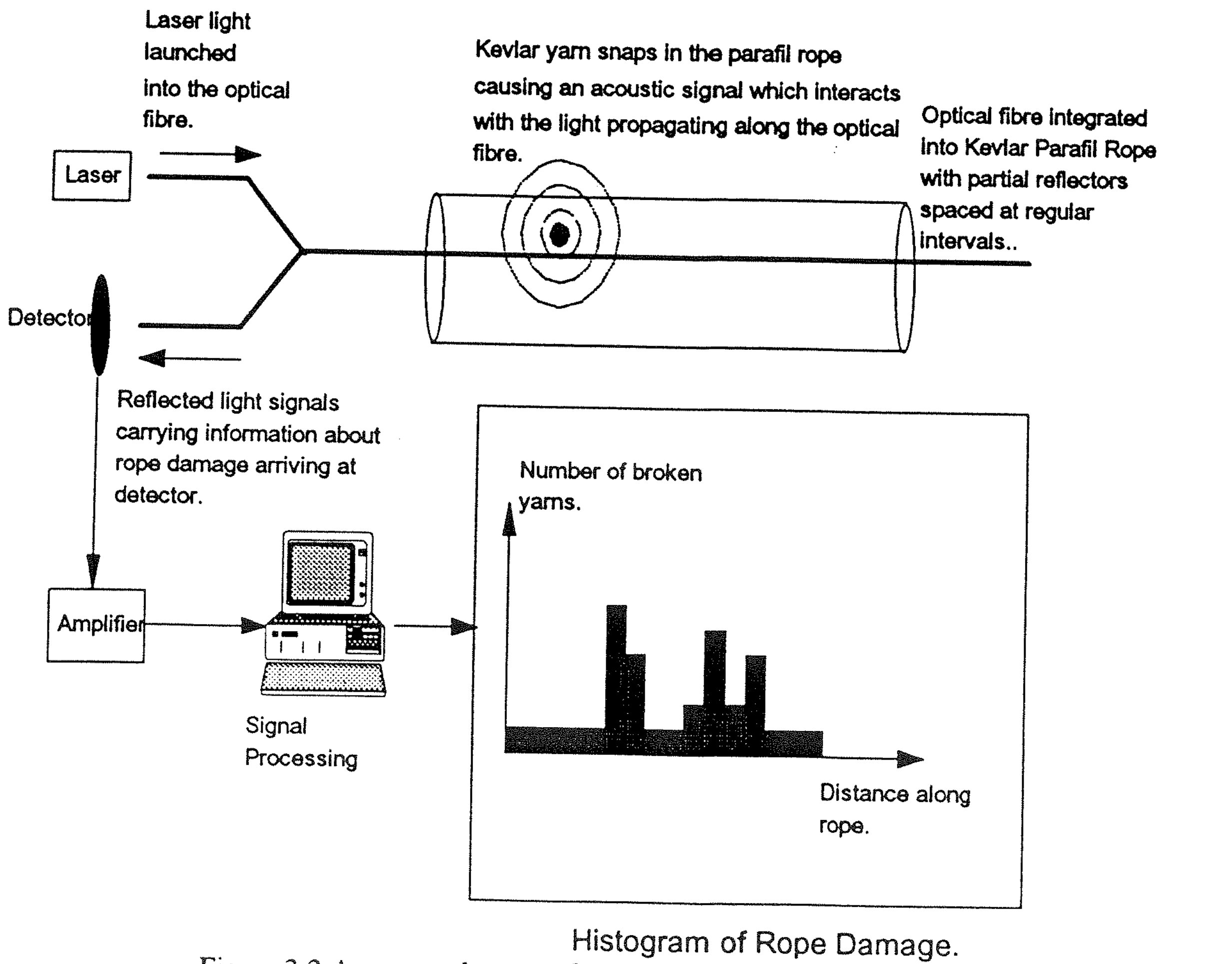

Figure 3.2 A proposed system for detection of damage in Parafil ropes

4 Conclusion

We have demonstrated the principles of a distributed optical fibre sensor for monitoring the integrity of large Parafil ropes in offshore applications. It has been shown that by introducing a number of partial reflectors along the fibre, and by interrogation of one particular property of the light , it is possible to detect and locate a short transient signal such as the acoustic emission caused by a yarn snapping.

It is envisaged that this type of sensor could be applied to any application where it is desirable to locate and/or identify a transient signal, such as a security perimeter fence or to measure traffic speed.

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