Local Analysis of Stimulated Brillouin Interaction in Installed Fiber Optics Cables

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Brillouin gain spectrum measurement along an optical fiber has recently gained a lot of interests owing to its potentiality for strain monitoring in installed telecom cables [1,2]. The purpose of this paper is to show that this potentiality is being now effective, since field measurements of installed fiber optics cables *currently in operation* are demonstrated. A portable instrument has been developed, based on an original experimental configuration developed in our Institute [3] that is shortly described below.

The Brillouin Gain Spectrum (BGS) in silical optical fibers is downshifted with respect to the pump light frequency by the Brillouin frequency shift ν_B which takes values from 11.5 to 13 GHz depending on the refractive index profile at a pump wavelength near 1300 nm [4]. The value of ν_B turns out to be very strain sensitive, shifting ν_B by about 600 MHz per percent of elongation [5]. This measurement requires two light waves propagating in opposite directions throughout the fiber, since Stimulated Brillouin Scattering (SBS) amplification is possible only in the backward direction. One light wave pumps the medium and the other acts as a probe signal, experiencing amplification when it lies within the Brillouin gain spectral range.

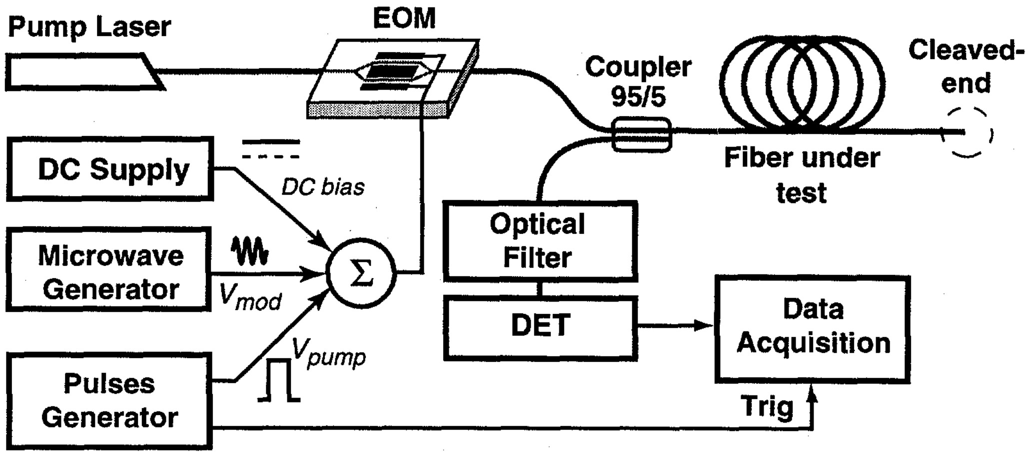

Fig.1: Experimental setup used for distributed temperature measurement.

Distributed measurements can be performed using a modified OTDR technique. The experimental configuration shown in Fig.1 is based on the pump and probe technique and presents the following advantages for field measurements: *1) a single fiber end is accessed, 2) a single laser source is used, 3) few optical elements are required.*

An ultra-wideband integrated $LiNbO_3$ intensity electrooptic modulator (EOM) is the key element of the setup, since it is used for: 1) pulsing the CW laser light from a 150mW Nd:YAG laser to form the pump signal, 2) the generation and frequency tuning of the probe signal. The frequency shift of the laser light is achieved by simply applying a CW microwave signal on the EOM electrodes. This creates sidebands in the laser spectrum, so that the first lower sideband lies in the BGS generated by the pump, when the modulation frequency f_m is close to the Brillouin frequency shift ν_B. The DC bias voltage on the EOM basically just determines the amount of transmitted amplitude of the fundamental frequency. It is set, so that the carrier is totally suppressed and the remaining probe signal is uniquely made of the modulation sidebands. The CW probe and the pump pulses are both launched into the fiber under test at the same fiber end. The pump pulse provides gain to the probe signal during its forward propagation through the SBS process while the probe signal is amplified on the way back. Only a few percent of reflection is necessary at the fiber far end, so that Fresnel reflection is actually sufficient. Since the first upper sideband is not relevant for the measurement and even has a negative effect on the contrast, it must be suppressed using an optical filter. The probe intensity is monitored as a function of time and the delay between the launch of the pump pulse and the detection of the probe signal gives the positional information.

This technique makes the scan of the probe optical frequency very simple and convenient by just varying the microwave signal frequency. Since this technique uses a single laser and a modulator for the generation of the pump and probe signals, it insures a perfect stability of their frequency difference. Measurements of the distribution of the Brillouin frequency shift along a sensing fiber can therefore be performed with an excellent resolution using this technique. The measured standard deviation in the determination of the Brillouin shift frequency is 300 kHz. The best spatial resolution obtained so far is 15 m for a standard fiber, given by the minimum pump pulse width leaving a sufficient gain.

Local analysis of stimulated Brillouin interaction (LASBI) measurements were carried out on a 6.8 km-fiber optics cable link between the Swiss Telecom exchange stations of Versoix and Anières across the lake of Geneva, Switzerland. A part of the cable is designed for underwater applications and contains 2 tubes with 10 single mode optical fibers. Each fiber link is actually made of 5 segments of fibers spliced together. The topographical arrangement is schematically shown in Fig.2a, the successive splices being indicated by S1 through S4. Starting from the exchange station of Versoix, the conduit route can be described as follow: the first section of cable (560m) is a standard unarmoured telecom fiber optics cable, then 60m of the same cable (S1-S2) is used to join the underwater cable (armoured reinforced cable). The first 460m of the underwater cable goes through the lake of Geneva shore line and approximately 3700m are laid on the lake bed. On the other waterside, 360m of conduit brings the cable to a manhole where it is spliced (S3) to a 550m standard telecom cable. Finally 590m of another cable joins from S4 to the exchange station of Anières.

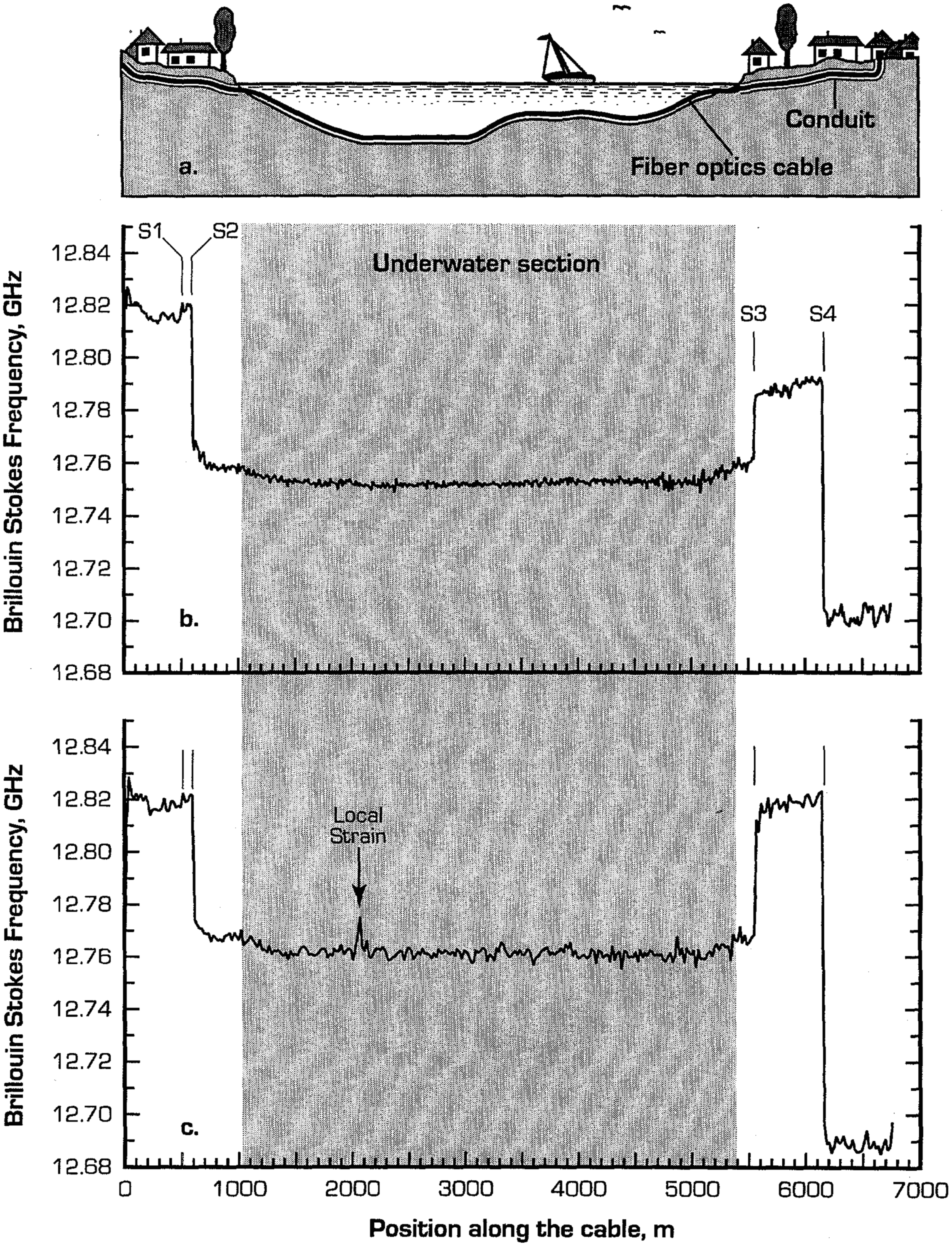

Fig.2 *Measurement of the Brillouin frequency shift on a underwater fiber optics cable. Topographical representation of the cable route (a). Local Brillouin frequency shift measured with a 20m spatial resolution for 2 different fibers of the cable (b and c).*

Several optical fibers of the cable have been tested. Fig. 2b and 2c shows the Brillouin frequency shift v_B along two fibers measured with a 20m spatial resolution. The different sections of the cable are clearly identified by their different v_B. The v_B value can differ from fiber to fiber depending on the fiber parameter [3].

On the terrestrial route, the cable is installed in a conduit. The temperature being relatively constant in the conduit, the changes in the Brillouin frequency shift are attributed to local strain. On the contrary the underwater portion is just laid on the lake bed and is consequently subjected to temperature variations. As a matter of fact the temperature gradient of the water is clearly observed on the two plots of Fig.2. The temperature is measured to be actually 5°C colder (frequency shift of 6.45 MHz smaller) at the deepest point (61m depth, positions 2000m to 3000m in the cable) than the water temperature nearby the shores (positions 1090m and 5300m). At 2600m away from the shore (position 3690m) the depth of the lake goes up to 31m and an 1°C increase is detected.

Concerning the strain experienced by the fibers, the first and last sections of the cable are installed through a winding route and undergo many strong curvatures. Nevertheless the variations of the measured Brillouin frequency shift (Fig.2b) is 12.9MHz and 11.6MHz for the first and last section respectively, corresponding to $2.15*10^{-4}$ and $1.9*10^{-4}$ equivalent strain. The section between S3 and S4 presents a slight slope that corresponds to a $1.1*10^{-4}$ strain. In Fig.2c the peak at position 2100m in the underwater section is attributed to a local strain. Even though the magnitude of the perturbation is not perfectly resolved because of the spatial resolution of the system (20m), the problem is easily detected. However the local strain is probably higher than the measured $2.7*10^{-4}$.

A portable instrument for local Brillouin gain spectrum analysis has been built and was used for on site measurements. Using the LASBI system, a fiber optics link can be guarantied to be strain free, which is the key information for its long-term reliability. Tests have been conducted on currently operating telecom cables and show that local strain can be introduced in the fiber by the installation procedure. The different fiber sections of fiber optics cables can also be easily identified, which is an interesting feature for diagnostic purposes. The results from this technique are steadily improving along with system optimization, in particular for spatial resolution. Other measurements were carried out on different installations such as aerial cables. These measurements show very minor fluctuations of the Brillouin shift, so that fibers are granted to be strain free.

References

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