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SINGLE END FIELD SYSTEM FOR LENGTH/STRAIN MEASUREMENTS IN OPTICAL CABLES

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Single end Field System for Lenght/Strain Measurements in Optical Cables

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Abstrac A system for optical fibre length/strain measurements during cable installation tests is presented. Tracted far end is free of optical components, replaced by a chemically deposited mirror. Accurate calibration of optical path/elongation ratio in single mode fibres has been done between $1.1\mu m$ and $1.7\mu m$.

1. INTRODUCTION

It is well known that stress and strain measurements in optical -fibres/cables are of utmost importance for cable manufacturers and installers. Large elongation of optical fibres during cable installation may give rise to failures or increased attenuation. A small residual strain accelerates static fatigue, shortening the expected life of the installed cable[1]. Several methods for measuring the fibre length and strain have been divised, most of them employing optical techniques in time[1,2] and frequency domain[3,4,5].

The major problem in this kind of experiment is the need to acess both sides of the measured fibre. Although a single end frequency domain measurement of lenght and strain in $.85\mu m$ has been reported[5], this task is usually accomplished by means of an auxiliary fibre spliced to the far end of the fibre to be tested or by splicing together the far ends of two fibres in the cable under test. This procedure brings up the question whether the observed strain effects arise from the test or the auxiliary fibre, since both are moving during traction or cable pulling conditions.

In this work we developped a single end field test system for fibre strain and length measurements, during cable testing or installation, based on the phase shift of a modulated signal launched into the fibre and reflected back at the far end.

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2. MEASURING PRINCIPLE

When an optical signal is sinusoidally modulated the phase of the modulation signal propagates with the group velocity along the fibre so that after a length L of fibre the phase will be

$$\phi = \frac{2\pi f}{c} N L \tag{1}$$

where f is the frequency of the modulation, c is free space velocity of light and N is the effective group index of the fibre, including material dispersion as well as waveguide or modal dispersion effects. When the frequency of the modulation signal is changed by a small amount Δf, the lenght of the fibre can be obtained from the variation of the phase change $\Delta\phi$ provided that it is smaller than 2π. This can always be achieved by a proper choice of Δf so that the length of the fibre can indeed be obtained by the slope of the curve $\phi \times f$

$$L = \frac{c}{2\pi f N} \frac{\Delta\phi}{\Delta f} \tag{2}$$

It is clear that this length measurement depends on the knowledge of the effective group index of the particular fibre which is being measured. This is the same problem which occurs in OTDR length measuremnts, in which the length is known from the time-of-flight of an optical pulse along the fibre. However, variations of this parameter from fibre to fibre are small, so that good accuracy is achieved using typical values for N.

When the length of the fibre is changed the group index also changes due to the elasto-optical effect. The relationship between the phase change and elongation of a stressed fibre is then given by the combined effect of length and refractive index changes. Differentiating equation 1 and using the strain-optic tensor to calculate the variation of the refractive index one obtains[6]

$$\Delta\phi = \frac{2\pi f}{c} N \left\{1 - \frac{N^2}{2}\left[p_{12} - \nu(p_{11} + p_{12})\right]\right\} \Delta L \tag{3}$$

where p_{11} and p_{12} are components of the strain-optic tensor and ν isthe Poisson ratio of the material.

The calibration of the phase/elongation ratio can be estimated from the properties of bulk silica and equation (3). Neglecting waveguide effects in the group index N, bulk silica values at $633\,nm$ give $\Delta\phi/\Delta L = 0.413^{o}/mm$ at $f = 300\,MHz$. This calibration, however, should not be expected to remain valid at $1300\,nm$.

3. MEASURING SYSTEM

The experimental set-up for the strain measurements is shown in figure 1. The $InGaAsP$ laser is driven by a $300\,MHz$ oscillator and the emitted laser light launched into the pigtail of a directional coupler having a ratio of 50% at $1300\,nm$. The other pigtails of the coupler are respectively connected to an $InGaAs$ pin photodiode and to the near end of the fibre to be tested so that the reflected light at the fibre far end reaches the detector with overall efficiency limited at 25%.

The far end of the test fibre is freshly cleaved and silvered by inmersion in a chemical solution of $AgNO_3$, $NaOH$, NH_3, isopropilic alcohol and dextrose. For a good quality cleaved face, reflection efficiencies near 100% can be easily obtained by this method. The chemical deposition of silver takes about 5 minutes depending on the concentration and temperature of the solution. The method is simple, harmless and easy to handle even in field tests. After the silver deposition, the free end needs no special care and the measurements can be done even if the free end is being pulled by the cable test or pulling equipment.

The detected reflection is amplified before being measured by a vector voltmeter. The phase reference comes directly from the driver oscillator. The output of the voltmeter is sampled and A/D converted so that the whole experiment is controlled by a computer. Test parameters such as the pulling force, cable length or elongation can also be controlled.

For multimode tests the optical components were all multimode and a mode scrambler was also needed between the test fibre and the coupler. Wrapping the fibre around a $3\,cm$ diameter mandrel was also very efficient in eliminating mode fluctuation noise. Although this system could also be used in single mode fiber tests, much better results were obtained with single mode coupler and laser pigtail.However, Fresnel reflection at the interfaces had to be eliminated by an index-matching liquid in order to avoid excess phase noise arising from interference effects in single mode optics.

The dynamic reserve of the multimode systems was about $15\,dB$, mainly limited by Fresnel reflection at the test fibre front end. This reserve could be improved to $25\,dB$ by using index-matching liquid at the interfaces. This is the same reserve obtained with single mode optics and index-matching liquid.

In length measurements the fixed part of the system (pigtails, coupler and electrical cables) also contributes to the phase change $\delta\phi$, so that the system must be calibrated by using the light reflected at the front end of the fibre which is

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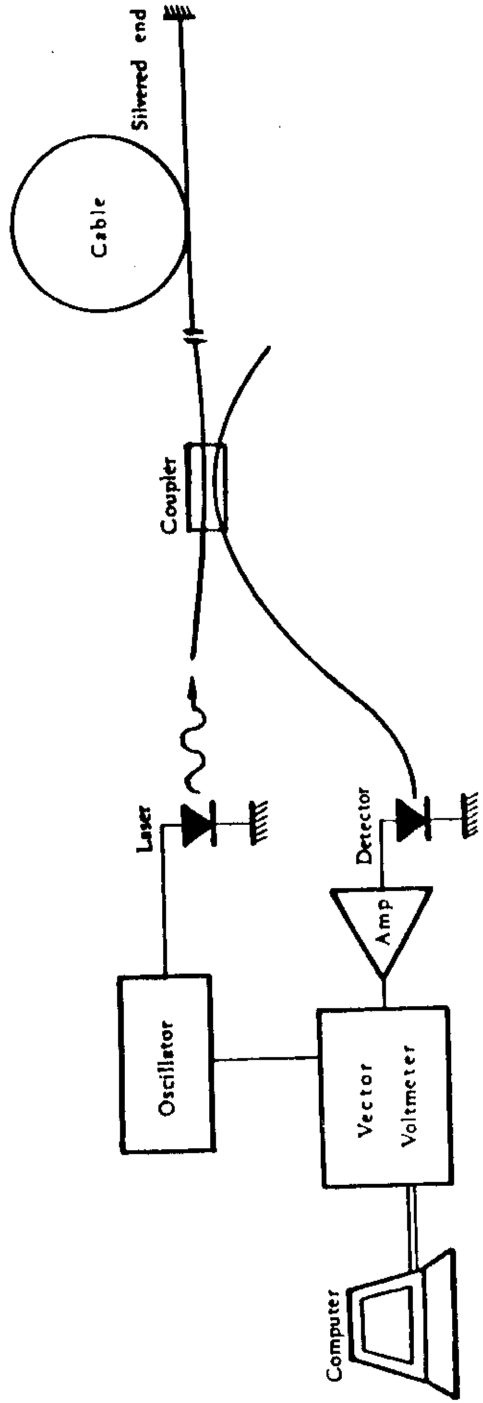

Fig.1 - Block diagram of measuring system.

replaced by a mirror for this experiment. The constant obtained must be substracted from the result of expression (2), and is equivalent to the effective length of the measuring system.

4. RESOLUTION AND CALIBRATION

The resolution of the phase measurements was limited by the vector voltmeter to $\pm 0.1^0$ including the phase fluctuations of the whole measuring system. Using the estimated calibration from bulk silica properties, the system sensitivity is limited to $\pm 0.25\,mm$. To avoid temperature fluctuation effects the calibration was done with an $1.5\,m$ long test fibre thermally isolated from the environment.

The fiber elongation was measured withing $\pm 0.1\,\mu m$ from zero to $6.5\,\mu m$ so that the maximum strain was limited to about 0.4%. Great care had been taken to avoid sliding effects at the anchoring points. No hysteresis effect was observed even after a great number of stressing cycles, confirming the good quality of the anchorage. The measured calibration constant was

$$\frac{c}{2\pi f}\,\frac{\Delta\phi}{\Delta L} = 1.18 \pm 0.02 \qquad (4)$$

corresponding to a phase/elongation ratio of $0.425^\circ/mm$ at $300\,MHz$. This value is slightly greater than previously reported values obtained either by direct calibration of the phase/elongation ratio[4] or by time delay in pulse experiments[3]. The main limitation of this calibration experiment was the small value of the maximum elongation which was established by the length of the test fibre. A real improvement of this calibration experiment would be unpractical unless a long test fibre and a system of pulleys were employed. However, spurious effects could be introduced either by temperature fluctuations or bending effects at the pulleys, which we wanted to avoid.

A more precise calibration curve was done by measuring directly the group delay as a function of the fibre elongation with a Michelson interferometer[6,7]. In this experiment, incoherent light was launched into the interferometer which had the first fibre in one arm and an air path in the other one. Interference fringes present maximum contrast when the group delay in both arms of the interferometer are equal so that the group delay of the test fibre was measured by the length of the air path for diferent fibre elongations. The elongation could be measured within $\pm 0.1\,\mu m$ whereas the group delay or optical path change could be measured within $\pm 3\,\mu m$. Figure 2 shows a typical calibration curve at $1300\,nm$ for a single mode fibre with step index $\Delta n = 0.0070$. The corresponding phase/elongation ratio at $300\,MHz$ is $0.422^0/mm$. Figure 3 shows the slope of the optical path/elongation ratio for

two different single mode fibres between $1100\,nm$ and $1700\,nm$. For most practical purposes this ratio may be considered to be independent of the wavelength and fibre profile, as far as waveguide effects in the group index can be considered to be small. Nevertheless, the scatter of the data shown in figure 3 is slightly greater than expected from the sensitivity of our measurments, and can be due to an uncontrolled parameter such as small variations in the temperature of the fibre. Taking the rms deviation from the mean as experimental error, one obtains a slope

$$\frac{c}{2\pi f}\,\frac{\Delta\phi}{\Delta L} = 1.171 \pm 0.001 \qquad (5)$$

For multimode fibre the effective group index may change from fibre to fibre and depend on the mode distribution at the fibre. However, these variations are still small, provided that good mode scrambling is achieved. In this case the accuracy in the calibration will be comparable to the one obtained in length measurements.

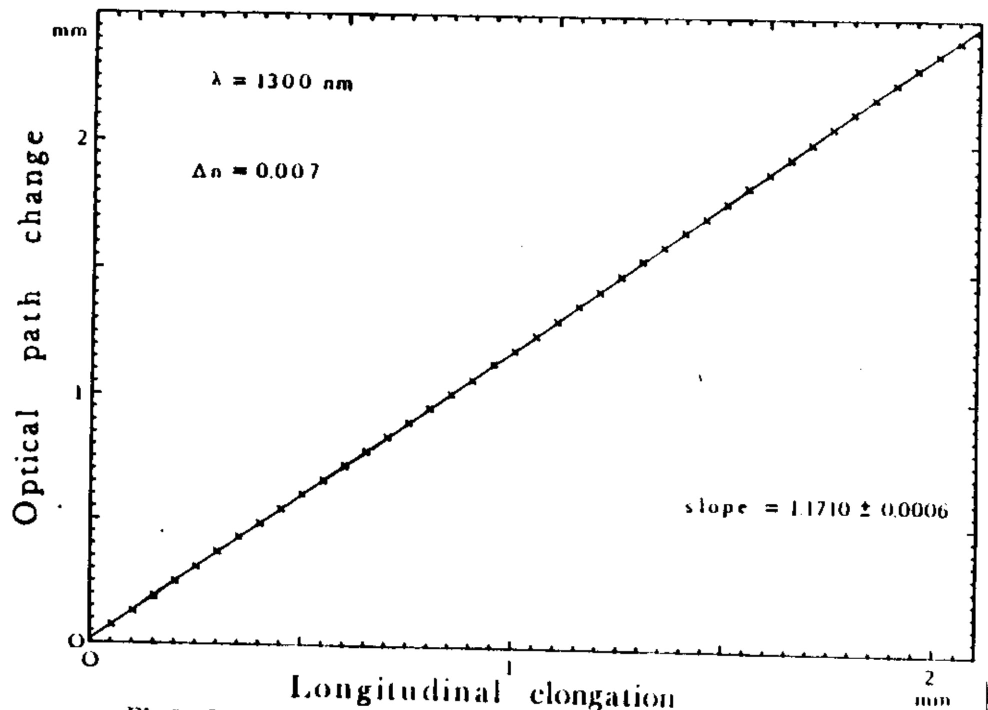

Fig.2 - Interferometric calibration of optical path/elongation ratio.

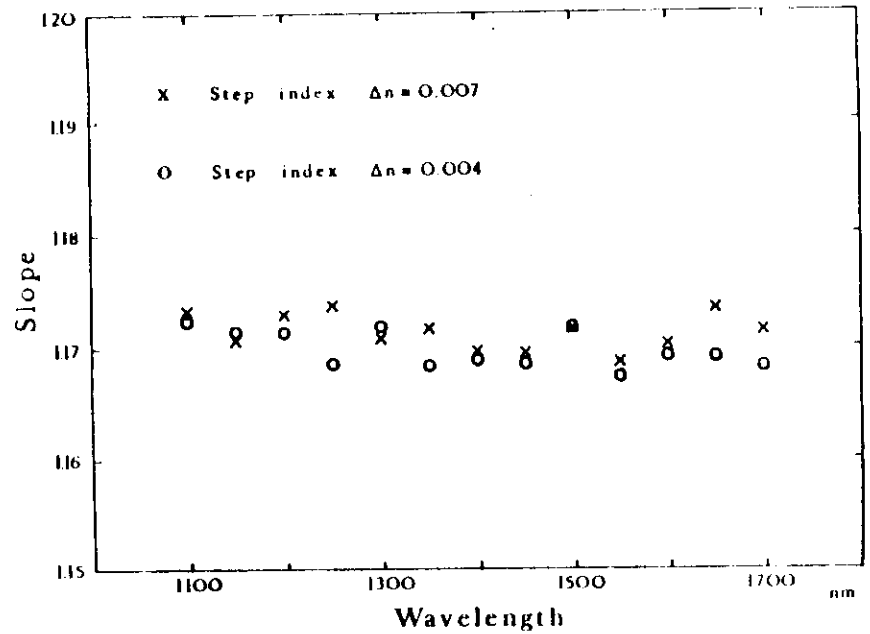

Fig.3 - Optical path/elongation ratio for two different single-mode fibres between 1100 nm and 1700 nm.

5. SYSTEM APPLICATION

An example of a cable traction test using the multimode configuration at 1300 nm is shown in fig.4, for a 30 m long loose filled buffer jacket cable (SIECOR). The threshold tracking force needed to produce fibre elongations in this kind of cable can be easily recognized. The phase noise level, measured before the application of the stress load, is small enough to allow the observation of small effects occurring during the cable traction. These effects are probably related to modal noise due to variations in the modal distribution but are still small enough to keep the resolution of the measurements within 5 mm. Temperature effects could also be observed during an overnight measurement of fibre elongation.

Length measurements were done with the single mode configuration, driving the laser source with an external variable frequency generator. The resolution was limited by the phase noise to within 0.4%. A test experiment was done with several meter-length single mode fibre samples. In all cases the optical and mechanical measurements agreed within the experimental errors. It should be pointed out that the variation of the group refractive index from fibre to fibre indeed affects

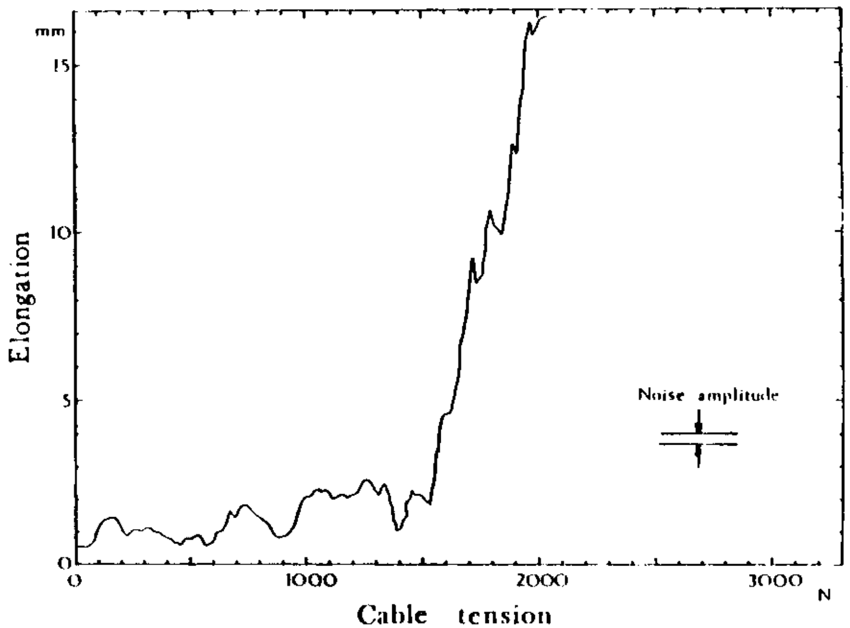

Fig.4 - Cable traction test application using the single end system in the multimode configuration. The noise amplitude was measured before stress application.

the optical measurement, but this effect is smaller than the phase noise of the vector voltmeter, so that a typical value fo N can be used. Of course, when special fibres such as dispersion shifted fibres, which have a larger value of N are to be measured, the typical value for N must be replaced by the actual group index of the fibre.

6. CONCLUSION

We developed a single end simple and reliable field test system for length and strain measurements of optical fibres and cables. An accurate calibration of the phase delay/elongation ratio was obtained, and the result was shown to be independent of wavelength and fibre profile in single mode fibres. Elongations of ~ 5 mm were measured in a 30 m optical cable strain test experiment corresponding to an accuracy of strain measurement better than 0.03%. Typical resolutions of

REFERENCES

1. Y. Katsuyama et al, J. Op. Communications *3*, 2 (1982)
2. A.H. Hartong et al, Opt. Quantum Electron. *11*, 265 (1979)
3. O. Kawata et al, J. Lightwave Technology *1*, 1, 190 (1983)
4. R.W.A. Ayre, J. Lightwave Technology *4*, 1, 15 (1986)
5. R. Kashyap and M.H. Reeve, Electronics Letters *16*, 18, 689 (1980)
6. L. Thevenaz, J.P. Pellaux and J.P. von der Weid, J. Lightwave Tech. *6*, 1,1 (1988)
7. L. Thevenaz, J.P. Pellaux and J.P. von der Weid, to appear in Rev. Fis. Ap. Instr., 1988

Resumo

Apresenta-se um sistema para medidas de comprimento e alongamento de fibras óticas em testes de instalação de cabos. A extremidade tracionada é livre de componentes óticos, substituidas por um espelho quimicamente depositado. A razão entre o caminho ótico e o alongamento em fibras monomodo foi objeto de uma calibração precisa entre $1.1\mu m$ e $1.7\mu m$.