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CROSS-TALK IN POLARISATION-MAINTAINING FIBRES

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ABSTRACT

We show that internal geometric imperfections have a negligible effect on polarisation cross-talk in a birefringent fibre. This is contrary to popular opinion and has considerable implications for the way in which polarisation maintaining fibres are specified.

INTRODUCTION

Cross-talk between the two polarisation states in a birefringent polarisation-maintaining fibre arises from random perturbations of the fibre. These can have two sources: i) internal geometric variations in the core or stress-creating sectors resulting from manufacturing imperfections and ii) externally applied stresses, twists, and bends resulting from, for example, winding on a drum.

The degree of cross-talk between the two polarised modes is commonly specified by the 'h-parameter'[1], the rate at which power is transferred from one polarised mode to the other. This parameter occupies a prominent position in specifying the characteristics of commercially available fibres. For existing fibres 'h' lies between 10^{-4} - 10^{-6} m^{-1} [1]. It should be apparent from the foregoing that the validity of the the 'h-parameter' in specifying the intrinsic properties of a given fibre depends on the fibre measurement being made under conditions in which external perturbing effects are eliminated and internal imperfections are therefore dominant. Failure to pay attention to this point results in an 'h-parameter' specification which is not a test of the quality of a birefringent fibre, but of the condition of the winding on the drum. Furthermore, efforts to improve fibre manufacture will be of little avail if the 'h-parameter' is dominated by extrinsic factors which reflect the condition under which the measurements are made, rather than the inherent quality of the fibre.

The main justification for assuming that the 'h-parameter' is a measure of inherent fibre quality and not of the winding condition appears to be several recent papers[2-5] which show that minute internal geometrical imperfections in the fibre structure cause large polarisation cross-talk. It is thus suggested that the measured cross-talk is dominated by these effects. For example, it is shown [3] that r.m.s. angular deviations of only 1 degree m^{-1} of one of the stress-creating regions in a birefringent fibre ($B = 10^{-4}$) results in a degradation of the 'h-parameter' to a value of 2×10^{-4} m^{-1}. Moreover, this result does not appear to depend on the <u>birefringence</u> of the fibre, a parameter which must surely be a measure of the resistance of a fibre to polarisation cross-talk.

In this paper we show that previous work is incorrect and that for random perturbations of the core or stress-producing regions to have a significant effect they must occur, with a correlation length similar to the polarisation beat length, typically a few mm. This is a conclusion which is expected from the well-known coupled-mode theory. Our result has implications not only for how the 'h-parameter' should be interpreted, but also for the manufacturing process itself.

ANALYSIS

Figure 1 shows the cross-section of a birefringent fibre with one of the stress producing regions perturbed by a small angle θ(z) at a point z along the fibre. Monochromatic light is launched at the input to the fibre with its polarisation parallel to one of the birefringent axes. We shall assume that θ(z) is a stochastic variable with auto-correlation function

$$R_{\theta}(u) = \bar{\theta}^{2} \exp(-|u|/l) \qquad (1)$$

The r.m.s. angular deviation is $\bar{\theta}$ and the correlation length is l. In the fixed X-Y coordinate system it can be shown that the modal coupling coefficient is given by [6]

$$\Gamma = k_{0} B \theta / 2$$

where B is the fibre birefringence. Calculating the average cross-talk in an ensemble of fibre we find that the "h" parameter is given by

$$h = \frac{1}{2} \bar{\theta}^{2} / l \qquad (2)$$

For $\bar{\theta}$ = 1 degree and l = 1 metre equation (2) gives an "h" parameter of 1.5×10^{-4} m^{-1}. This result suggests that there is very strong mode coupling but that conclusion would be wrong. We note that (2) does not contain the fibre birefringence, although intuition suggests some correlation between "h" and birefringence. The fallacy contained in (2) is that it refers to modes defined with respect to the fixed X-Y axes. In any experiment the output polariser would be alligned with the output birefringent axes and not the original fixed axes. To describe what is actually measured we must transorm the coupled mode equations to a frame rotating at θ/2 with respect to the fixed X-Y axes. This simple point has been consistently overlooked in the literature. A calculation of "h" now yields:

$$h = \frac{\bar{\theta}^{2}}{4l} \cdot \frac{1}{1 + (lBk_{0})^{2}} \qquad (3)$$

DISCUSSION The "h" parameter given by equation (3) describes the coupling of local modes rotating with the random twists of the birefringent axes, unlike equation (2) which describes coupling between ideal modes referred to a fixed set of axes. In any experiment it is the former that is measured. If we again assume $\bar{\theta}$ = 1 degree and l = 1 metre we find that (3) gives $h = 3 \times 10^{-10}$ m^{-1} for λ = 1um and $B = 10^{-4}$. This degree of mode coupling is negligible. For any significant mode coupling to occur the correlation length must be comparable to the fibre beat length, typically a few mm. It is difficult to see how random angular deviations could occur with such a small period as a consequence of the fibre pulling process. We are led to the conclusion that other effects, perhaps irregularities in the fibre coating, must be responsible for the observed levels of mode coupling in present fibres. Recent measurements on the effects of different fibre coatings would tend to support this view. [7]

CONCLUSIONS

The present observed levels of polarisation cross-talk in birefringent fibres *cannot* be due to imperfections within the fibre. They are almost certainly a consequence of uneven fibre coatings and externally applied stresses and bends resulting from winding on a drum.

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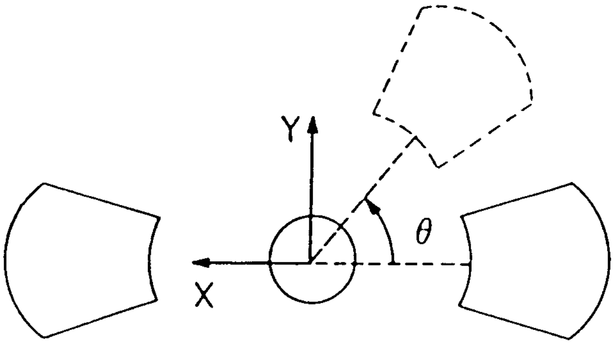

Fig.1. Perturbation of a stress applying region in a birefringent fibre through a small angle θ.