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A NEW TECHNIQUE FOR THE MEASUREMENT OF AXIAL-STRESS IN OPTICAL-FIBRE PREFORMS

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The ability to measure the axial stress in optical-fibre preforms is essential for the development of highly-birefringent[1] and other specialist fibres, in which high levels of thermal stress are deliberately introduced to modify the fibre propagation characteristics. Conversely, it has been found that the loss of telecommunications-grade fibre can be reduced by minimising the stresses within the core[2]. To date, axial stress profiles have been measured by the rather cumbersome method of reconstruction from the retardation profiles measured transversely across the preform[3,4,5]. However, this technique has not seen widespread routine use, presumably because the results rarely justify the complexity of the measurement. In this paper we present a new method for measuring the axial stress profile which should see widespread adoption as a result of its simplicity and convenience. The method has the advantage that it uses the same hardware and software that are commonly used in transverse refractive-index profiling [6,7,8] and it is therefore readily incorporated into existing equipment. The technique can also in principle be applied to two-dimensional stress profiling of asymmetric preforms. In addition, the work provides a new insight into how thermal stresses affect fibre refractive-index profiling techniques.

Transverse refractive-index profiling of both symmetric and asymmetric preforms is based on the measurement, either directly or indirectly, of the optical path-length difference $\eta(\rho,\theta)$ between a ray passing through the preform and an equivalent ray in the index-matching fluid[6]. (Here ρ is the ray offset and θ is the azimuth of the ray - see Figure 1). The axial stress $\sigma_z(r,\theta)$ in the preform causes $\eta(\rho,\theta)$ to be dependent upon the polarisation orientation of the incident light. Hence a retardation,

$$R(\rho,\theta) = \eta_z(\rho,\theta) - \eta_\theta(\rho,\theta) \qquad (1)$$

exists across the preform. Here η_z, η_θ are the optical path-length differences seen by light polarised axially and transversely to the preform axis respectively. Reconstruction of the refractive-index profile from the η_z and η_θ data will yield two different <u>effective</u> refractive-index profiles, $n_z'(r,\psi)$ and $n_\theta'(r,\psi)$ respectively. The difference between these profiles can be shown by the application of elementary elastic theory to be:

$$n_z'(r,\psi) - n_\theta'(r,\psi) = -C\,\sigma_z(r,\psi) \qquad (2)$$

where the stress-optic coefficient $C = -3.5 \times 10^{-5}$ mm^2/kg for high silica glasses. Thus the difference between the refractive index profiles seen transversely by z-polarised and θ-polarised light gives the axial stress profile directly.

The above therefore suggests a remarkably easy method for measuring the axial stress profile $\sigma_z(r,\psi)$ in axi-symmetric and non axi-symmetric optical fibre preforms. Using existing transverse refractive-index profiling techniques, we simply measure $n_z'(r,\psi)$ and $n_\theta'(r,\psi)$ with light polarised axially and then transversely to the preform axis, followed by calculation of $\sigma_z(r,\psi)$ from equation (2). Fig. 2 illustrates the two profiles $n_z'(r,\psi)$ and $n_\theta'(r,\psi)$ measured by the standard spatial-filtering technique[6] with the sole addition of a polariser. In this case, the preform is circularly symmetric and consists of a silica substrate, a phosphorus/fluorine-doped outer matched cladding, a depressed boron-doped inner cladding and a germania-doped core. The axial-stress profile reconstructed from these measurements, Figure 3, reveals that the depressed boron-doped inner cladding supports 15 kg/mm^2 of axial tensile stress, whereas the levels of tensile stress in the core are somewhat lower at 5 kg/mm^2. As expected, the outer matched cladding and substrate exhibit a lower compressive stress of 2 kg/mm^2.

The existence of stress-induced multivalued refractive-index profiles in the preform which depend on the polarisation of the measurement light source obviously affects conventional transverse refractive-index profiling measurements. A related topic has been addressed by Scherer[9], who showed that thermal stresses cannot be neglected in the design of graded-index fibres. We note that the effective refractive-index profile measured with unpolarised light is the average of the effective profiles, $(n'_z + n'_\theta)/2$. Again, elasticity theory reveals that this is equal to $(n_x + n_y)/2$, where n_x and n_y are the real real refractive indices seen by light polarised in the x and y directions respectively (see Figure 1). Fortunately, therefore, the transverse refractive-index profiling techniques yield the average profile seen by unpolarised light travelling down the fibre. This is an important result, since it quantifies for the first time how thermal stresses affect the transverse profiling methods.

The axial stress measurement is currently being applied to non axi-symmetric profiles (e.g. Bow-Tie preforms[1]). Data concerning resolution, accuracy and repeatability will be presented at the Conference.

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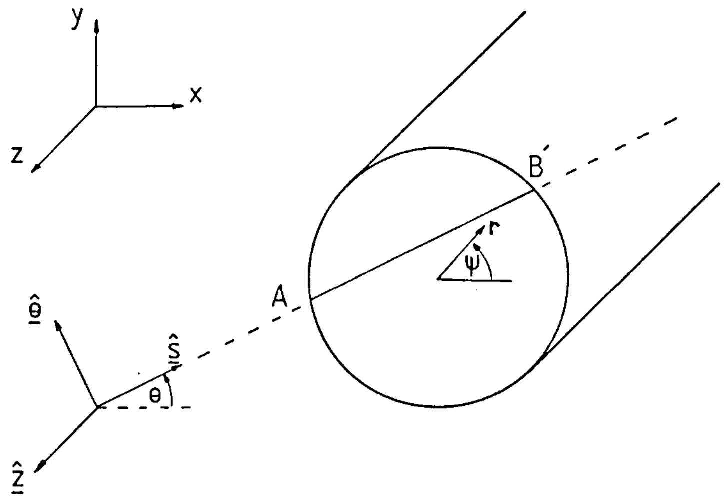

Fig. 1: Co-ordinate system

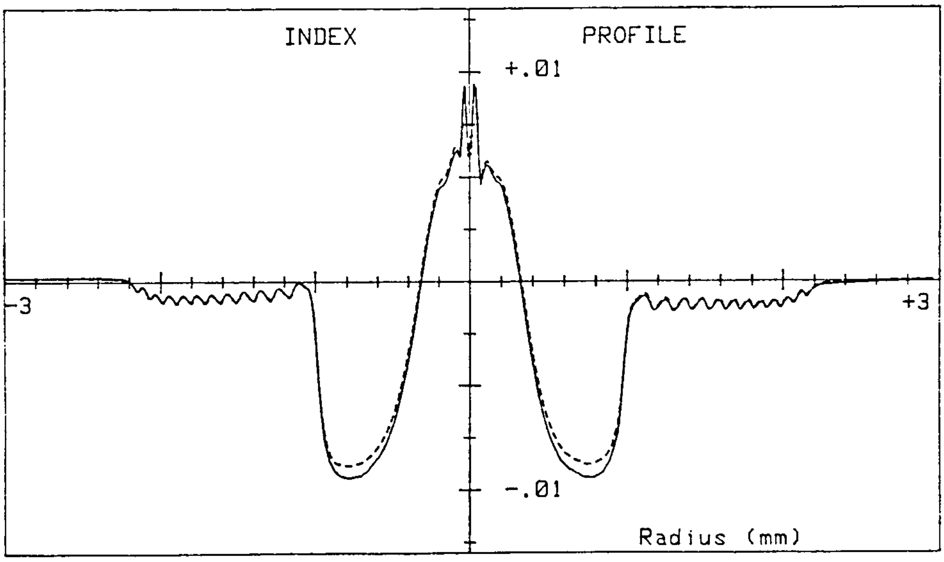

Fig. 2: Refractive index profiles measured for light polarised axially (dashed) and transversely (solid line) to the preform.

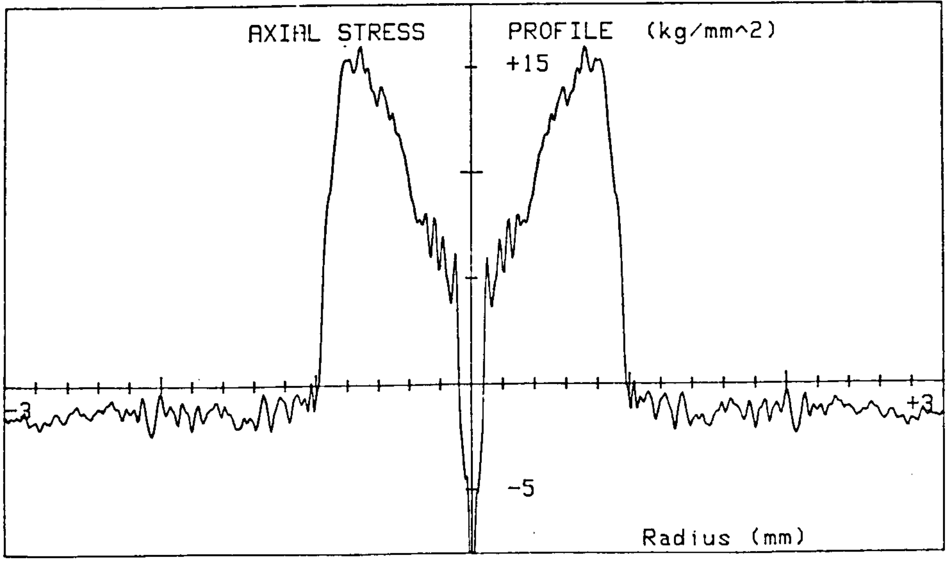

Fig. 3: Axial stress profile calculated from Fig. 2.