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Birefringence and polarization mode-dispersion in spun single-mode fibers

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A theoretical and experimental analysis of the polarization properties of twisted single-mode fibers is presented. It is shown that whereas a conventionally twisted fiber possesses considerable optical rotation, a fiber which has a permanent twist imparted by spinning the preform during fiber drawing exhibits almost no polarization anisotropy. It is thus possible to virtually eliminate the commonly observed fiber linear birefringence. As a consequence, fibers made in this way are ideally suited for use in the Faraday-effect current transducer. It is further shown that a permanent twist of a few turns/meter effectively eliminates polarization mode-dispersion. The technique therefore appears attractive for enhancing the bandwidth of very long unrepeatered telecommunication links.

I. Introduction

Single-mode optical fibers are of interest both for transmission of high-capacity long distance telecommunications and for use in a number of sensor applications. Fiber interferometers are used in rotation sensors[1] and in the detection of acoustic fields,[2] while magnetic fields (or electrical current flow) can be detected by the Faraday effect.[3] Single-mode fibers are used since in principle they have a single well-defined phase velocity and hence polarization state, small variations in which can be readily observed. Whereas this is the case in a circularly symmetric stress-free, straight fiber, in practice a degree of ellipticity invariably exists, accompanied by an associated stress asymmetry.[4] The fiber then supports two orthogonally polarized modes with differing phase velocities and thus appears birefringent. Consequently, the output state of polarization (SOP) varies cyclically along the fiber length with period $L_p = 2\pi/\Delta\beta$, where $\Delta\beta$ is the difference in propagation constants of the two modes. Furthermore, the output SOP is not stable with time as a result of thermal and mode-coupling effects, and this is a disadvantage in interferometric applications.

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A solution to the problem is to excite only one polarized mode in a fiber having very high birefringence—the polarization-maintaining fiber.[5] For the Faraday-effect current transducer, however, such an approach is unsuitable since the presence of linear birefringence in the fiber quenches the small Faraday rotation once the fiber length exceeds half of the polarization beat length L_p.[3,6] Thus, the interaction length between the fiber and the magnetic field (and hence the sensitivity) is very small for the polarization-maintaining fiber[5] with its submillimeter beat length, whereas it can be several tens of meters for a low birefringence fiber.[4] The latter may thus be looped around a large current-carrying conductor to form an ammeter.

The presence of two modes in the fiber can also be a disadvantage in telecommunications systems where it leads to a reduction in bandwidth as a result of a difference in the mode group delays (polarization dispersion). The magnitude of the effect has been estimated at 10–40 psec/km,[4,7] although this would be considerably greater for a polarization-maintaining fiber with its high birefringence.[8] Polarization dispersion could thus become significant in future links of 100 km or more, as presently envisaged for undersea use.

In this paper we direct our attention to the analysis and fabrication of a fiber which exhibits very low polarization anisotropy. This is accomplished by spinning the preform during fiber drawing to impart a permanent twist to the fiber and thus restore an average circular symmetry to the waveguide structure. Fibers made in this way (spun fibers) are ideally suited for use in the Faraday-effect current transducer since it is shown that their response is close to that of a perfect fiber provided at least two twists occur for each polarization beat length L_p. Furthermore, we show that such fibers possess negligible polarization dispersion, an attribute which may assume importance in future telecommunications systems.

We begin with a theoretical analysis of twisted single-mode fibers to distinguish between spun fibers and those twisted after drawing. It is shown that in the latter, reduced linear birefringence is obtained at the expense of substantial circular birefringence, whereas spun fiber has neither measurable linear nor circular birefringence and thus behaves as a perfectly circular isotropic waveguide. These predictions are confirmed by experiment.

II. Analysis of Twisted Fibers

Using a planewave approximation, McIntyre and Snyder[9] have analyzed the properties of an isotropic twisted medium by modeling it as a stack of rotated birefringent plates and employing coupled-mode theory. We use their approach since it is intuitively appealing and allows a better understanding of the difference between spun and twisted fibers. Consider a fiber with an intrinsic linear birefringence $\Delta\beta$ (in the untwisted or unspun state) which is twisted with a rate ξ. From Ref. 9 analytical expressions for the amplitude of the fields in the two orthogonally polarized modes are obtained as a function of length for any input condition. We proceed from this result by writing the solution in matrix notation and equate the expression to the well-known Jones matrix for a retarder and a rotator.[10]

The following expressions are obtained for retardance $R(z)$, rotation $\Omega(z)$, and principal axis orientation $\phi(z)$ as a function of length z.

$$R(z) = 2\sin^{-1}\left(\frac{\rho}{\sqrt{1+\rho^2}}\sin\gamma z\right), \tag{1}$$

$$\Omega(z) = \xi z + \tan^{-1}\left(-\frac{1}{\sqrt{1+\rho^2}}\tan\gamma z\right), \tag{2}$$

$$\phi(z) = \frac{\xi z - \Omega(z)}{2} \pm \frac{m\pi}{2} \qquad m = 0,1,2,\ldots, \tag{3}$$

where

$$\rho = \frac{\Delta\beta}{2(\xi - \alpha)}, \tag{4}$$

$$\gamma = \tfrac{1}{2}\sqrt{\Delta\beta^2 + 4(\xi-\alpha)^2}. \tag{5}$$

In the case of a twisted fiber, α is the optical rotation introduced by the photoelastic effect. It has been shown[11] that

$$\alpha = g'\xi, \tag{6}$$

where the proportionality constant g' is found experimentally to be 0.08. On the other hand, for a spun fiber no shear stress is present since the fiber has a permanent twist; thus $\alpha = 0$.

We have assumed a fiber with only linear birefringence having retardance $\Delta\beta$ in the untwisted state. Generally $\Delta\beta$ arises from a combination of stress asymmetry and core ellipticity. In practice most fibers also exhibit a degree of intrinsic circular retardation, i.e., they behave as if already slightly twisted.[12] This effect can be incorporated into the above analysis as a constant term in the parameter α.

In the planewave approximation used by McIntyre and Snyder[9] the coupling coefficient between the modes is $(\xi - \alpha)$. More recently, Fujii and Sano[13] have derived the coupling coefficients in twisted fibers taking account of the waveguiding effect. Provided $V > 1.5$ and the fiber ellipticity does not exceed 5%, their analysis similarly gives a coupling coefficient of $(\xi - \alpha)$.

III. Physical Interpretation

We have obtained expressions [Eq. (1)–(3)] which describe the net polarization properties of a length z of twisted birefringent fiber in terms of a discrete equivalent birefringent element having a retardance R and principal-axis orientation ϕ, followed by a discrete optical-rotator element with rotation Ω. This description is intuitively appealing since it readily allows a physical interpretation of the polarization evolution along the length of the fiber. Note, however, that some care is required in the interpretation of the principal-axis orientation ϕ. It can be seen from Eq. (1) that R can be positive or negative, implying that the principal axis is coincident with either the fast or the slow polarization axis depending on the sign of R. The principal axis should therefore be considered as the axis to which the retardance is referenced, this axis being the fast axis when the net retardance is positive and the slow axis when negative.

It is instructive to consider the net polarization characteristics of the postdraw twisted fiber for various twist rates. Such an interpretation assists in distinguishing the characteristic differences between a spun and a twisted fiber.

A. Small Twists

For twist rates which are small relative to the intrinsic fiber retardance ($\xi \ll \Delta\beta$), the principal-axis orientation $\phi \simeq 0$, i.e., it coincides with the minor axis of the core ellipse at the input, and little modification of the fiber linear birefringence occurs. This is illustrated in Fig. 1 for $\Delta\beta/\xi = 4000$, where the retardation is seen to increase linearly with length, i.e., $R \simeq \Delta\beta z$. At the same time the rotation Ω is similarly linear with length, $\Omega \simeq \xi z$ [Eq. (2)], except near points at which $z = (2m+1)\pi/\Delta\beta$, where a singularity occurs. Thus the SOP rotates with the twist as if locked to it[9,11]; linearly polarized light injected into the fiber parallel to the principal axis remains linear as it propagates down the fiber and rotates in synchronism with the fiber twist. The photoelastic rotation is effectively swamped by the large linear birefringence.

B. Large Twists

In the limit of a high twist rate ($\xi \gg \Delta\beta$) the retardance becomes, from Eq. (1),

$$R(z) \simeq \frac{\Delta\beta}{(\xi - \alpha)}\sin[(\xi - \alpha)z] \tag{7}$$

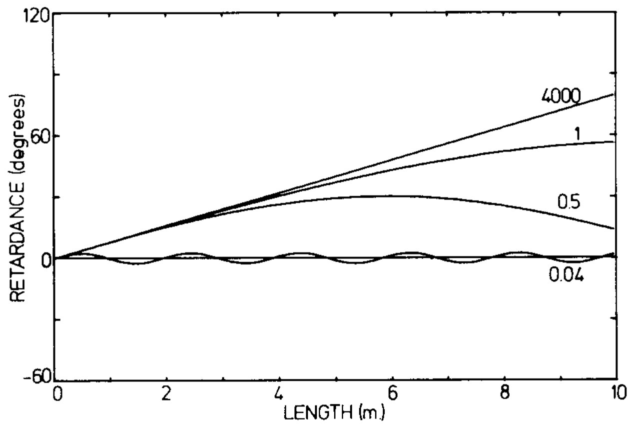

Fig. 1. Calculated fiber retardance as a function of length for various twist rates ξ given by the values of $\Delta\beta/\xi$ shown. Curves are plotted for an intrinsic linear retardance $\Delta\beta$ of 8°/m.

and the rotation

$$\Omega(z) \simeq \alpha z. \tag{8}$$

In this case the fiber retardance is considerably reduced by the twist and becomes oscillatory about zero (Fig. 1, $\Delta\beta/\xi = 0.04$). Launching linearly polarized light into the fiber at any azimuth results in near-linear output, rotated with respect to the input by angle αz. In fact, the SOP along the length consists of an oscillation between very slightly left and right elliptically polarized light which rotates in orientation.

A useful conceptual aid for the effect is to regard the fiber as composed of untwisted birefringent sections, each having a length of one quarter of a twist period and rotated with respect to each other by $\pi/2$ rad. Thus, an interchange of fast and slow axes occurs at the junction between the sections, and the birefringence of the first section is exactly canceled by the second and so on. As we proceed along the fiber length the birefringence oscillates about zero with a magnitude which depends on the birefringence of the individual sections. Clearly, the shorter the twist period relative to the intrinsic birefringence beat length L_p, the less will be the birefringence of the sections and thus the smaller the birefringence oscillation amplitude (Fig. 1). In the limit of a very large twist the fiber appears to have zero birefringence, and we are left with the residual rotation only.

The highly twisted fiber can be regarded as performing for circularly polarized light that which the highly birefringent polarization-maintaining fiber achieves for linearly polarized light. The normal modes of the former are circularly polarized and would have a large difference in propagation constants if the fiber could be sufficiently tightly twisted to induce a large photoelastic rotation.

In this case the fiber would preserve circularly polarized light and would be insensitive to microbending and pressure effects. Unfortunately, as with the linear polarization-maintaining fibers, a submillimeter beat length is necessary, and this would require an optical rotation of greater than $2\pi \times 10^3$ rad/m. The required twist would fracture the fiber; consequently, circular polarization-maintaining fibers are not a practical proposition.

IV. Spun Fibers

As outlined above, twisting the fiber has the advantage that it can effectively eliminate the intrinsic fiber linear birefringence. It is shown in later sections that such a quasi-low birefringence fiber has increased sensitivity to magnetic fields and reduced polarization mode-dispersion. However, although a twisted-fiber Faraday current-monitor has been demonstrated,[14] twisting the fiber after drawing is difficult when a large twist is required and furthermore results in residual photoelastic rotation, which is highly temperature sensitive. In this section we show that the same advantages accrue for fibers twisted during the drawing process (spun), with the added advantage that no residual optical rotation occurs.

When a fiber is pulled from a preform which is simultaneously rotated, a large uniform twist-rate ξ can be frozen in to the fiber. No photoelastic effect will be present as the twisting occurs in the furnace hot-zone, where the glass viscosity is sufficiently low to prevent the support of shear stress. Thus, $\alpha = 0$ in our previous analysis and in the limit of large twist rate ($\xi \gg \Delta\beta$) we have for the residual polarization anisotropy

$$R(z) = \frac{\Delta\beta}{\xi} \sin(\xi z), \tag{9}$$

$$\Omega(z) = -\frac{(\Delta\beta)^2}{8\xi} z \simeq 0, \tag{10}$$

$$\phi(z) = \frac{\xi z}{2}. \tag{11}$$

The fiber now has very small values of both retardation and rotation and, in the limit of large spin, behaves as a perfectly isotropic waveguide capable of transmitting any polarization state unchanged. Thus, as we might intuitively expect, the asymmetries in the waveguide caused by ellipticity or stress can be restored to near perfect average symmetry by rapid rotation of the fiber about its axis. For finite spin rates, however, some very small anisotropy remains, and we have, as before, an SOP which is oscillatory between slight right and left elliptically polarized light. Moreover, only a very small second-order residual rotation $\Omega(z)$ now exists, in contrast to the case of a fiber twisted after drawing where the rotation is substantial.

As an example of the use of preform spinning to produce a quasi-low birefringence fiber, let us take some typical figures for practical fibers. We have found that it is possible[4] to reproducibly manufacture fibers with an intrinsic linear retardance of better than 1 rad/m. Laboratory experiments have similarly shown that a spin period as short as 1 cm is relatively easily obtainable during fiber drawing. A fiber of 1 rad/m retardance with a spin of 1 turn/cm has [Eq. (9)] an oscillatory birefringence of 1-cm period and maximum

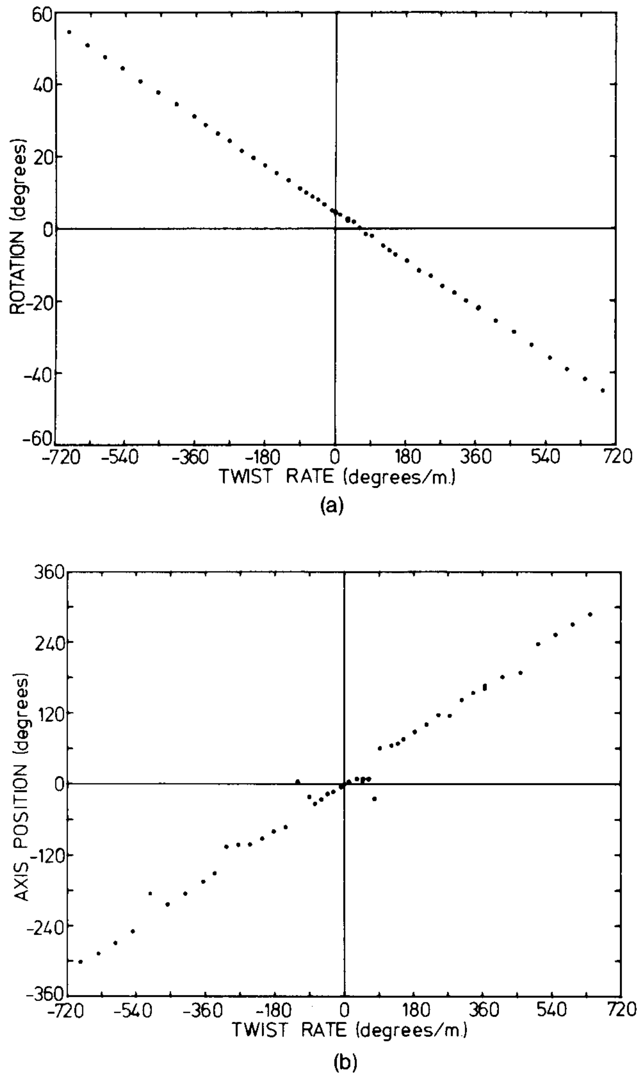

Fig. 2. Measured optical-rotation parameters in fiber GSB4 as a function of fiber twist rate; length = 0.983 m: (a) rotation, (b) principal-axis orientation.

retardance of only 1.6×10^{-3} rad, an immeasurably small value. The residual rotation is 2×10^{-4} rad/m, i.e., one complete rotation in 31.6 km! Such a fiber would be ideally suited for use in a Faraday-current monitor, since the intrinsic polarization anisotropy is negligibly small.

Owing to their intrinsic geometric symmetry, spun fibers have no significant birefringence due to ellipticity and asymmetric stress and, as a consequence, are insensitive to temperature or wavelength effects. However, the fiber is just as sensitive as a normal low birefringence fiber to external effects such as twist, applied stress, or bending. These are effects which upset the near-perfect circular symmetry of the guide on a local scale and thus induce the usual birefringence or rotation. Although the fiber is a near-perfect waveguide, it cannot *maintain* a given state of polarization as power transfer readily occurs between modes. For example, magnetic fields produce a Faraday rotation in the normal way, as will be shown in Sec. VI.

V. Experimental Verification

To verify the predictions of the analysis, experiments were performed on fibers twisted both before and after drawing. The fibers were made by the CVD method and consisted of a GeO_2/SiO_2 core, a B_2O_3/SiO_2 cladding, and a silica substrate. Geometry was similar to that reported in Ref. 4, and the measurement technique employed was as in Ref. 10.

A. Postdraw Twisted Fibers

Experiments on the effect of twist on rotation and fast-axis orientation were performed on a low birefringence fiber (GSB4) having a retardation of $\sim 8°$/m, so that large twist to retardance ratios could be investigated without encountering mechanical limitations on twist angle. However, since retardation is difficult to measure at such low levels, a fiber (VD214) with a much larger birefringence of 123°/m was used to determine the relationship between retardation and twist.

The fibers were clamped at one end and suspended vertically to ensure an even rate of twist. The results for GSB4 rotation [Fig. 2(a)] and principal-axis orientation [Fig. 2(b)] were obtained up to a twist ratio of $\xi/\Delta\beta = 90$, corresponding to 2 turns/m. Figure 2(a) shows a linear relationship between rotation Ω and twist ξ, as expected for high twist rates [Eq. (8)]. From the slope we have $g' = 0.073$, in excellent agreement with Ref. 11. (Here g' is defined in terms of the rotation, i.e., half of the circular birefringence of Ref. 11.) In Fig. 2(b) we see that the principal-axis orientation ϕ is similarly linear; moreover, ϕ shows considerable departures from the untwisted position which we may assume coincides with the minor axis of the core ellipse. Disregarding the small residual rotation found in the fiber at zero twist, the relationship between ϕ and Ω predicted by Eq. (3) is found to be valid.

The measurement of retardation R with twist rate ξ on fiber VD214 is shown in Fig. 3 and compared with the prediction of Eq. (1).

Here much lower twist/birefringence ratios prevail, and this serves to show the rapid reduction in net birefringence as the twist is increased up to $\xi/\Delta\beta \simeq 5$. The comparison with theory shows excellent agreement despite a slight difference in periodicity, which is probably caused by an uncertainty in the initial measurement of $\Delta\beta$.

B. Spun Fibers

Preforms having similar characteristics to those from which the above fibers were drawn were used to draw both spun and unspun fibers. The latter were used in a control experiment. For spun fibers the preform was rotated at ~ 1000 rpm during the drawing process and the drawing speed chosen to give a twist rate of ~ 2 turns/cm. For the unspun control sections the rotation was stopped and the fiber taken from the length immediately adjacent to the spun section.

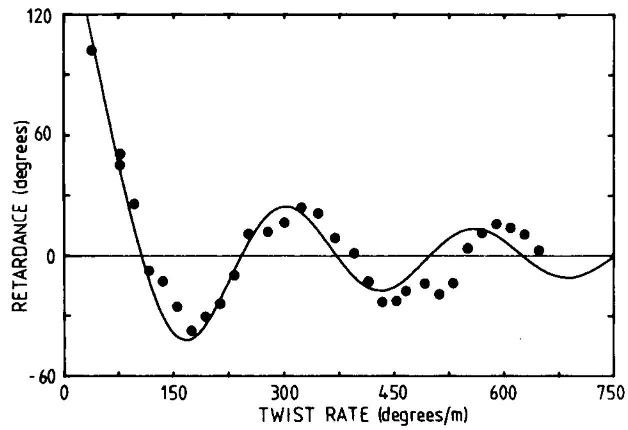

Fig. 3. Measured linear retardance in 1.54 m of fiber VD214 as a function of twist rate (dots). Solid line shows values calculated for $g' = 0.073$ and $\Delta\beta = 123°/m$.

The results for two fibers are shown in Table I. Fiber VD302 was found to have an unspun retardation of 60°/m at 0.633 μm; this was reduced to <1°/m by spinning, being below the limit of our measurement resolution. Fiber VD319 was measured at wavelengths of 1.06 and 1.30 μm and was found to have an intrinsic birefringence $\Delta\beta$ of 232°/m and 208°/m, respectively.

These values were reduced to <4°/m by spinning. Moreover, both spun fibers exhibited negligible rotation. Although precise measurements are difficult at such low values, these results conclusively demonstrate that spinning the fibers reduces their apparent polarization anisotropy to an insignificant level. It remains to be shown, however, that such quasi-low birefringence fibers behave in a similar manner to conventional low birefringence fibers as regards the Faraday effect and polarization mode-dispersion.

Table I. Birefringence Characteristics of Spun and Unspun Fibers Measured at Various Wavelengths

		Fiber drawn with no spinning (/m)	Fiber drawn with spinning (/m)
Fiber VD302 at 0.633 μm	Retardation	60°	<1°
	Rotation	4.3°	~0°
Fiber VD319 at 1.06 μm	Retardation	232°	<4°
	Rotation	1.1°	0.4°
Fiber VD319 at 1.30 μm	Retardation	208°	~4°
	Rotation	4°	0.6°

VI. Faraday-Rotation in Spun Fibers

In the optical fiber current-transducer the magnetic field-induced Faraday rotation is detected by launching linearly polarized light along a principal axis and analyzing the output SOP by detecting the intensities (I_1 and I_2) in two orthogonal directions rotated 45° to the principal axes. The two intensities are related to the Faraday rotation angle per unit length f by[3]

$$P(z) = \frac{I_1 - I_2}{I_1 + I_2} = \frac{2f}{\eta} \sin\eta z, \tag{12}$$

where

$$\eta = (\Delta\beta^2 + 4f^2)^{1/2}. \tag{13}$$

Thus the sensitivity is oscillatory with fiber length, having a maximum for small f of $\sim 2f/\Delta\beta$. The maximum usable interaction length with the field occurs when $\Delta\beta z = \pi/2$, i.e., a quarter polarization beat period $L_p/4$. If the fiber is longer than $L_p/4$, the only section in which interaction with the field will be observed is the length remaining after subtraction of an integral number of half beat periods. Note that if the length corresponds to an exact number of half beat periods, no sensitivity at all will be found.

Since we are only interested in unidirectional propagation, Faraday rotation in the fiber is indistinguishable from twist-induced photoelastic rotation. Thus, in the analysis of the effect of magnetic fields on twisted fibers it is only necessary to add an additional Faraday rotation term f to the photoelastic rotation term α.

After similar calculations to those presented in Ref. 3 we obtain for a twisted fiber

$$P = \frac{I_1 - I_2}{I_1 + I_2} = \sin[2(\delta_1 - \gamma_1)z] \frac{1 + \tan^2\delta_1 z}{1 + \tan^2\delta z}, \tag{14}$$

where

$$\delta = \tfrac{1}{2}\sqrt{\Delta\beta^2 + 4(\xi - \alpha + f)^2}, \tag{15}$$

$$\tan\delta_1 z = \frac{(\xi - \alpha + f)}{\delta} \tan\delta z, \tag{16}$$

$$\tan\gamma_1 z = \frac{(\xi - \alpha)}{\gamma} \tan\gamma z, \tag{17}$$

and γ is given by Eq. (5). For very small twists, i.e., ($\xi \ll f, \Delta\beta$), Eq. (14) reduces to the result for untwisted fibers given in Eq. (12).

Inspection of Eq. (14) reveals that for large relative twist rates ($\xi \gg \Delta\beta$) we have $\gamma_1 \simeq \gamma$ and $\delta_1 \simeq \delta$ giving $P = \sin(2fz)$, which is identical to the response of a perfectly isotropic fiber. Thus twisting or spinning birefringent fibers dramatically increases their sensitivity to the Faraday effect.

Figure 4 plots the sensitivity of the fiber relative to that of an isotropic fiber as a function of the applied spin rate for three different values of the net fiber intrinsic retardance $\Delta\beta z$. The curves are plotted for $2fz = 10°$, but are valid for all small values of Faraday rotation. The values of $\Delta\beta z$ have been chosen to illustrate three effects:

(1) When $\Delta\beta z = \pi/2$ (i.e., a quarter beat period) we have relatively good sensitivity without twist as predicted from Eq. (12). Maximum sensitivity is obtained by twisting the fiber only a small amount.

(2) For $\Delta\beta z = 7\pi/2$, sensitivity is very low for no twist since only the length of fiber corresponding to the final $\pi/2$ is active. Small twist actually decreases the sensitivity since small twists can modify the net bire-

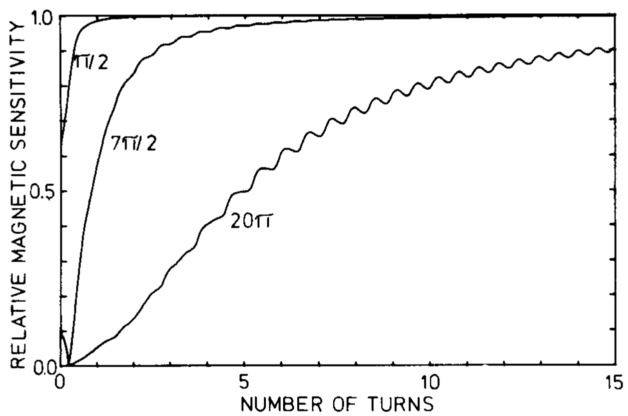

Fig. 4. Relative magnetic sensitivity of a given length of twisted linearly birefringent fiber as a function of number of turns in the length. Curves are shown for the values of net retardance $\Delta\beta z$ marked.

fringence so that the retardance becomes equal to an integer multiple of π [Eq. (1)], at which point we will have zero sensitivity.

(3) When $\Delta\beta z$ is large we have a slightly oscillatory variation in sensitivity with the number of twists in the fiber. These oscillations correspond to those in the net retardance R of the fiber (Fig. 1).

It can be seen from Fig. 4 that in each case the sensitivity is 90% of that for the perfect fiber when the twist has a value of 2 turns/beat period, i.e., the fiber is rotated once every $L_p/2$. This phenomenon is closely related to the conclusion drawn by Stolen and Turner,[6] namely, that for maximum sensitivity in a birefringent fiber the magnetic field should be changed in polarity every $L_p/2$. In our case, we have reversed the idea and changed the fiber polarity by twisting it every $L_p/2$.

VII. Polarization Dispersion in Spun Fibers

We now direct our attention to the bandwidth limitation produced by the group-delay differences between the two orthogonally polarized normal modes of a single-mode fiber and observe the effect of twisting or spinning the fiber. In the case of an untwisted linearly birefringent fiber having retardation $\Delta\beta z$, the modes are linearly polarized and the difference in arrival time $\Delta\tau_0$ between the two modes is

$$\Delta\tau_0 = \frac{z}{c}\frac{d(\Delta\beta)}{dk}, \tag{18}$$

where k is the free-space wave number and c the velocity of light. If the same birefringent fiber is now twisted, the normal modes are, in general, elliptically polarized and are given by[9]

$$\overline{E}_{1,2} = [\hat{x}(z) - i(\rho \pm \sqrt{1+\rho^2})\hat{y}(z)] \exp[i(\beta_s \pm \gamma)z], \tag{19}$$

where γ is given by Eq. (5). Thus the difference in propagation constants between the two modes is 2γ, and the group-delay difference $\Delta\tau$ is

$$\Delta\tau = \frac{z}{c}\frac{d(2\gamma)}{dk} = \left\{1 + \left[\frac{\Delta\beta}{2(\xi-\alpha)}\right]^2\right\}^{-1/2} \times \left[\frac{\Delta\beta}{2(\xi-\alpha)}\Delta\tau_0 - \frac{2z}{c}\frac{d\alpha}{dk}\right]. \tag{20}$$

In the limit of large twist ($\xi \gg \Delta\beta$) and considering a spun fiber

$$\Delta\tau = \frac{\Delta\beta}{2\xi}\Delta\tau_0. \tag{21}$$

This result could also have been obtained by taking the derivative of $2\Omega(z)$ directly from Eq. (10).

Note that the final term in Eq. (20) represents the pulse dispersion which results from the wavelength dependence of the photoelastic coefficient α. Preliminary measurement shows this to be ~2.5 psec/km at a wavelength of 1.3 μm for a twist rate of 50 turns/m, a contribution of similar order to that introduced by linear birefringence. Thus, twisting the fiber will add an additional pulse dispersion, whereas spinning it will not. In practice, using readily manufactured fibers having L_p = 1 m, a tenfold reduction in polarization mode-dispersion can be obtained by imparting a 10-cm spin period to the fiber.

The result of Eq. (21) was also found by Crosignani *et al.*[15] using strong mode-coupling theory. In fact the result given by Eq. (20) represents the reduction in dispersion to be expected in any two-mode waveguide when a form of deterministic mode-coupling such as twist is applied.

VIII. Conclusions

Spinning single-mode fibers provides a solution to the problems of polarization birefringence and dispersion by simultaneously reducing both phase- and group-delay differences. Analysis has shown that, provided the spin rate exceeds the intrinsic birefringence beat length by a factor of 10 or more, residual polarization-anisotropy is reduced to a negligible value. Spinning restores the average circular symmetry of the fiber, and it thus behaves as a near-perfect isotropic medium. The effect has been confirmed experimentally by spinning a fiber at a rate of ~2 turns/cm, when it was found that the intrinsic birefringence was immeasurably small.

Analysis has shown that, despite their relatively high microscopic birefringence, spun fibers are as sensitive as conventional low birefringence fibers to the Faraday effect and furthermore are not expected to exhibit significant polarization variation with temperature. Since low birefringence fibers are difficult to manufacture reproducibly, the spun fiber provides a simple alternative and is thus ideal for use in the Faraday-effect current-transducer.

Twisting a birefringent fiber induces deterministic coupling between the modes and as a consequence reduces the polarization mode-dispersion in inverse proportion to the twist rate. The bandwidth limitation caused in practice by polarization mode-dispersion is at present unknown since in long cabled lengths some natural mode-coupling will occur, and this will improve the bandwidth. However, low-speed fiber spinning at ~2–10 turns/m ensures that sufficient mode-coupling will occur to reduce residual polarization mode-dispersion to a negligible value, and thus the technique appears attractive for long unrepeatered links.

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