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In-line control of polarization sensitivity for fiber-optic biconical fused single-mode couplers

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The possibility to use the fiber-optic coupler input port as the polarization vector rotator of linearly polarized light introduced therein to control the coupler polarization sensitivity has been demonstrated in experiment. The experimental dependences of the polarization vector rotation at the fiber coil output on the fiber straightening extent are presented.

Экспериментально продемонстрирована возможность использования входного порта волоконно-оптического разветвителя в качестве вращателя вектора поляризации вводимого в него линейно поляризованного света для контроля поляризационной чувствительности разветвителя. Приведены экспериментальные зависимости угла поворота вектора поляризации света на выходе из витка волокна от степени выпрямления волокна.

The polarization sensitivity of a fiber-optic coupler is a parameter that characterizes the dependence of the electric power distribution over the coupler output channels on the light polarization vector orientation in the input channel. Since laser sources in networks emit as a rule an almost 100 % polarized wave that has an essentially unpredictable polarization state at the coupler input in the network, the couplers having a too high polarization sensitivity may influence negatively the optical network operation. In this connection, of urgency are the control problems of the coupler polarization sensitivity both in the course of its manufacturing and at the acceptance into service.

To study the polarization characteristics of fiber-optic couplers, traditional polarizing devices as well as commercial fiber-optic polarization controllers similar to that presented in [1] can be used to control the polarization of light being introduced therein. Often, however, the polarization sensitivity is to be estimated in a case when such a device is not available or it is impossible to connect the coupler thereto.

In the procedure proposed, the polarization at the functional block input of the element to be studied is controlled using its single-mode fiber inlet. To that end, a feature of the single-mode fiber under torsion described in [2] is used. The fiber exhibiting a linear birefringence is able to rotate the light wave polarization plane at the fiber torsion angle if $\tau << \beta$ and $\tau >> \beta$ where τ is the torsion angle per unit length of fiber; β, the fiber linear birefringence.

The method to provide the linear birefringence in a fiber with initial small intrinsic birefringence value (about 0.02 deg/m) is similar to that described in [3]. The birefringence is formed by winding the single-mode fiber onto a flat bobbin or as a helix. In that manner, a linear birefringence is induced by the bending stress. The fast and slow birefringence axes lie in the plane defined by the fiber bending radius and perpendicular thereto, respectively.

The input and output fiber outlets of the bobbin are arranged tangentially to the corresponding turns and are stretched in a straight line coincident with the bobbin rotation axis. The light polarization at the fiber output is varied by turning the bobbin and thus the linear birefringence axes. In contrast, the input and output fiber outlets of the helical winding are stretched along the straight line coincident with the axis around which the fiber is wound, the winding should be turned about that axis to vary the polarization of the transmitting light. In both cases, the fiber outlets are fixed at their ends in points arranged at a distance from the corresponding windings, so that the free sections of straight fibers are twisted about their axes as the bobbin or the helical winding are turned. Thereby, the twisting birefringence is induced in fibers being twisted in opposite directions. The polarization change induced by torsion of the straight fiber free end at the winding inlet is compensated by the torsion of a similar section at the output.

Unlike the devices described in [3] where the polarization is changed by rotating the windings, in the procedure presented in this work, the fiber convoluted freely into a single loop of 5 to 10 cm diameter is straightened or convoluted again without torsion, similar to straightening or shifting, respectively, of the helix turns. Thereby, the polarization is changed due to one-sided axial torsion of the fiber at its straightening and returns to the initial state as the coil loop is restored. This operation is easy to reproduce by hand without any mechanical devices.

Fig. 1 represents schematically the fiber in the convoluted single loop (5) and under straightening (5′). When the fiber sections at the loop start and end arranged along the tangent to the loop are fixed in movable clips, then, as the loop is straightened, the fiber is twisted at an angle being in proportion to the distance between the clips and the number of turns and in inverse proportion to the initial bending radius of the fiber in the turn. Thereby, if the polarization vector of linearly polarized light at the input coincides with one axis of the fiber linear birefringence in the convoluted state and the condition $\tau << \beta$ is met, the light polarization plane must be rotated together with the fiber principal axes as the fiber is straightened. In the course of the further straightening, the twisting birefringence becomes predominant gradually.

The bending birefringence can be calculated using approximate expression [4]

$$\beta \approx 1/8 \cdot (d/R)^2 \cdot E \cdot C \cdot k$$

where $E = 7.6 \cdot 10^{10}$ N/m^2 is the Young modulus for melted quartz; $C = 3.5 \cdot 10^{-12}$ m^2/N, the photoelasticity constant; $k = 2\pi/\lambda$. The bending birefringence calculated for $R = 2$ cm and fiber diameter $d = 125$ μm is $\beta \approx 6.25$ rad/m. For a completely straightened fiber loop (twisting of 360°) with that radius, $\tau \approx 50$ rad/m.

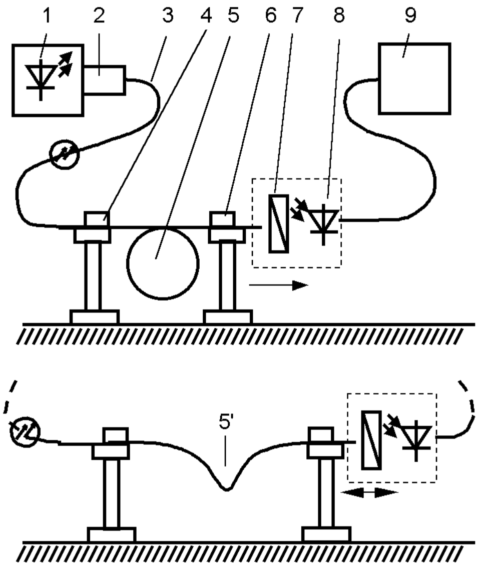

Fig. 1. Experimental setup diagram.

In experiments on the polarization behavior at the fiber straightening and recoiling, single-mode fiber (Corning SMF-28 TM) was used that is applied to produce the couplers. Fig. 1 shows schematically the experimental setup where 1 is the semiconductor laser emission source ($\lambda = 1.31$ μm); 2, optical joint; 3, leading fiber to introduce the linearly polarized laser emission into the fiber under study; 4, stationary clip to fix the input end of the fiber turn; 5, the loop under study in the initial state; 5′, that under straightening; 6, movable clip to fix the output end of the fiber turn; 7, polarization analyzer; 8, germanium light receiver; 9, photocurrent recorder. The movable clip 6 can be shifted in the direction coaxial with the input and output fiber loop ends. The analyzer 7 and photoreceiver 8 are moved together with the clip 6. As the clip 6 is moved, the loop is straightened. In the intermediate state 5′, the loop has a helical shape. The fiber turns with initial bending radii R_c of 2.5 and 5 cm that are most consistent with limits of the loop radius values as the method is used with the loop being handled by hand.

The linearly polarized laser emission with the polarization vector lying it a plane parallel to that of the loop one was introduced into the loop of a certain radius via the input loop section fixed in the stationary clip 4. The maximum (I_{max}) and minimum (I_{min}) light intensity at the loop out-

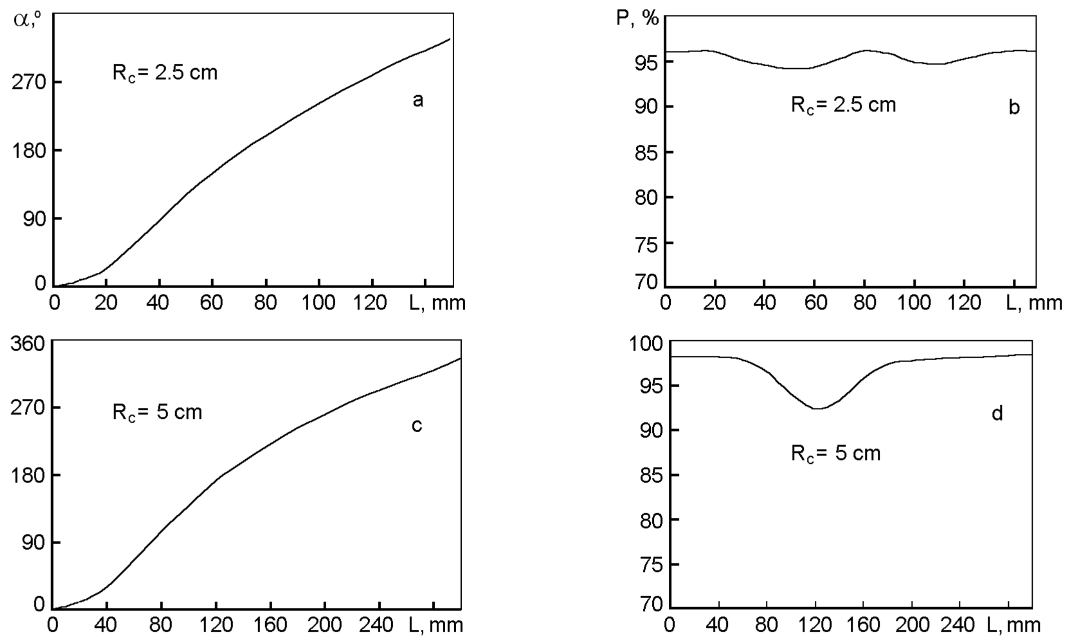

Fig. 2. Polarization plane rotation angle at the output of the fiber loop being straightened and the polarization extent of the output emission as functions of the clip-to-clip distance at different bending radii of the fiber loop.

put were recorded at rotation of the analyzer 7 using the photodiode 8 and recorder 9. At the maximum intensity, the analyzer reading was fixed answering to the initial the polarization vector direction of the light passing through the turn. In all the experiments, that direction coincided with the loop plane within the experimental accuracy. As the clip 6 was shifted by every 0.5 cm together with the analyzer 7 and the light receiver 8, the polarization extent and direction of the light passed through the fiber were measured. The polarization extent was determined as $P = (I_{max} - \mathrm{I}_{min})/(I_{max} + I_{min})\cdot 100$ % and the polarization direction, from the analyzer limb reading at the maximum photocurrent value indicated by the recorder 9.

In Figs. 2a and 2c, presented are the obtained experimental dependences of the polarization vector rotation angle α at the output of the fiber turns being straightened on the clip-to-clip distance L for $R_c = 2.5$ cm and $R_c = 5$ cm, respectively. Figs. 2b and 2d show similar experimental dependences of the polarization extent P. It follows from those plots that the polarization vector rotation varies almost linearly as the fiber loop is straightened at both loop radius values. As the movable clip is returned to its initial position, that is, as the loop ends become closer to one another, the polarization vector is rotated in the opposite direction. The light polarization extent remains essentially unchanged as the distance between the loop ends varies. Only slight (about 5 %) drops (characteristic valleys in the curve) are observed that, as the method application practice has shown, have no practical influence on the estimation of the coupler polarization sensitivity.

The relatively low light polarization extent shown in the Figures seems to be caused by either a somewhat orientation inaccuracy of the laser source in relation to the fiber loops studied or a some light depolarization in the matching elements 2 and 3 of the measuring setup (a fiber connecting element of about 1 m length was used). This circumstance was considered to be of no substantial importance, because the experimental purpose was not to study fine physical effects but to model a real situation to be used in the procedure.

The polarization vector rotation technique described here was tested in experiment during estimation of the polarization sensitivity of fiber-optical biconical fused couplers.

A fiber (Corning SMF-28 TM) input of a 1×2 coupler connected to a linearly polarized light source ($\lambda = 1.31$ μm) is convoluted within the plane longitudinal to the polarization direction (or orthogonal thereto) into a single loop with bending radius 2.5 or 5 cm. The fiber outputs 2 and 3 are connected to the optical power monitoring devices where output signals I_2 and I_3 are recorded. The fiber sections forming the loop tangent at its start and end are fixed in movable clips. As the clips are moved apart along the tangent, the loop is deconvoluted up to the fiber straightening. As a result, the fiber becomes twisted by 360° causing the light polarization plane rotation at the output almost at the same angle. In the course of the loop deconvolution, the minimum and maximum light intensities at the coupler outputs I_{imax} and I_{imin} are recorded, $i = 2, 3$ being the numbers of the coupler fiber outputs. The polarization sensitivity of the coupler is estimated as $\Delta_p = 10 \cdot \log(I_{imax}/I_{imin})$.

The so determined values of polarization sensitivity for 10 couplers were compared with values obtained by the traditional rotation method of the light polarization vector at the front of the coupler input fiber. The discrepancy of the results did not exceed 10 %.

It is to note that the proposed method yields to traditional ones (based on standard volume polarization optics and fiber-optical polarization controllers) in the accuracy of polarization azimuth setting at the input of the element under study as well as in opportunities of the polarization state and extent in the introduced emission. Nevertheless, the experimental results show that, under observance of simple guidelines in matching of the laser source and connecting fiber with the element being examined, the method provides an accuracy sufficient to reject the pieces and an effective estimation of the polarization sensitivity of a fiber-optical element at reduced labor expenditure of that estimation.

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Оперативний контроль поляризаційної чутливості волоконно-оптичних біконічно сплавлених одномодових розгалужувачів

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Експериментально продемонстровано можливість використання вхідного порту волоконно-оптичного розгалужувача як обертача вектора поляризації лінійно поляризованого світла, яке вводиться в порт, для контролю поляризаційної чутливості розгалужувача. Наведено експериментальні залежності кута повороту вектора поляризації світла на виході з витка волокна від ступеню випрямлення волокна.