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# Taper twisting for higher FOGs production yield.

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## Abstract

Twisting affects performance of fiber optic components fabricated by fusion-tapering process. Fiber Optic Gyro «spliceless» manufacturing technique («**S-process**») has involved taper twisting as a method of in-process adjustment to get higher production yield.

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The most miniature fiber optic gyros (∅ 27 mm x 58 mm including processing analog electronics entirely) are built using special thin (40μ) birefringent fiber. Refractive index profile of this fiber does not contain depressed regions. Fusion-tapering technique may be used for fabrication of all components (couplers, polarizer) of minimal configuration gyro assembly. Fabricated components are miniature (less than 20mm) due to fiber diameter is low.

«In line spliceless» process (**S-process**) developed in the company utilizes only ***single fiber length*** for manufacturing of complete fiber optic assembly. Couplers and polarizer are sequentially fabricated along fiber so that predetermined configuration springs up just after last component (polarizer) is made. Optical characteristics of the components are subject of in-process reading while some of them may be controlled during tapering and other procedures.

Giving advantage in miniaturization thin fiber reveals certain problems of assembly manufacturing. Torsion resistance of the fiber is negligible compared with torque arising during winding and handling. As a result thin fiber is always twisted randomly along its length with rates up to 5 turns per meter.

Due to high internal birefringence of the fiber ($L_b < 3$mm) and its high (>0.2) aperture such twist is not reflected essentially in fiber optical loss and polarization maintainance.

However the orientation of fiber birefringent axis affects directly on the optical assembly performance [1]. The most critical component is a loop coupler which determines ring interferometer visibility. Despite loop coupler *power* splitting ratio is 1:1 the interference signal may vanish if fibers birefringent axis in the coupler are perpendicular. S-process begins with fabrication of the loop coupler while coupling ratio and visibility signal are acquired to control elongation process. In this case maximal visibility (V) is given by

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$V = 1/2[1+COS(2\alpha_C)]$ , where $\alpha_C$ is an angle between birefringent axes of fused fibers. In our experience there is no means to control visibility in-process.

And it's rather difficult to detect and control mutual fibers orientation prior to fusion. Small diameter and absence of depressed regions makes visual axis indication ineffective. Mechanical probe method when induced additional birefringence is used for detection may result in defects on quartz surface. But even if axis were aligned before fusion they would lose alignment because of internal unavoidable tension which relieves under heating and turns fibers.

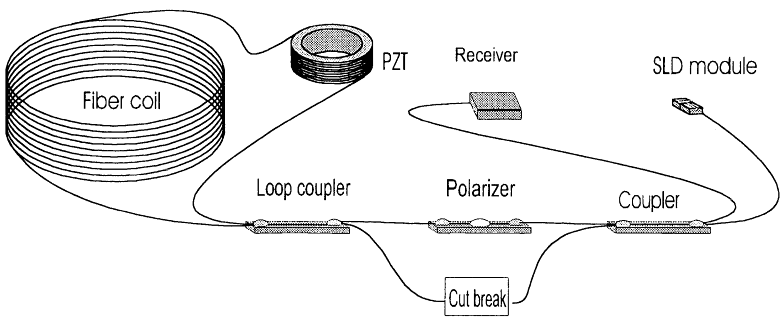


Fig.1 Conventional open loop gyro assembly. S process completed.

**Loop coupler and the other coupler are fabricated in sequence. One of the fibers between them is cut («Cut break») to form symmetric output of the assembly. Residual fiber is further used for polarizer fabrication.**

Practically problem of fiber alignment in the loop coupler was solved by selection procedure. Randomly aligned fibers were fused till splitting ratio reaches 1:1 and visibility was estimated. Acceptance criteria $V > 1/2$ was taken that resulted in a natural failure rate of this procedure 50%. If visibility was less then 0.5 ($\alpha_C > 45°$) lead fibers were cut and loop coupler was fabricated again until the criteria is fit. After loop coupler the other coupler and polarizer were fabricated (polarizer is made by growing birefringent crystal around taper waist). For these both components fiber axis alignment does not affect essentially interferometer signal but only optical bias and quadrature bias of resultant assembly [1]. For low and medium grade gyros their influence may be neglected. Such method requires extra amount of fiber to built complete optical assembly and some extra production time (which is spent for rejected couplers manufacturing).

Recently in our report it was shown [1] that problem associated with random fibers orientation may be solved by means of additional component - «polarization mode converter». PMC is a long fiber taper 90° twisted. Elongation of such taper should be enough to eliminate residual birefringence of the taper waist. In this case Converter is a perfect polarization rotator coupling orthogonal polarization modes of the fiber. Visibility of interferometer may be always corrected to exceed 1/2 by placing Corrector into sensing fiber loop. However in already established miniature gyros like VG941-3 there is no space to mount any additional fiber optic component (Converter size is the same like coupler size 20x2x2mm). Therefore we were unable to use the approach for increasing production yield of miniature gyros.

This report describes further development of S-process by the new method of a posteriori visibility correction. The method does not require manufacturing of additional component and easily introduced in the main process. The method provides opportunity to achieve acceptable visibility despite fibers axis orientation in the loop coupler.

Let's consider conventional gyro optic assembly (Fig.1) which appears after S-process completing. If we assume that polarization coupling in the coil is low then the output signal **Va** of the assembly may be written in the form:

$$Va = 1/2 * [ 1 + COS(2\alpha_C) * COS^2(2\alpha_P)] \qquad (*)$$

where $\alpha_C$ is an angle between fiber axis in the loop coupler, $\alpha_P$ is an angle between fiber birefringence axis and transmission axis of the polarizer. When all axis are perfectly the maximal output is achieved which corresponds to the unit visibility at the loop coupler and polarizer alignment along fiber birefringent axis.

From the above expression it can be derived that final assembly signal may be adjusted by only tuning of polarizer transmission axis. Polarizer design provides such opportunity (Fig.2) due to the presence of short waist piece not covered by the birefringent crystal. Waist diameter near the crystal is small and waist residual birefringence is negligible. Turning of the fiber coming from the loop coupler corresponds to the variation of $\alpha_P$ in expression (*). Such tuning may be easily done since solder melting temperature is much lower than crystal melting temperature and there is some time (15min) to make adjustment.

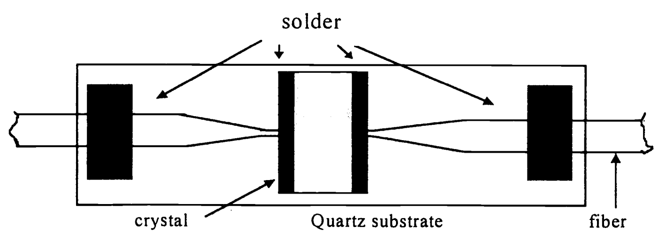


Fig. 2 Fiber crystal polarizer outline.

**Crystal covers 2-3mm of fiber length while taper length is 15mm. Solder is used to fix fiber and crystal to a quartz substrate.**

Special tool was designed to turn thin fiber around its longitudinal axis. Based on clamp with simultaneously movable parts it provides opportunity to rotate fiber without shifting its center position (shown on Fig.3). By this tool we got opportunity to adjust visibility signal after entire assembly is completed.

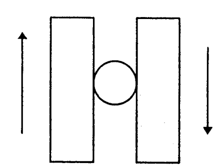

Fig.3

**Special clamps design concept.**

Loop coupler is now fabricated to achieve only coupling ratio 1:1 and other components are further fabricated. If at the loop coupler visibility is less than 0.5 then by the adjustment effective visibility 0.5 may be achieved. If visibility at the loop coupler exceeds 0.5 then by tuning polarizer axis more then 0.5 is achievable. Evidence for that is given by the expression (*) as well as by our production results.

Visibility of the ring interferometer achieves at least 0.5 of the maximal value by tuning orientation of the polarizer transmission axis while fiber optic sensing assembly is completed by a standard S-process. Update of the process with a fiber twisting procedure realizes its industrial capacity.

**Conclusion:**

Adjustment of the FOG optical assembly output by twisting the fiber close to the polarizing crystal is a powerful method of the a posteriori improvement of the product fabricated in the S-process. Independence of final assembly signal on the random alignment of the fibers birefringent axes opens up opportunity to achieve production yield close to 100% for most miniature fiber optic gyros.

**Reference:**

1. V. LOGOZINSKI, V. SOLOMATIN : «Fiber optic gyro performance improvement by optical compensation method», Proc. 5th S.-Petersburg International Conference on Integrated Navigation Systems, 1998, p.233