Reducing the size and cost of fiber gyroscopes

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A novel winding method promises smaller but still accurate fiber-optic rotation sensors made from less expensive components.

The US Department of Defense (DoD) wants small inertial sensors that offer highly accurate performance at a low cost. At the moment, ring laser gyros are commonly used, but fiber-optic gyroscopes (FOGs) would be attractive inertial sensors if we could reduce their relatively high cost. FOG technology, which uses lengths of optical fiber coiled around a mandrel (see Figure 1), exploits interfering waves of light. When using polarized light, it produces optimal signal amplitudes and thus high accuracies. Accordingly, these sensors require the use of expensive polarization-maintaining (PM) fiber. Previous attempts at reducing cost by using less expensive single-mode fiber (SMF) either resulted in lower accuracy or required sophisticated electronics to compensate for fluctuations in polarization, which cancelled fiber-based cost savings. We are developing a different SMF-based FOG technology—based on a method patented by US Army researchers in 1998—that uses a crossover-free (CF) winding scheme.

FOG technology is attractive because it can measure rotation in very small increments. As explained above, however, cost prohibits placement of these sensors into the commercial and military markets. Similarly, efforts to miniaturize PM fiber-based sensor coils have been reported, albeit at the cost of sensor accuracy: although reducing the length of the fiber reduces the coil size, it also reduces the coil’s Sagnac area (SA), a parameter directly related to the sensor’s resolution.

Researchers have demonstrated that reduced accuracy of SMF-based FOGs is based partly on the SMF’s sensitivity to microbends and crossovers in the coil. Crossovers are caused by layering the fiber onto itself during the coil-winding procedure. The CF technique we have developed allows an increased Sagnac area while minimizing the number of crossovers and permits the use of SMF.

To implement a radically new winding technique and design, our group set three objectives. The first was to develop a fiber placement machine capable of creating the coils. The second objective was to assemble a testbed to evaluate the performance of the coils. The third was to build a geometrical and mechanical model that would predict the configuration that optimizes performance.

The CF sensor coil can be thought of as a pancake of optical fiber arranged in spirals (see Figure 2). The fiber is placed into a horizontal plane and then transitioned to another substrate layer using the inside or outside of the coil stack. A 21-layer CF coil that incorporates 350m of optical fiber can be seen in Figure 3.

Figure 1. Sensor coils, each made from 350m of optical fiber, were wound using standard precision methods onto mandrels of three different sizes.

Figure 2. An exploded diagram shows the winding scheme for a crossover-free sensor coil, in which the optical fiber is arranged in spirals.

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Figure 3. A 21-layer crossover-free coil pancake incorporates 350m of optical fiber.

Figure 4. The output from a standard precision-wound sensor coil shifts over time. The coil has an outer diameter of 1.2in and includes 350m of optical fiber.

We built the testbed to measure both the performance of our CF coils and the ability of the fiber placement machine to accurately assemble coils. The FOG testbed was operated on an air-bearing single-axis rate table. We compared performance data collected from the test setup with a standard precision straight-wound gyroscope coil.

The bias output of our coil was better than that of a standard precision wound coil of the same length. Specifically, the 1.2in. inner diameter standard precision coil shows a 1σ bias stability of 28°/h (see Figure 4). Our CF coil, which has a 0.6in. inner diameter and a 2.37in. outer diameter, demonstrated a 1σ bias stability of 8.39°/h with a 1s integration time (see Figure 5). We did not filter the raw data or perform any post-processing.

A figure of merit often quoted when evaluating traditional coils is the total optical fiber length wound onto the coil. However, the accuracy of a FOG sensor is proportional not to the length, but to the total area (i.e., the SA) circumscribed by the coil loops. One of the major advantages of the CF coil is that the SA for a given length is substantially larger than that of a traditional coil.

As expected, the SMF exhibits an induced birefringence upon bending. The relationship between the fiber’s bend radius and birefringence has been published. Thus, we know that the birefringence depends on the bend radius at any point along the spiraled fiber. This induced birefringence allows the CF coil to behave like a pseudo-PM coil while using SMF. We are modeling these parameters and others—such as modal birefringence, beat length, and polarization mode coupling—to further optimize the geometry of the CF coil and improve the performance of the FOG sensor.

We hope our efforts will allow FOGs to play an increasingly important role in the world of military guidance, navigation, and control (GNC) systems. This would fulfill the DoD’s goal of obtaining non-GPS-aided GNC options with high accuracy but low cost. Our work to date has focused on developing the CF winding configuration and measuring its capability. We plan to demonstrate improved coil designs and winding methods. In addition, we plan to perform further modeling of the FOG components and lower-order geometrical parameters in future programs.

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References