FIBER-OPTIC GYROSCOPES KEY TECHNOLOGICAL ADVANTAGES

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1 Introduction

This paper is a short analysis of key technological advantages of Fiber-Optic Gyroscope (FOG) technology for high performance applications over competing technologies. In particular, we show the advantages of the FOG technology over the Ring-Laser Gyroscope (RLG) technology.

In the first section, we emphasize the differences and similarities between FOG and RLG.

In the second section, we list several advantages of FOG technology.

Evidence is provided with reference to published documents available on demand (see reference list at the end).

2 Fiber-Optic Gyroscopes and Ring-Laser Gyroscopes

This section is based on references [1], [2], [24] and in particular [18] for the comparison between Fiber-Optic Gyroscope technology and Ring-Laser Gyroscope technology.

2.1 Similarities and technological differences

FOG and RLG technologies are based on the same physical principle discovered at the beginning of the 20th century that is called the Sagnac effect. This effect shows that the propagation time of light along a closed-loop path depends on its rotation rate.

In the original experiment, light circulated only once along a closed path defined by mirrors, hence a very small effect. However, with the advent of the laser in the 60s, and the low-attenuation optical fiber in the 70s, it became possible to enhance this physical effect and then very accurately measure rotation rate.

While based on the same physical principle, and having similar theoretical performance, the designs of FOG and RLG are very different technologically:

An RLG is based on a gas laser in a sealed ring-cavity with very high-quality mirrors. The cavity acts as an active resonator for the two counter-propagating waves that can then re-circulate several thousands of times (the exact number depends on the precise design). This amplifies the Sagnac effect, but also provides a natural linear read-out, by simply recombining both counter-propagating wave outputs and measuring directly their frequency beating that is proportional to the rotation rate.

A FOG is based on an optical-fiber coil in a passive interferometer and uses a solid-state semiconductor source. Light can also re-circulate in the multi-turn fiber coil several thousands of times (again, the exact number of turns depends on the precise design) to enhance the Sagnac effect. However, in such a passive interferometer, the signal is a phase difference between both counter-propagating waves and not a frequency difference anymore. The raw response is then a power-dependent nonlinear rise cosine, but very efficient all-digital signal processing techniques (patented by iXSea) enabling the user solve the problem perfectly, and also get an accurate low-noise linear response. These processing techniques provide in addition a very small angular increment, much smaller than the one naturally obtained in an RLG.

2.2 Consequences of the technological differences between FOG and RLG

The different technological implementations of the Sagnac principle in FOG and RLG have several important consequences.

2.2.1 Simple and controllable manufacturing (FOG) versus complex manufacturing (RLG)

A FOG uses optical component technologies (optical fiber, semiconductor light source, integrated-optic circuit to name but a few) developed for the Telecom industry and whose lifetime and reliability have been proven on a large scale. FOG manufacturing is actually an assembly of these standard telecom-technology components and is competitive even with small production quantities [4].

On the other hand, an RLG is based on delicate manufacturing processes with very specific components (sealed cavity, mirrors to name just two). The manufacturing of RLG requires large and complex production facilities with obviously very severe requirements to ensure the quality of the final product.

2.2.2 Moving parts (RLG) versus solid-state (FOG)

At low rotation rates (typically under 100°/h), the two counter-propagating waves of an RLG experience a lock-in effect that prevents direct measurement around zero. To overcome this dead-zone effect, an RLG uses a mechanical dither that degrades the theoretical rate-measurement noise by an order of magnitude. It also generates vibrations, which requires expensive damping mechanisms to limit the increase of acoustic signature in submarines.

With a FOG, there is no possibility of lock-in between the counter-propagating waves since it is a passive interferometer and not an active resonator anymore. A FOG is a purely solid-state sensor with extremely low measurement noise (and no quantification noise) over a very high dynamic range.

Unlike its rival, a FOG does not generate any acoustic vibration, and since it doesn't have any mobile component, it is extremely reliable over a very long period of time.

2.2.3 Sealed cavity (RLG) versus solid-state (FOG)

An RLG is based on a sealed cavity filled with a mixture of helium and neon gases. Since the cavity cannot be perfectly hermetically sealed, there is some residual gas leak that limits the lifetime of the RLG. There is also a wearing-out problem of the high-voltage discharge electrodes that excite the amplifying gas. As a result, RLGs require expensive retrofits every five to seven years.

A FOG is a pure solid-state device without any problem of leakage nor wearing-out mechanism. The lifetime of optical fibers has been proven to be several tens of years by the Telecom industry, and even active components such as the light laser diode are in the twenty-year range.

2.2.4 Scalability (FOG) versus limited range of performance (RLG)

In a FOG, the Sagnac effect is proportional to the equivalent area of the multi-turn optical-fiber coil. FOG technology is then easily scalable by just changing the length and the diameter of the coil while keeping the same other optical components. In the 90s, the first medium-performance products had coil length in the hundreds of meter range with a diameter of few centimeters, but today, for the highest performance, length has been easily increased up to several kilometers with a diameter of few tens of centimeters.

In an RLG, it would be necessary to enlarge the resonator cavity and improve the mirror quality. Both are big technological challenges and in practice, RLGs are limited in performance and not suitable for applications requiring top performance (SSBN navigation and some specific space applications). The only way to overcome this difficulty in these specific applications is to place the RLG on a rotating mechanical structure hence coming back to the old-time mechanical gyroscope design and its related maintenance problem.

3 Advantages of the FOG technology

In this section we describe more in depth the advantages of the FOG technology based on technological differences with RLG mentioned above.

3.1 No emitted acoustic noise

Since a FOG does not have any dither mechanism, it is a perfectly silent device. This characteristic, while not important for many applications, can be critical when stealthiness is a requirement such as for submarine navigation.

3.2 *Reliable – low maintenance*

Since a FOG is a solid-state device (no moving part, nor sealed cavity), it is highly reliable, has a long lifetime and does not require any preventive maintenance.

IXSea FOG technology has been chosen by EADS-ASTRIUM over competing technologies for its long life/low maintenance/high performance ([8])

More than 50 space-FOG flight models have been delivered by iXSea as of 2010.

Planck scientific European satellite [19] is using iXSea FOGs.

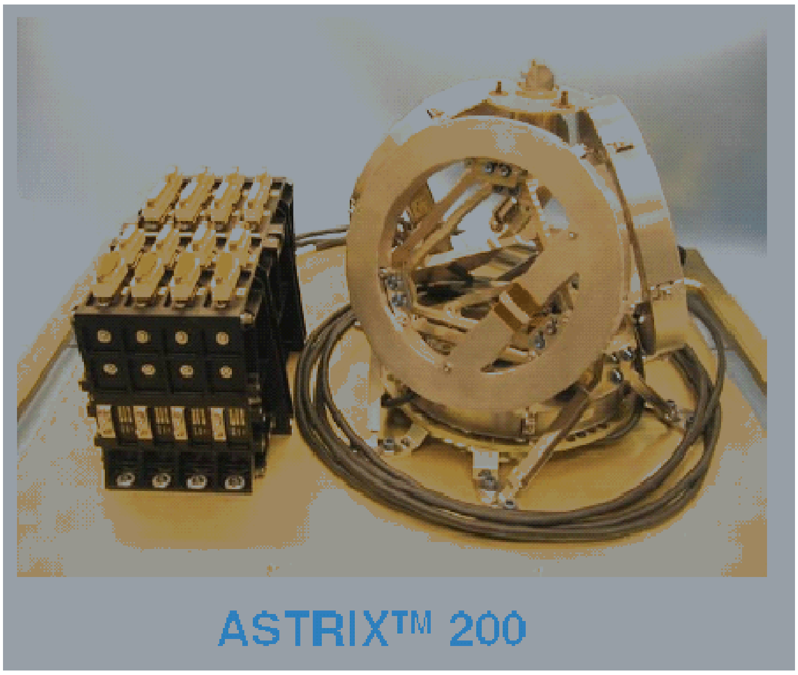

Figure 1 - ASTRIX200 very high performance 4-axis FOG system for space applications (EADS-ASTRIUM / IXSEA)

3.3 High performance

Contrary to RLGs, where dithering degrades measurement noise, FOGs are very close to their theoretical performance and have already proven their capacity to achieve random white noise as low as $10^{-4}\,\mathrm{deg}/\sqrt{h}$ while RLGs are limited in practice to $10^{-3}\,\mathrm{deg}/\sqrt{h}$ [18]. In addition, as we have already seen, a FOG has no quantification noise.

Due to its inherent low random noise and its scalability the FOG technology is one of the very few technologies able to cope with the applications requiring the highest performance [14].

Over the past few years the American Government has sponsored a $100m dollar research project to develop high performance FOGs for use in SSBN [4].

The FOG technology is seen by US experts as the only technology in the future able to replace the mechanical gyroscopes used for SSBN [8].

IXSea FOG-based inertial navigation system MARINS has been chosen by the UK Navy as the main navigation reference for ASTUTE-class submarines [21].

IXSea FOG technology has been chosen by the French space agency (CNES) for high performance Earth-observation Pléiades satellites [23].

Figure 2 - MARINS high-performance inertial navigation system chosen by the UK Navy for ASTUTE-class submarines

3.4 ITAR free – Full mastery of technology

The development of FOG technology at iXSea started 25 years ago (at that time the company was called Photonetics). Since then, iXSea has been granted several key patents on the design of high performance FOGs, and iXSea has progressively fully integrated the design and manufacturing process of FOGs. Today iXSea directly controls the full chain of key technological FOG components from the manufacturing of the fiber (iXFiber), to coil winding and the optical integration of components.

IXSea FOG technology has been chosen by the European Space Agency (ESA) as the European ITAR-free technology for high performance applications [22].

Figure 3 –FOG fiber manufacturing at iXFiber

3.5 Proven

FOG is a proven technology used all over the world for applications with the most severe requirements.

More than 2,000 FOG-based inertial systems (6,000 FOGs) manufactured by iXSea are in operation all over the world for all kind of applications from Offshore operation at 3,000m depth to Space applications, going through defense applications and land survey applications,… ([3], [5], [6], [7], [10], [12], [13], [15])

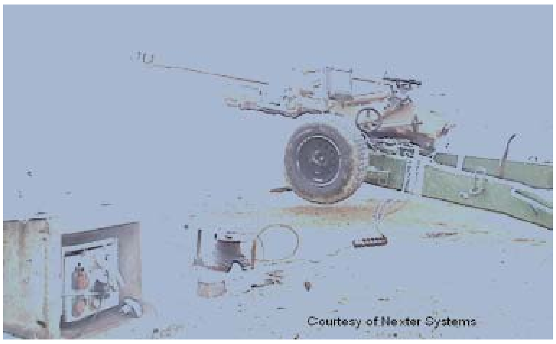

Figure 4 - NEXTER 105 GUN equipped with iXSea inertial navigation system

An analysis based on more than 1,000 iXSea systems on the field (cumulating 2,500 years on the field) has shown that iXSea FOG triads (three FOGs integrated to be used inside an inertial navigation system) have an MTBF of more than 500,000 h (60 years)[1] [17].

Litton, a subsidiary of Northrop Grumman and a competitor of iXSea, has sold more than 20,000 LN200 FOG-based guidance systems for missile applications [20].

[1] *the MTBF of the complete systems including the computing and interface boards are more than 80,000 h (8 years)*

IXSea FOG-based Inertial Navigation Systems are used all over the world by more than 20 navies.

4 Conclusion

FOG is today a proven technology and the best choice for high-performance applications. Over the years, iXSea FOG-based systems have been used all over the world for the most demanding applications, ensuring its users the best performance and the lowest maintenance cost.

At iXSea we work continuously to keep our FOG technology and FOG-based systems such as MARINS at the highest level among all competing technologies and systems.

We hope that with our technology and systems, our customers will continue to be able to reduce their costs of ownership, benefiting from the low maintenance and extend their operational possibilities using the high performance of our systems over time.

5 References

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