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Fibre-Optic Gyroscope

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Abstract. Comparative study of mechanical, ring-laser and fibre-optic gyroscopes has been made. The single mode fibre-optic gyroscope having a large number of turns of the optical fibre in the spool, replacing *He-Ne* gas laser by a *GaAs* laser diode, thereby reducing the noise level, and using fully integrated fibre-optics, works out to be the best in the final analysis, for safe navigation and homing of the guided missiles.

1. Introduction

Interference phenomena in optics, specially after the invention of lasers and fibre-optics, have created innumerable industrial applications. As early as 1913, George Sagnac had experimentally demonstrated that the spinning of a closed loop carrying light about an axis perpendicular to its rotating plane, changes the interference fringe pattern of two monochromatic and coherent light waves travelling inside the loop in opposite directions. Based on this principle, rotating sensors for navigational purposes had been made. However, these were mechanical spinning gyroscopes. But soon optical rotating sensors are about to over-take them. Ring laser gyroscopes, already developed by Honeywell, are soon going to be fitted in the new Boeing jet planes. With fibre-optic gyroscopes attaining a sensitivity of 0.01°/h, a thousandth of earth's rotation rate, it would be possible to direct ships, missiles and air-crafts etc., very accurately and without any reference to radio beams or magnetic compasses.

Fibre-optic gyroscopy has been attracting the attention of many workers for the last so many years and several kinds of approaches have been studied[1-7]. Under the joint Services Electronics programme of USA, Davis & Ezekiel[8] of MIT have presented preliminary performance results of a closed loop, 200m long, multiturn fibre optic gyro with little noise of the order of 0.1°/*h*, in an averaging time of 30 sec, which is also the photon noise limit. Two acousto-optic frequency shifters within the fibre interferometer were employed and the photon noise limit was accomplished by an electro-optic phase modulator. A second generation of optic rotation sensors is now round the corner to achieve the required sensitivity for navigation.

2. Experimental Procedure

The basic principle involved in Sagnac effect is that if two coherent and monochromatic light waves travel in opposite directions round a stationary circular ring of radius R from a source fitted in the ring itself, they remain in phase after they return back to the source. If, however, the ring along with the source of light, rotates with a tangential velocity v the beam rotating with the loop will have a longer optical path than the other one going in the counter-rotating direction by an amount equal to $4\pi R\, v/c$. If λ be the wave-length of the monochromatic light, the phase difference would be $4\pi R\, v/c \times 2\pi/\lambda$ or $8\pi^2 R\, v/\lambda c$. In a multi-turn Sagnac interferometer, this would lead to an observable rotation sensitive shifting of the fringes in the pattern. This, so called Sagnac shift, is very small for ordinary rates of rotation.

In early 1960's, with the invention of the *He-Ne* gas laser, a Sagnac fibre-optic gyro became a possibility and in 1981, Davis and Ezekiel[2] developed a close loop multi-turn fibre-optic rotation sensor. Light from a 5mW *He-Ne* gas laser was made to go through an acousto-optic isolator and after crossing a polariser, entered into a Sagnac interferometer's beam splitter, where it was broken into clockwise and anti-clockwise directions to cover a long path through a single mode fibre coil 200 metres long and 19 cm diameter. The recombination occured at the same beam splitter. The *He-Ne* laser tube, infact, forms an integral part of the fibre-optic gyro and the end mirrors of the laser are replaced by mirrors that send the laser beam in opposite directions. When at rest, the laser system resonates in two (clockwise and anti-clockwise) degenerate modes at a single frequency. But as soon as the system is rotated, there is a little change in frequency which is, infact, a direct measure of the rate of rotation. The purpose of the ring laser gyro is to measure the integrated rotation. This is done by counting interference beats.

3. Results and Discussion

In ring laser gyros at slow speeds the problem of 'lock-in' due to small frequency change is quite a serious one. The laser merges the two counter-rotating modes into a single frequency in between. Though Honeywell have solved this problem to some extent by 'dithering' the gyroscope, this has created its own problems of mechanical vibrations.

The fibre-optic gyros developed by Telefunken claim a noise level down sufficiently to even detect earth's rate of rotation. For this the frequency difference of less thanone part in 10^4 has to be detected and that is a very delicate measurement. The mechanical gyros are extremely sensitive to accelerations. The optical gyros 'Massless', as they are, are immune to this. The mechanical gyros, like the spinning tops, take a long time to start-up, as one has to naturally keep waiting till the precision dies down. In addition, they are not robust and since they are delicately suspended, sudden turning by large angles is not advisable. No dithering is required in the fibre-optic gyros because the light source is external to the loop and as such, it does not suffer from 'lock-in'. Such gyros are going to be compact, rugged and not very costly either as compared to ring laser interferometers. Gas lasers are not advisable for such delicate navigational purposes because of their size, cost, maintenance and spurious phase shifts popularly called 'Fizeau drag'. It would be better if the fibre-optic gyro has a solid state laser, or an LED even. There would not be any need for alignment of laser beam and mirrors in an integrated fibre-optic gyro, as it is the case for a ring laser Sagnac sensor. The entire equipment can be housed in a small container of the size of a tea box. The MIT fibre-optic gyroscope (Fig. 1) has achieved the same rotation sensitivity as the Stanford one (Fig. 2) despite retaining bulky gas laser, optical components, electro-optic phase modulator and acousto-optic isolator.

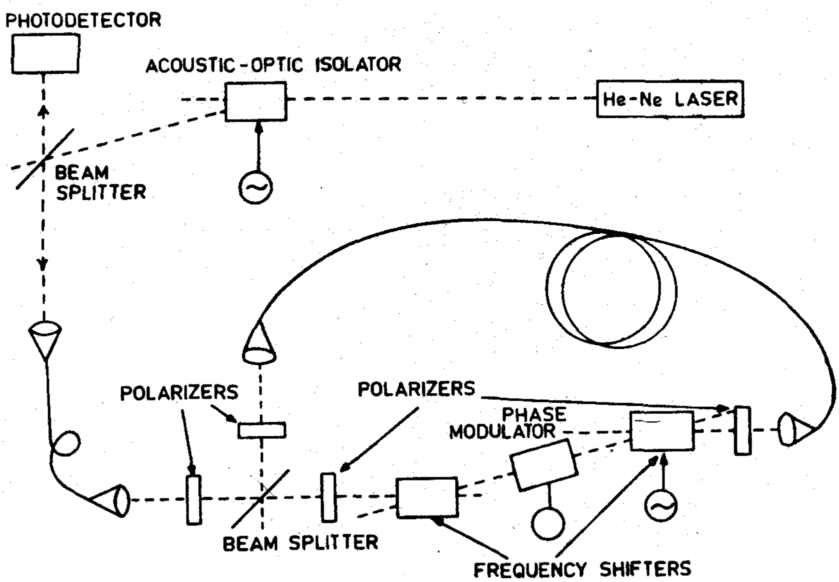

Figure 1. MIT fibre-optic gyroscope

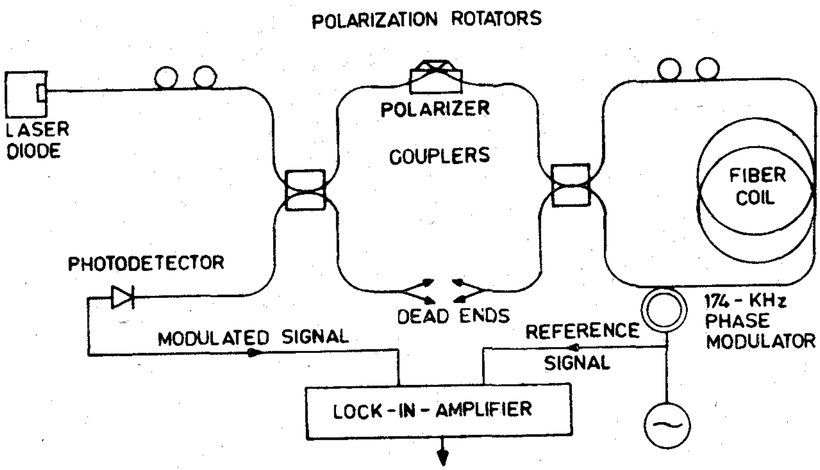

Figure 2. Stanford fibre-optic gyroscope

A Conference on 'optical rotation sensors', was organised at San-Diego, California in 1978. Calculations presented therein indicated that fibre optic can be made as sensitive as ring laser gyros. The Telefunkan group of Germany had succeeded to a great extent, but primary noise sources appeared to be scattering at mirrors and other inter faces in their devices and coherent back scattering (Raleigh) in the optic fibres.

A fully integrated 580m long optical path of the gyro (wound on a spool of radius 7 cm) with a single interface at the built-in *GaAs* laser diode has been developed by Stanford[9] group. The half silvered mirror beam splitters, polarisers and other optical components producing unwanted scattering at the interfaces, have been replaced by integrated couplers (fibre-optic), polarisers and polarising rotators. The laser beam in the *IR* is split into two by an integrated coupler. They travel in the clockwise and anti-clockwise directions in the spool several thousand times before returning to the coupler for recombination and diversion to a silicon photodiode interference detector. With a core diameter of 8 micron in the Stanford fibre-optic gyro, the optical fibre is a single mode fibre; thus transmitting only the lowest mode at the *IR* frequency originating from the *GaAs* diode laser. Single mode fibres in gyro have definitely several advantages over the multi-mode ones; because then the coherence so assential for the Sagnac sensor gets degraded.

4. Conclusion

The attenuation between in-put fibre and the detector was found to be 13 db; with source wavelength of 0.633 μm. It was mostly due to internal loss in the fibre, directional coupler and scattering by the optical components. Long term stability at rest of better than 0.2°/*h* was observed with 30 sec integration time. In the final analysis it turns out that with a judicious choice of the modulating frequency in the single mode fibre-optic gyro, these effects will not effect the minimum detectable rate of rotation of the gyroscope.

By winding more turns of optical fibre in the spool, reducing the noise level and replacing the *He-Ne* gas laser by a *GaAs* laser diode, Stanford scientists expect soon to be able to enhance the sensitivity of their fully integrated fibre-optic gyro to 10^{-3} of the earth's rotation rate necessary for navigation. Some military application such as submarine navigation needs high rotation sensitivity and reliable stability, while others., 'Smart Bombs' need relatively less sensitive sensors that are compact, rugged and less costly. With the development of highly sensitive fibre-optic gyro in future, one may not have to depend on 'Fixed Stars' for safe navigation.

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