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Practical method for eliminating the magnetic bias sensitivity of square ring laser gyros by adjusting the nonplanar angle

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ABSTRACT

In order to eliminate the magnetic bias sensitivity of square ring laser gyros, a novel practical method by adjusting the nonplanar angle of a ring resonator in the assembly process has been proposed. The ratio coefficient of the magnetic bias sensitivity to non-planarity has been obtained experimentally for the first time and it is found to be almost constant for this kind of square ring laser gyros. This result is useful for the practical elimination of the magnetic bias sensitivity. The magnetic bias sensitivity of every square ring laser gyroscope can be reduced to near zero with the novel method theoretically and it is proved experimentally. These findings are extremely useful for the research on super high precision ring laser gyroscopes.

1. Introduction

The principle of operation of the laser gyro is best described by considering a rotating ring interferometer that utilizes a beat frequency between two counter-propagating laser beams circulating within a closed ring resonator. As a high precision rotation sensor, laser gyroscopes are widely used in many areas such as strap down laser inertial navigation and missile guidance systems [1–3]. The ring resonator, an overview of which has been given by Siegman [4], is a central component of the laser gyro. Among various configurations of ring resonators, square ring resonators have been widely applied in super high precision laser gyroscopes for its larger scale factor than triangular ring resonators'. Large-scale versions of square ring laser gyroscopes promise to eventually provide a super high resolution for the measurement of the nano-rotations absolute such as variations in the Earth rotation rate, environmental rotational noise etc [5–8].

The non-planarity of the square ring resonator causes the cavity polarization state to be slightly elliptical, which in turn yields a magnetic bias sensitivity via the Faraday Effect in the gain medium [9]. With certain inevitable ambient magnetic fields possibly generated by nearby electromagnetic devices such as accelerometers, these sources can induce a serious magnetic bias into the gyroscope output. Such a magnetic bias degrades the accuracy of the gyroscope and thereby limits its application in a magnetic environment. According to the research done before, the non-planarity of a square ring laser cavity is the most effective factor that induces magnetic bias sensitivity but not the only one. Other factors such as the linear birefringence and the stress effect of the mirrors could also cause magnetic biases in laser gyro's output. In order to eliminate the magnetic bias sensitivity of the square ring laser gyros, there has been a lot of research on the magnetic effect of ring resonators [10–18]. Magnetic effect induced by nonplanar angle in square ring resonators has been analyzed by Smith and Martin [10–12]. A method to decrease the magnetic effect by controlling the nonplanar angle of square ring resonators during the alignment process has been proposed by Moore, Hammons, etc. [13,14]. A method to decrease the magnetic effect by controlling the difference between the amplitude reflectivity terms for 's' and 'p' type polarized light on the reflected mirrors has been proposed by Cote [15,16]. Laser beam polarization effects induced by non-planarity of ring resonators were analyzed by Zhiguo and Bilger [17]. The stress effect of the output mirror has been considered by Yuan and it is found that the stress effect has unsymmetrical influences on the ellipticities of clockwise and counterclockwise beams. According to Yuan, the out of plane angle is unequal to zero when the ellipticities of clockwise and counterclockwise output beams are equivalent [18]. The method proposed by Moore may be ineffective when the stress effect is serious. In other words, the methods for eliminating the magnetic effect of laser gyros proposed before all impose critical requirement on the coating films of the reflectors in ring cavity but their effects were limited.

In this article, an experimental method to eliminate the magnetic bias sensitivity of the square ring laser gyroscopes has been proposed. The method is based on the linear relationship between the magnetic bias sensitivity and the nonplanar angle of the square ring gyros which is obtained by Smith and Martin

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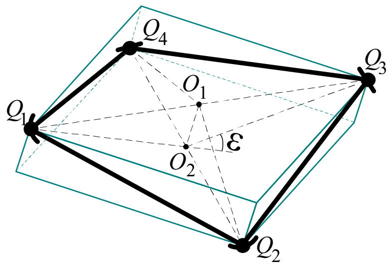

Fig. 1. The square ring resonator with slightly nonplanar beam path. Q_i ($i=1,2,3,4$): reflection points of beam path on four mirrors, nonplanar angle ε: the angle between the line Q_1O_2 and the line Q_3O_2, O_1 and O_2: the midpoints of straight lines Q_1Q_3 and Q_2Q_4 separately.

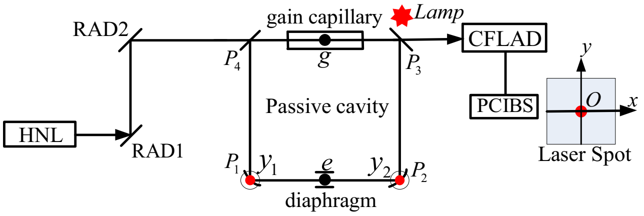

Fig. 2. Optical alignment system for aligning light beam to a square ring resonator. HNL: He–Ne laser with path length control device, RAD1 and RAD2: reflectors with adjusting device, P_1 and P_2: the curved mirrors, P_3 and P_4: the flat mirrors, y_1 and y_2 are the bi-normal axis of the mounting surfaces of P_1 and P_2, respectively. e and g: the centers of the diaphragm and the gain capillary respectively, CFLAD: CCD with focusing lens and adjusting device; PCIBS: personal computer with image grabber and image processing software and the laser spot (red spot) O represents the position of the light path at the diaphragm. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

[10–12]. The nonplanar angle of a square ring laser cavity is used as a controlling factor for reducing magnetic bias sensitivity. The non-planarity is more serious in a large square ring laser cavity to some extent. Therefore, the method is useful for improving the performance of the ring laser gyroscopes, especially for super high precision large square ring laser gyros applied in magnetic environment [5–8]. It is worthy of note that the ratio coefficient of the magnetic bias sensitivity to the nonplanar angle is found to be a constant experimentally for the first time in this paper.

2. Theoretical foundation

As shown in Fig. 1, ε is the out of plane angle and it can be changed by translating the spherical mirrors. The slight nonplanar square ring laser gyro exhibits a significant magnetic bias sensitivity. This is almost certainly due to nonreciprocal Faraday Effect created within the gain plasma, which is operating on an atomic resonance. In order for there to be any Faraday Effect the cavity polarization state should contain some ellipticity. This ellipticity is believed to originate in a slight out of plane configuration in the square ring laser gyro. The linear relationship between the magnetic bias sensitivity B and the out of plane angle ε was obtained by making small angle approximations [10–12]

$$B = (4kl\varepsilon/\gamma)(c/L) = \left(4\frac{klc}{\gamma L}\right)\varepsilon = D \times \varepsilon. \tag{1}$$

where the value of kl is the total Faraday rotation angle in radians per oersted produced by the plasma, the birefringence γ of all the mirrors are assumed to be the same. L is the total cavity length; c/L is the cavity free spectral range. For example, in a 36 cm ring laser gyro without properly alignment, an arc-second of nonplanar angle may induce gyro output bias of between 0.02 Hz/G to 0.05 Hz/G. Such bias degrades the accuracy and thereby limits the gyro application.

Eq. (1) indicates that the magnetic bias sensitivity can be changed by adjusting the out of plane angle. Therefore, the out of plane angle of a square ring laser cavity is used as a controlling factor to reduce magnetic bias sensitivity.

3. Practical method for eliminating the magnetic bias sensitivity

A method for the alignment of the Gaussian laser beam to a stable optical resonator or a square ring cavity was described in detail by Moore and Anderson [14,19,20]. The method for eliminating the magnetic bias sensitivity is based on the optical alignment system shown in Fig. 2. The alignment process of the square ring resonators comprises the steps of:

(a) Extracting the planar mirror P_3 from optical block and placing a lamp near P_3, then projecting the images of the diaphragm and the gain capillary in the ring cavity on the center of charge coupled device (CCD) area exactly by adjusting the direction of the CCD with focusing lens and adjusting device (CFLAD).
(b) Adjusting the curved reflectors with adjusting devices RAD1 and RAD2, directing the alignment He–Ne laser (HNL) into cavity, projecting the image of alignment laser on the center of CCD camera too and putting the planar mirror P_3 back to its original position.
(c) Replacing the curved mirror P_2 with a planar mirror, translating the curved mirror P_1 until the laser spot O locates at the center of the CCD area.
(d) Replacing the said planar mirror with the curved mirror P_2, then translating the curved mirror P_2 until the laser spot O locates at the center of the CCD area. In other words, the alignment process aims at placing the image of the same laser beam after going around the entire cavity on top of the direct image.
(e) The curved mirrors P_1 and P_2 are translated by equal amounts in opposite directions along the y_1 and y_2 axis as determined from a measurement of the magnetic bias sensitivity shown in Fig. 4. Here the displacements of the curved mirrors P_1 and P_2 along the y_1 and y_2 axis, which are bi-normal axis of the mounting surfaces of P_1 and P_2 respectively, are named radial displacements in this paper. The accurate value of radial displacement is the ordinate of the laser spot O with respect to origin locates at the center of CCD area when the first curved mirror P_1 is translated only [21,22]. The laser spot O returns to the center of the CCD area when the second curved mirror P_2 is translated reversely with equal amounts with respect to P_1. The resolution of the optical alignment system is 5 μm.

The magnetic bias sensitivity of an unqualified active laser gyro may be serious and it should be eliminated to improve the performance of the laser gyro. Based on step (e), the detailed procedure of eliminating the magnetic bias sensitivity of laser gyro contains four steps.

First step, after the passive cavity in Fig. 3(a) is turned into an active laser gyro, the gyro's magnetic bias marked with B_1 should be measured at first. The gyroscope output without additional magnetic field is denoted as N_0. The bias of the gyroscope output marked with N_1 is measured when a constant magnetic field was applied in Q_3Q_4 direction. The bias of the gyroscope output marked with N_2 is also measured when the constant magnetic field was applied in Q_4Q_3 direction. B_1 is obtained by

$$B_1 = N_1 - N_2, \tag{2}$$