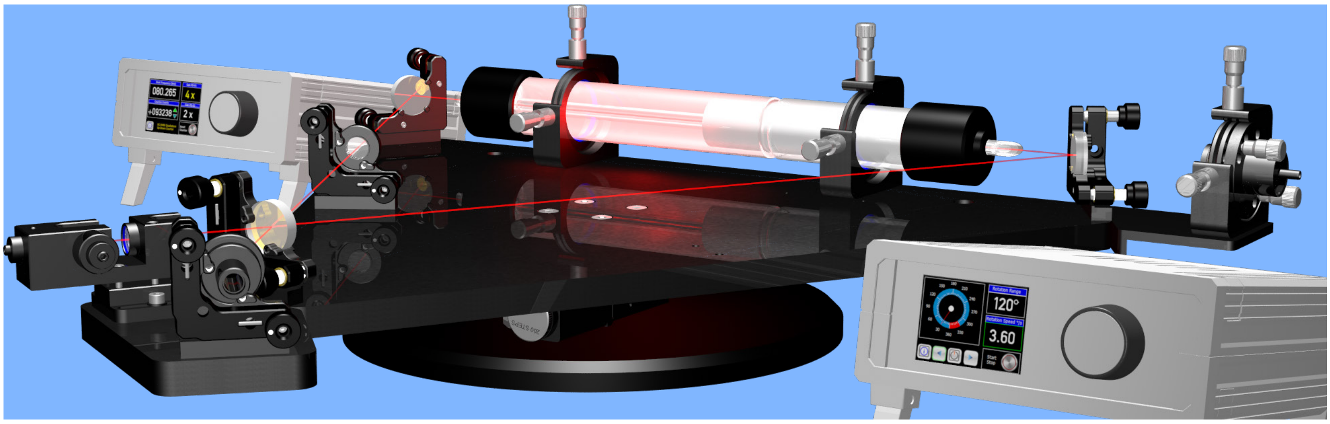
LM-0600 Laser Gyroscope



Keywords

Sagnac Effect	**Interference**	**Half and quarter wave plates**
HeNe Ring Laser	**Beat Frequency Detection**	**Optical 90° phase shifter**
Single Mode Etalon	**Linear and Elliptical Polarisation**	**Direction Discrimination**
Lock-In Effect	**High Precision Angle Measurement**	**Active Laser Gyroscope**
Processor Controlled Rotation	**Quad Frequency Counting**	

Introduction

Despite the existence of high precision satellite navigation (GPS) each transport vehicle which relies on navigation must have its own GPS independent navigation system to be prepared if the GPS may fail. Regardless of the manufacturer like Airbus or Boeing, air planes nowadays are equipped with laser gyros for navigation.

Shortly after the invention of the laser in 1960 the idea of Georges Sagnac from 1913 (France) was applied in conjunction with a HeNe ring laser. However the difference of such a ring laser gyroscope to the idea of Sagnac lies in the fact that within Sagnac's set-up the light source is separate from the ring structure and the signal is as a phase shift between the counter propagating beams. In the laser gyroscope discussed and applied here, the light source is part of the ring laser and the output is a beat frequency between the counter propagating laser modes. This class of laser gyroscopes are termed as "active" and those of the Sagnac' s type as "passive" laser gyroscopes. In general the active laser gyroscope provides a much higher precision and long term stability as against the passive ones. The basic specifications are:

Range:	$1x10^{-6}$ to $1x10^{3}$ °/sec
Resolution:	app. 2 arc sec
Zero stability:	$1x10^{-3}$ °/h
Scale factor stability:	app. 3 ppm

The precision of the laser gyro becomes more evident, when it is compared to other well known measuring devices for instance a micrometer screw gauge with a resolution of 0.01 mm. It must have at least a length of at least 3 km (!) for having the same resolution.

Within this experimental system the basics of the laser gyro are explained and practically studied at the system, which allows full access to all components. The experimental laser gyroscope consists of a rugged turntable on which the ring laser is mounted. A rotational stage driven by a stepper motor rotates the turntable. The angular speed and range can be set via the provided controller. The ring laser consists of three laser mirrors arranged at the corners of an equilateral triangle. The point of rotation lies well within the centre of this triangle. At one mirror a beam bending device is positioned in such a way that the clockwise and counter clockwise propagating modes are superimposed and the beat frequency is detected by two photo detectors. The signal of the photodetector has a phase shift of 90° to each other so that a subsequent direction discrimination is performed. The created TTL signal is fed to a frequency counter.

For the first alignment of the ring laser an adjustable green laser pointer is used. Once the system is aligned, the single mode etalon is inserted to obtain the required single mode operation. The beat frequency of the modes is measured as function of the angular speed. A special measurement is focused on the so called lock-in threshold, which is an unwanted effect of active laser gyroscopes.

How it works

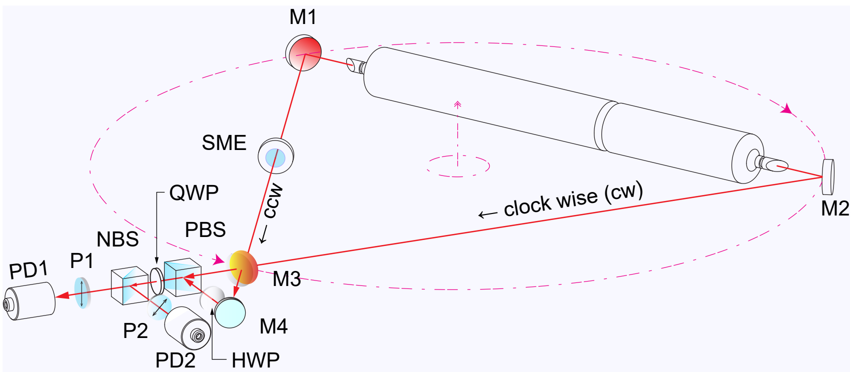


Fig. 2.31: Principle of Helium Neon Laser Gyroscope

At the mirror M3 a fraction of both the cw and ccw mode leaves the ring cavity formed by the three mirror M1, M2 and M3. Both modes are linearly polarised whereby the polarisation direction is defined by the Brewster windows attached to the laser tube. The cw beam enters and directly leaves the polarising beam splitter (PBS). The ccw beam is directed in such a way that its direction is perpendicular to the cw beam. The half wave plate (HWP) turns the polarisation direction of the ccw beam by 90° thus the beam is reflected at the PBS and travels from here onwards collinear to the cw beam which is necessary for the superimposition to obtain the beat frequency. After leaving the PBS both beams are travelling in one direction however, the polarisation state is orthogonal to each other. The quarter wave plate (QWP) converts both beams into circular polarisation, one right and the other left circularly oriented. If both modes having the same frequency the respective electrical field vector are rotating with the frequency ω the resulting vector is fixed in its orientation. As soon as there is a frequency shift between the two modes, the resulting vector starts to rotate with the beat frequency of $\omega_b = \omega_{cw} - \omega_{ccw}$.

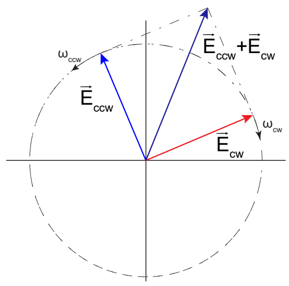


Fig. 2.32: Vectorial presentation of the electrical field vector of the cw and ccw mode.

By placing photodetector behind a polarizer (P1) the rotating E vector is converted into a corresponding intensity variation. The neutral beam splitter (NBS) divides the two circular polarised beams into two channels each having a photodetector (PD1, PD2). The polarizer P2 in front of the photodetector PD2 is tilted by 45° with respect to P1 resulting in a 90° phase shift between the signal of PD and PD2 which will be used in a phase discriminator to detect whether the gyroscope rotates cw or ccw.

Description of the components

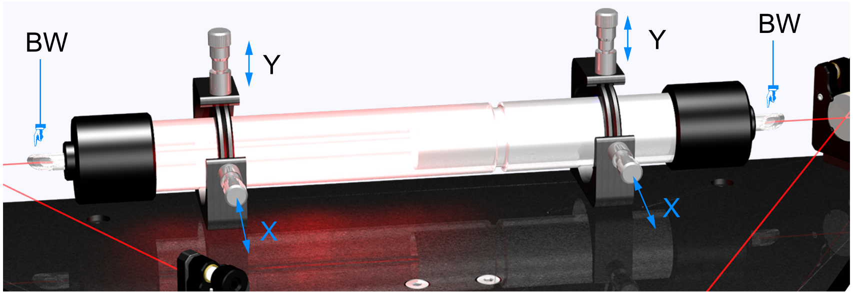


Fig. 2.33: **Helium Neon Laser Tube**

The Helium Neon laser tube is terminated with two Breswter windows (BW) and is mounted into a pair of XY adjusters (XY). The tube is fixed by slightly pressed soft rubber O-rings. The precise adjustment screws allow the tube to be aligned in XY direction. The interplay of both adjusters also allows the angular wobble of the tube. For the operation, a high voltage power supply is supplied (DC-0064) which provides the start-up ignition voltage of about 10 kV and 6.5 mA at 1400 V for the continuous operation.

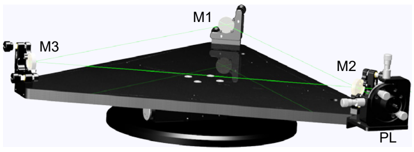


Fig. 34: Laser Ring Cavity

The sturdy and yet light weight ribbed aluminium plate has an equilateral shape. On each corner an adjustable laser mirror holder is mounted forming with mirror M1, M2 and M3 the optical cavity. The plate is attached to the drive unit by means of four countersink screws and will be dismounted from the drive unit before shipment. Although it is not really a circle such a cavity is also termed as ring cavity. The distance between the mirror is 460 mm resulting in a cavity length L of 1380 mm and free spectral range (δν=c/L) of 217 MHz.

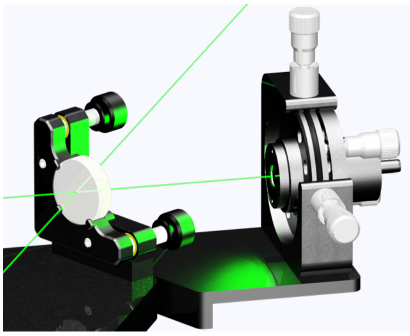


Fig. 35: Green adjustment laser

For the reliable alignment of the mirror of the laser ring cavity, a green emitting laser pointer is used. It is held in a four axes adjustment holder in such a way that the pilot laser can be shifted and tilted to align the alignment beam with respect to the laser tube via the mirror M2.

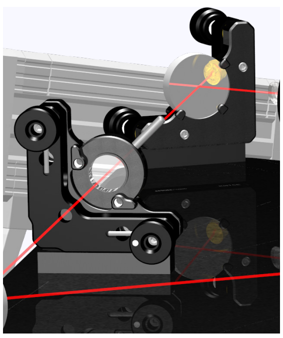


Fig. 36: Single mode etalon

For the operation of the laser gyroscope it is required that the laser operates in a single mode only. This is achieved by inserting an etalon into the cavity. A kinematic adjustment holder allows the precise orientation of the etalon with respect to the laser beam.

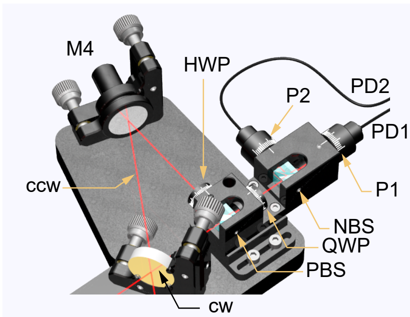


Fig. 37: Dual beat frequency detector

To obtain the beat frequency, the cw (clockwise) and the ccw (counterclockwise) modes must propagate collinearly. At mirror M3 a small fraction of both modes is leaving the cavity. The cw mode passes directly the polarising beam splitter (PBS) and the ccw mode is reflected by the mirror M4 in such a way that it enters the polarising beam splitter (PBS). Since it has the same polarisation as the ccw mode we need to turn its polarisation by 90° so that the mode is reflected inside the PBS and continues to travel collinear with the cw mode. Now both modes are perpendicularly polarised to each other. The quarter waveplate (QWP) converts both modes into circular polarised light. By using a neutral beam splitter (NBS) with a splitting ratio of 1:1 we create two channels. At the end of each channel a polarizer (P1, P2) is located in front of a photodetector (PD1, PD2) converting the light back to linear polarisation allowing the detection of the beat frequency. To obtain a 90° phase shifted optical signal the polarizer P1 and P2 are oriented under an angle of 45° to each other. This allows the detection of the rotation direction of the laser gyro. The photodiodes PD1 and PD2 are connected to the 2 channel photodiode amplifier DC-0080.

Fig. 38: DC-0080 Quad counter & 2 channel photodiode amplifier

The microprocessor controlled amplifier DC-0080 contains two independent amplifier channels whereby the gain of each can be set via the touch screen and the one knob digital selector. The amplified photodetector signals are internally converted to TTL signals and fed to the internal quadrature counter. The microprocessor reads and transfers the counter results to the display as numerical value of the frequency, the counted fringes and the direction of rotation. The analog as well as TTL signals of the photodetector channel are available at the rear panel via BNC sockets. Due to the quadrature signals an interpolation can be performed which results in a maximum 16 times higher resolution.

Fig. 39: Turntable drive unit

The turntable is rotated by a stepper motor which drives a zero-play pre-loaded worm gear drive. The powerful stepper motor needs 200 full steps per turn which relates to a rotation of 2° or 0.6' per step. The stepper motor is connected via a 15 pin Sub-D connector to the DC-0300 stepper motor controller.

Fig. 40: DC-0100 Stepper motor controller

The microprocessor controlled DC-0100 operates the turntable drive. It can drive the stepper motor in full step or micro step with 1/2 to 1/64 micro steps. By means of the touch panel and the one knob digital selector, the speed can be set in a range from 0.1 to 12 °/s and the maximum rotation range of ±180°. The controller can repeat the rotation by an adjustable number of repetitions. The provided remote control is a useful add-on for the initial alignment or demonstration to an audience.

Both the controller, the DC-0080 quad counter and photodiode amplifier and the DC-0300 Stepper motor controller are equipped with a USB bus and can be controlled by the Laser gyroscope control software WIN in combination with an external PC or tablet.

The LMH-0600 Laser gyroscope can be fully operated without any external computer.

Experimental Work

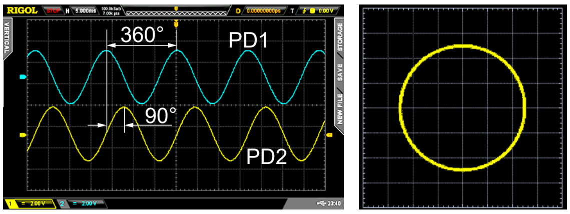


Fig. 2.41: Beat frequency signals 90° phase shift and XY representation

Once the initial alignment of the ring cavity has been completed and the ring laser operates with the inserted etalon, it is time to adjust the beat frequency detector. PD1 and PD2 are connected to the photodiode amplifier and the output connected to an oscilloscope. By aligning the polarizer P1 and P2 the phase shift of 90° between the signal of PD1 and PD2 is achieved. In case both amplitudes are the same a circle appears when the oscilloscope is switched to the XY mode. If the gyroscope is resting, only a dot on the circumference track is visible. Depending of the rotation direction, this dot moves accordingly.

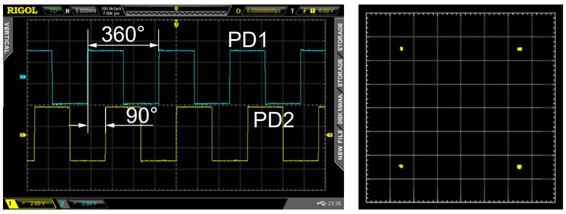


Fig. 2.42: Beat frequency converted to TTL and its XY representation

The DC-0080 amplifies not only the photodiode signal, it also converts it to TTL level. In the XY representation we will notice a dot jumping from one corner to the next one. Depending on the rotation of the laser gyro this dot either jumps in cw or ccw direction. The TTL signal of PD1 and PD2 is connected to the input of a quadrature counter which fulfils three tasks. Firstly it interprets the rotation direction, secondly it counts the TTL events and thirdly it can interpolate one event into 4 (each dot of the corner). In frequency mode the beat frequency is measured and displayed.

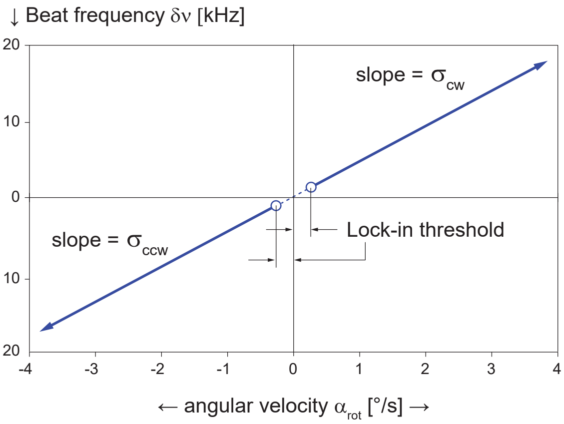


Fig. 2.43: Lock-in threshold and gyro constant

$$\delta\nu_{beat} = \frac{4 \cdot F}{L \cdot \lambda} \cdot \omega_{rot}$$

This formula derived from Sagnac's equations describes the dependency of the beat frequency on the rotary frequency ω_{rot} and constant parameter of the gyroscope. F denotes the area which is encompassed by the light beam, L is its circumference and λ the wavelength of the laser. Applying this formula to our gyroscope with the equilateral shape with the length a of one side of 460 mm we get

$$\delta\nu_{beat} = 4.202 \cdot 10^5 \cdot \omega_{rot}$$

Converting ω_{ro} into the angular velocity α_{rot} in °/s we get:

$$\delta\nu_{beat} = 7.334 \cdot 10^3 \cdot \alpha_{rot}$$

With an angular speed of 1°/s for example, we should expect a beat frequency of 7.334 kHz.

It is a part of the measurement task to determine this value. The stepper motor controller is set in such a way that the gyro shall turn let's say 180 ° in cw and subsequently in ccw direction for a given set of angular velocities α_{rot}.

A sample graph with arbitrary units is shown in Fig. 2.43. From the slope of the cw and ccw rotation we will get the value of σ and compare it with the predicted value. Furthermore the lock-in threshold is determined.

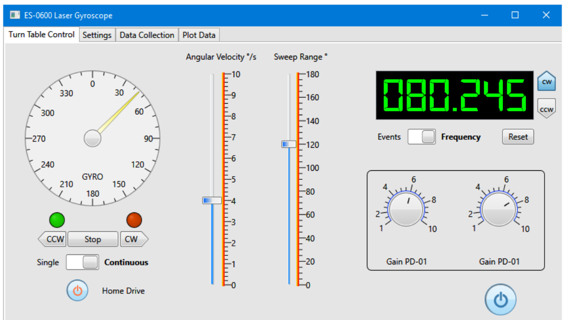


Fig. 2.44: Laser gyroscope control software WIN

You may want to perform automated measurement or demonstrate the experiment as a live lecture in front of your students. In this scenario the "Laser gyroscope Control software WIN" is the right choice. From a central location like a notebook for instance, the entire experiment can be controlled and automated measurements taken. In case the laptop is connected to the video system of the lecture hall the students can see the experiments via the lecture hall camera and the control and incoming data via the notebook on the lecture hall screen. To operate the software both controller the DC-0080 as well as the DC-0300 are connected via their USB busses to the notebook. All required settings like the angular velocity, rotation range and direction are accessible. Furthermore the gain of the photodiode amplifier and the settings of the quadrature and beat frequency counter can be set by the software.

A central feature is the automated operation and data collection possibility. The laser gyroscope is operated at different rotation velocities and direction whereby the beat frequency is recorded. A live graph is displayed and can be printed or stored either numerical or graphical form as PDF document.

LM-0600 HeNe Laser Gyroscope consisting of:

Item	*Code*	*Qty.*	*Description*	*Details page*
1	CA-0080	1	Optics cleaning set	128 (12)
2	DC-0064	1	High voltage supply 6.5 mA	122 (9)
3	DC-0080	1	Quad counter & 2 channel photodiode amplifier	123 (11)
4	DC-0100	1	Stepper motor controller	123 (13)
5	MM-0700	1	Turntable drive unit	98 (41)
6	OM-0700	1	Gyroscope turntable	116 (39)
7	OM-0720	1	Alignment laser 532 nm with power supply	116 (40)
8	OM-0780	1	Dual beat frequency detector	116 (41)
9	UM-LM06	1	Manual HeNe laser gyroscope	
	Option (order separately)			
10	ES-0600	1	Laser gyroscope control software WIN	
	Required Option (order separately)			
11	CA-0200	1	Oscilloscope 100 MHz digital, two channel	129 (19)

Highlights

Premium class ★★★ experiment

★ No external computer required

★ New directional discrimination

Intended institutions and users:
Advanced
Physics Laboratory
Engineering department
Electronic department
Naval college, aerospace, aviator and earth-bound navigation