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Sagnac Effect in the Colliding-Pulse-Mode-Locked Dye Ring Laser

D. Gnass, N.P. Ernsting, F.P. Schäfer

Max-Planck-Institut für biophysikalische Chemie, Abt. Laserphysik
P.O. Box 28 41, W-3400 Göttingen, Fed. Rep. Germany

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Abstract. A colliding-pulse-mode-locked dye ring laser was mounted on a rotary stage and the beat frequency of the two output pulse trains was measured as a function of the rotation rate. The measurements are in good agreement with the Sagnac theory.

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Colliding-pulse-mode-locked (CPM) dye ring lasers [1] are characterized by ultrashort pulses, counterpropagating in the ring resonator, which always meet in the saturable absorber. Here they create a transient bleached absorber grating and are therefore phase-locked via Bragg reflection [2]. Salin et al. [3] overlapped the two resulting output beams temporally and spatially in an interferometer and observed the field- and intensity-cross-correlations with a slow photodiode. At maximum temporal overlap, the observed signal showed an envelope modulation which corresponds to a beating between the two pulse trains. Dennis et al. [4] used the Fresnel-Fizeau effect to achieve different round-trip times for the two counterpropagating pulses and observed a shift of the beat frequency. They concluded that a rotating CPM ring laser might perhaps be used as a laser gyroscope based on the equivalent Sagnac effect [5, 6].

However, several nonlinear effects govern the pulse evolution in a passively mode-locked femtosecond dye laser [2, 7-10]. Therefore the question arises whether the gyroscopic response of the CPM-laser follows the scaling law given for the Sagnac effect [5, 6].

Here we report on a rotating CPM dye ring laser and show that this ringlaser indeed exhibits a Sagnac effect and can be used as a laser gyroscope.

Equation (1) is the Sagnac equation for an active ring-laser gyro [5, 6].

$$\Delta\nu = \frac{4A}{\lambda P}\Omega + \Omega_B . \tag{1}$$

Here, $\Delta\nu$ is the beat frequency, A the area enclosed by the light path, λ the wavelength, P the perimeter of the path, Ω the rotation rate of the laser, and Ω_B a possible frequency bias. The constant of proportionality between $\Delta\nu$ and Ω (scale factor) is independent of the frequency bias and therefore the parameter to be determined. Since the CPM dye laser exhibits an intrinsic beating between the two output pulse trains which depend on pump power and absorber jet position relative to the intracavity waist [2], we made sure that these parameters were kept constant throughout the experiment.

The laser used was a six-mirror, two-prism CPM dye laser that produces 100 MHz pulse trains near 610 nm. The dye laser was pumped by an Ar-ion laser (Coherent Innova 200-15) at 514 nm via a single mode optical fiber (Newport SA 10). Solutions of Rh6G and DODCI in ethylene glycol were used as gain and absorber media, respectively. Typical pump power levels were 1.5÷2 W measured after the fiber; the average output power of the dye laser was ca. 2 mW per beam. The whole set-up was mounted on a rotary stage (Spindler & Hoyer RT-300). The pulses had a bandwidth of 2 nm FWHM, corresponding to 195 fs pulse duration (assuming a sech^2 pulse shape).

An interferometer consisting of a pellicle beamsplitter BS and mirrors M_3 and M_4 with a variable delay in one beam was used for the measurements (Fig.1). The delay was adjusted to obtain interference fringes from the two pulses. Slight vertical tilts of mirrors M_3 and M_4 ensured that no laser light was backscattered into the laser. The pulse train envelope was then observed with a photodiode and registered by a digital storage oscilloscope (Tektronix DSA-602) with a numerical FFT option. The pulse-train envelope was observed to be modulated at a beat frequency of 2÷20 kHz as in [2]. The

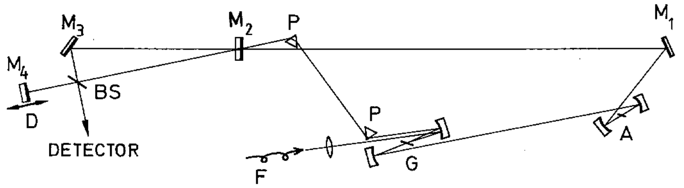

Fig.1. Experimental set-up used in the experiments. The CPM dye laser is on the right. (P: prism; A: absorber section; G: gain section; F: optical fiber; M_2: output coupling mirror; BS: pellicle beam splitter; D: variable delay; M_1-M_4: mirrors

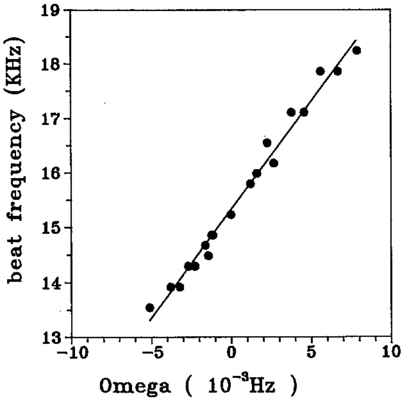

Fig.2. Dependence of the beat frequency on rotation rate. The circles are experimental data, the straight line is a best fit to the data (see text).

FFT option of the DSA-602 was used to determine the mid-beat-frequency of the pulses.

When a rotation was applied to the ringlaser, the observed beat frequency shifted to higher or lower values for clockwise and counterclockwise rotation, respectively. Figure 2 shows the dependence of the beat frequency on rotation velocity. The frequency shift clearly shows linear behavior. In the figure, the straight line indicates a best fit with a dimensionless slope of 395000. The scale factor for the Sagnac effect for our laser parameters is 393000, as calculated by (1) using the measured area, perimeter and wavelength of the CPM laser ($A = 0.18\text{m}^2$, $P = 3\text{m}$, $\lambda = 610\text{nm}$). Even for rotation rates as low as 10^{-3} Hz a frequency shift was observed.

The optical fiber used was a single mode fiber with core diameter of 3 μm. The Ar-ion laser was coupled into the fiber with a microscope objective. Another microscope objective was used for coupling out the light. Long-term drifts of the pump power after the fiber were due to thermal effects in the first few millimeters of the fiber. This drift and short-term variations resulted in the scattering of the experimental data.

In conclusion, we demonstrated experimentally that the classical Rh6G - DODCI CPM laser exhibits a Sagnac effect upon rotation and may be used as a biased laser gyroscope. The bias of this laser gyroscope circumvents one of the most severe difficulties of cw-laser gyroscopes, namely the lock-in effect and as a corollary the need for extremely scatter-free mirrors.

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