Federal Agency for Cartography and Geodesy

Improved Measurement of short-periodic Polar Motion by the Wettzell G Ring Laser

Introduction

The rotation of the Earth is routinely monitored by a global network of radio telescopes using quasars as fixed markers in space. The operation of such a network requires expensive equipment and a lot of maintenance effort, while on the other hand no other technique yields Earth rotation parameters with such a precision: 10 microseconds in length of day (LOD) and 0.1 milliarcseconds (mas) in polar motion.

Ring lasers open up an alternative way for continuous monitoring Earth rotation. Basing on the Sagnac effect ring lasers measure rotations absolute without the need for observing external objects like stars or satellites. Attached to the Earth they allow the measurement of the Earth rotation rate and the orientation of the instantaneous rotation axis in an Earth fixed frame.

Benefits of ring laser measurements are:

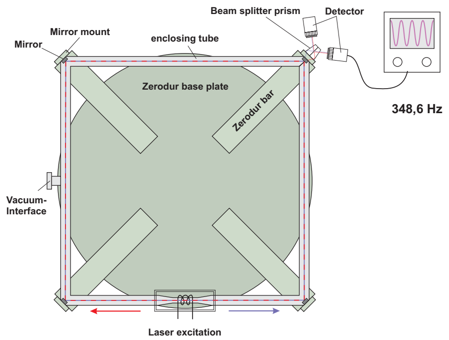
- ✶ Complementary measurements to geodetic space techniques
  - completely different type of measurement
  - high temporal resolution for monitoring subdaily variations
  - continuous operation, real time availability
  - no network required
- ✶ Direct access to polar motion
  - Ring lasers are sensitive to motions of the rotation axis with respect so the Earth
  - They are not sensitive to motions of the rotation axis in space

Principle of Operation

Ring lasers use the Sagnac effect, which is the frequency splitting of two counterrotating laser beams forming a closed light path in a ring resonator due to rotation (Sagnac 1913). The resonator cavity is filled with a Helium/Neon gas mixture, which is excited by an alternating electrical field. The frequency difference between the co-rotating and the counter-rotating beam is described by the Sagnac formula for active resonators:

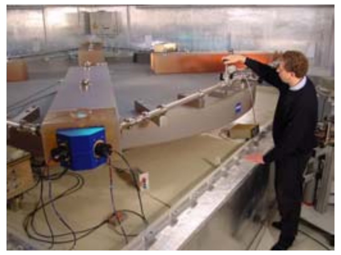
$$\Delta f = \frac{4A}{\lambda L}\,\vec{n}\cdot\vec{\Omega}$$

- Δf Sagnac frequency
- A circumscribed area
- L laser beam path length
- λ wavelength
- Ω rotation vector



The task is to measure the frequency of the optical interference pattern, which is roughly 12 magnitudes below the optical frequency, with a relative precision of 10^{-9}. For the given ring laser size of 4 x 4 m and horizontal installation at the latitude of Wettzell, the Sagnac frequency is 348.6 Hz.

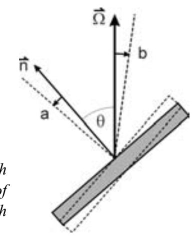
The "G" operates in an extremely isolated underground lab, where the thermal variations are in the order of 10 mK over several days mostly caused by adiabatic compression / expansion from atmospheric pressure variations.



The 4 x 4 m ring laser "G" in the underground lab during maintenance work.

Orientation Monitoring

Because ring lasers measures the projection of the Earth rotation vector on the instrument axis, it is sensitive to both spin variations and orientation changes of the Earth's axis with respect to the instrument.



The angle between the ring laser normal and the Earth rotation vector q can either be altered by local tilting of the instrument (a) or by motions of the rotation axis with respect to the Earth (b), i.e. polar motion

- ✶ A set of platform tiltmeters (type Lippmann) placed on top of the ring laser continuously monitor the orientation with a resolution of better than 1 nrad.
- ✶ The tiltmeter records are corrected for tidal attraction, i.e. the sum of tidal potential V_t and tidal deformation potential V_d, where k is the degree 2 Love number:

$$V_{tot} = V_t + V_d = (1+k)V_t$$

- ✶ Correction for air mass attraction using numerical weather models (see Poster XY0334)
- ✶ Orientation correction of Sagnac frequency of a horizontally installed ring laser at latitude φ, tilting towards north by δ_N:

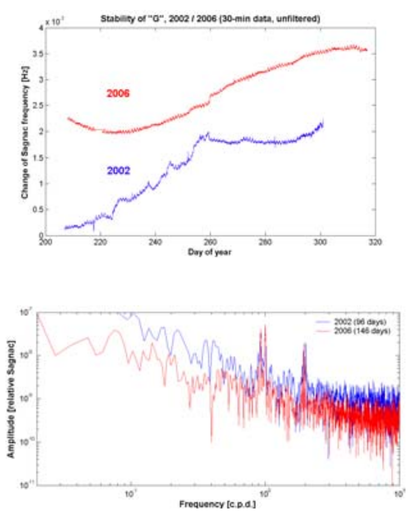
$$\Delta f_{cor} = \Delta f\,\frac{\sin(\varphi - \delta_N)}{\sin(\varphi)}$$

Modifications in 2006

- ✶ Improvement of the vacuum system
  - Stability of the Sagnac frequency suffered from outgassing from impurities (H_2, H_2O) from the stainless steel surfaces
  - Replacement of the old 50 mm by 150 mm tubes
  - Installation of a getter tank to catch gas impurities
- ✶ Replacement of the Rb frequency standard by a reference frequency coming from a hydrogen maser

G ring laser after installation of 150 mm vacuum tubes and getter tank (behind wheel valve).

Improvement in 2006



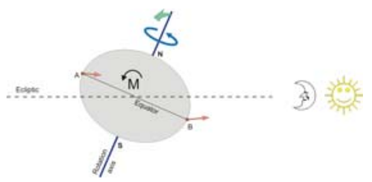
The technical upgrade in 2006 resulted in a significant improvement in stability and resolution.

The time series (upper graph) exhibit a strong reduction of varying drift rates and signal excursions with respect to 2002, which had been the best time series till then. The smooth drift is mainly due to thermal relaxation. The diurnal polar motion signal is clearly visible.

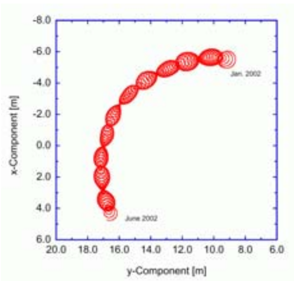
The amplitude spectrum (lower graph) shows a reduced noise in a wide spectral range.

Diurnal Polar Motion

- ✶ The gravitational forces of Sun and Moon apply a torque on the tilted ellipsoidal Earth, which responds by precession. As the tidal forces vary with time, the precession is super-imposed by a periodic variation, the astro-nomical or forced nutation.

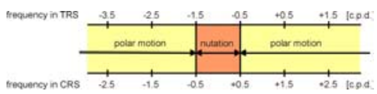


- ✶ The forced nutation affects the orientation of the angular momentum axis and as a consequence the orientation of the instantaneous rotation axis with respect to the angular momentum axis.
- ✶ In a space-fixed frame, these additional angular increments (Oppolzer terms) add up to the nutation terms having the same phases and frequencies.
- ✶ In an Earth-fixed frame these angular shifts manifest as a quasi-diurnal motion of the rotation axis.



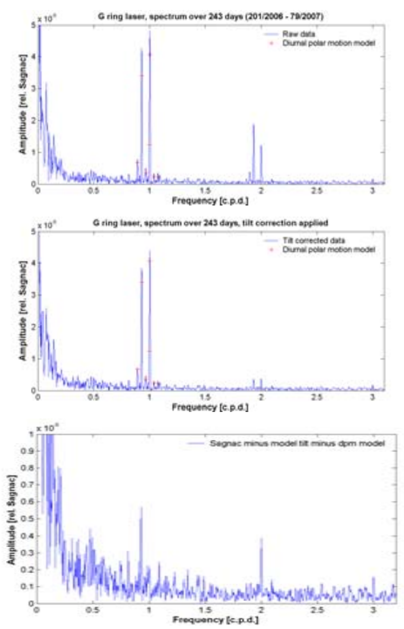
Superposition of the annual and Chandler wobble with the Brzezinski (1986) model time series of diurnal polar motion.

Polar motion vs. nutation:



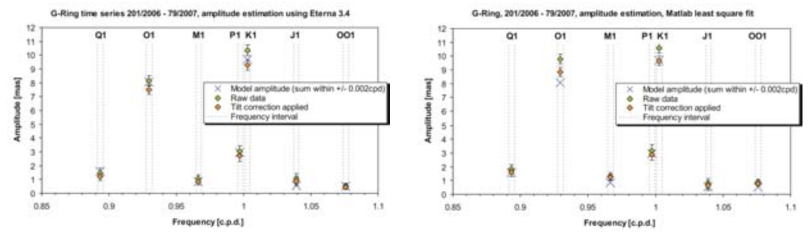
According to the IERS conventions 2003, the terms nutation and polar motion are defined only by frequency, rather than by their physical cause. In this sense diurnal polar motion, showing a retrograde motion of 1 cycle per day (cpd) in the terrestrial reference system (TRS), is denoted as nutation.

Amplitudes at Tidal Frequencies



Amplitude spectrum of raw data (top) showing several peaks at diurnal and semidiurnal tidal frequencies. After tilt correction (middle) the semidiurnal tides nearly completely vanish, and the main diurnal polar motion constituents show amplitudes close to their model values. After having substracted the Brzezinski (1986) model (bottom), all peaks disappear with the exception of the O1 wave. Peaks at exactly 2 and 3 cycles per day are assumed to be of atmospheric origin.

Estimation of Diurnal Polar Motion Terms



Astr. arguments $l\ l'\ F\ D\ \Omega\ \theta$	Symbol	Frequency [c.p.d.]	Matlab raw data Ampl. [mas]	Matlab tilt corr. Ampl. [mas]	Bernese, tilt corrected Ampl. [mas]	Bernese, tilt corrected *rms [mas]*	Eterna, tilt corrected Ampl. [mas]	Eterna, tilt corrected *stdev [mas]*	Model [mas]
1 0 2 0 2 -1	Q1	0.8932	1.82	1.61	1.53	*0.07*	1.24	*0.31*	1.59
0 0 2 0 2 -1	O1	0.9295	9.78	8.83	8.65	*0.07*	7.51	*0.33*	8.08
1 0 0 0 0 -1	M1	0.9664	1.32	1.24	1.19	*0.07*	0.84	*0.24*	0.83
0 0 2 -2 2 -1	P1	0.9973	3.18	2.87	2.94	*0.07*	2.70	*0.39*	2.96
0 0 0 0 0 -1	K1	1.0027	10.60	9.66	10.06	*0.07*	9.28	*0.35*	9.69
-1 0 0 0 0 -1	J1	1.0390	0.78	0.63	0.66	*0.07*	0.89	*0.33*	0.57
0 0 -2 0 -2 -1	OO1	1.0759	0.89	0.78	0.67	*0.07*	0.45	*0.19*	0.52
synthetic signal (1 mas)		1.5000	1.03	1.01					

Amplitudes of diurnal polar motion constituents are estimated using least square fits of sinusoidal functions of given frequencies. The model amplitudes are the sum of all constituents within bins of +/- 0.002 cpd around the given frequency, because the frequency resolution of the analyzed time series is 0.004 cpd. The error bars represent 2 sigma.

Summary

- ✶ The performance of the Wettzell ring laser has been significantly improved in 2006
- ✶ The average noise level at subdaily frequencies is less than 10^{-9}
- ✶ The recent detection limit for periodic subdaily signals is 0.5 mas for polar motion and 0.2 ms for LOD
- ✶ The amplitudes of 7 diurnal polar motion terms (Q1, O1, M1, P1, K1, J1, OO1) has been reliably determined with formal errors less than 0.2 mas
- ✶ Regarding the technical feasibility there is still potential for an increase in resolution and stability

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