The Geosensor - Rotation as a new Observable in Seismology

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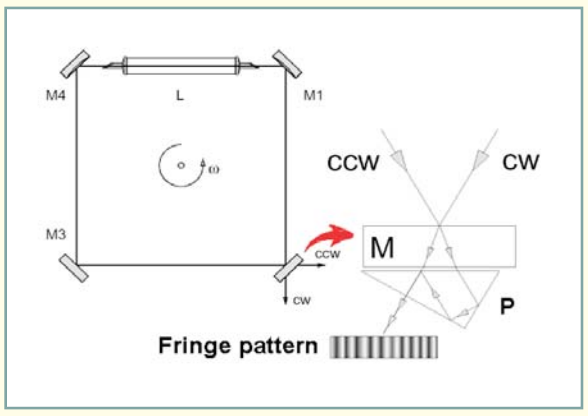
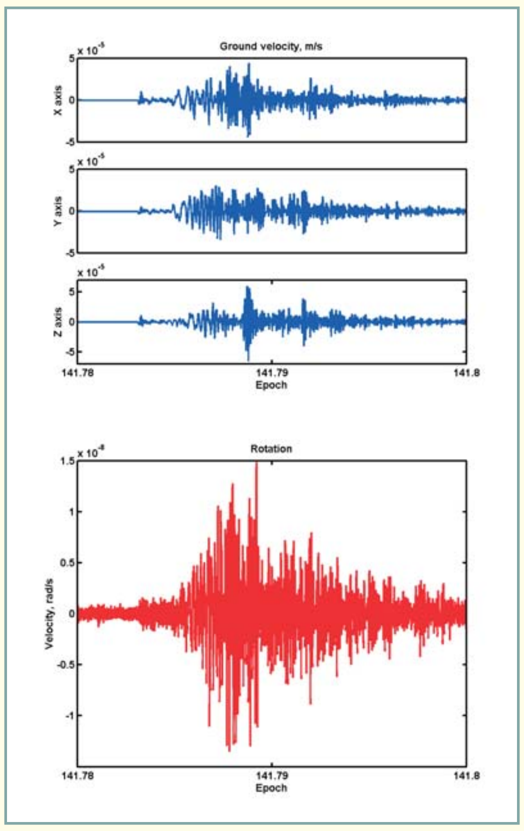
The principle of ring laser gyro (RLG) operation is based on the Sagnac effect when two oppositely propagating beams in the rotating cyclic cavity oscillate on slightly different optical frequencies where the frequency difference is proportional to the velocity of rotation. This beat frequency is proportional to the product of the geometric area (*A*) enclosed by the laser beams and the rotation rate ( ) imposed on the cavity and inversely proportional to the wavelength ( ) of the laser and the perimeter (*L*).

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

The resolution of the ring laser gyroscope is proportional to the area covered by the beam path. Therefore the increase in the size of a ring leads to the sensitivity improvement. The 1.6 by 1.6 meters square ring laser component of GEOSENSOR has a resolution of f = 8 x 10^{-11} rad/√s. In a standard seismology the earthquake induced rotation has been neglected because the corresponding magnitudes were thought to be small and no instruments with required precision existed. The expected range of seismically induced angular velocities to be measured is estimated as $_S$ = (10^{-14} .. 1) rad/s and the signal frequency range f_s = (0.003 .. 10) Hz. The superior resolution of large ring lasers along with their insusceptibility to acceleration makes the application of these instruments very attractive for the seismological studies.





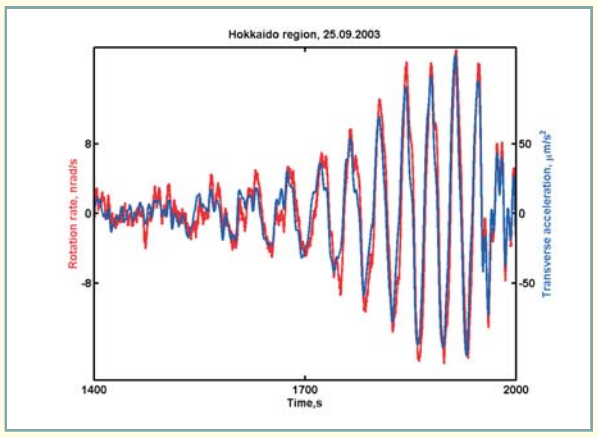
Since the very beginning of the large ring lasers project the substantial variations of the beat frequency caused by earthquakes were observed. Those variations, by analogy to conventional linear displacement records, are called rotational seismograms. In general, seismically induced rotation rate can be expressed as

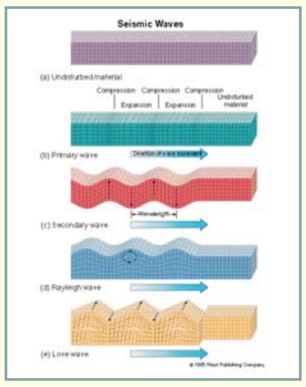
$$\Omega_S = \begin{pmatrix}\omega_x\\ \omega_y\\ \omega_z\end{pmatrix} = \frac{1}{2}\nabla\times V = \frac{1}{2}\begin{pmatrix}\partial_y V_z - \partial_z V_y\\ \partial_z V_x - \partial_x V_z\\ \partial_x V_y - \partial_y V_x\end{pmatrix}$$

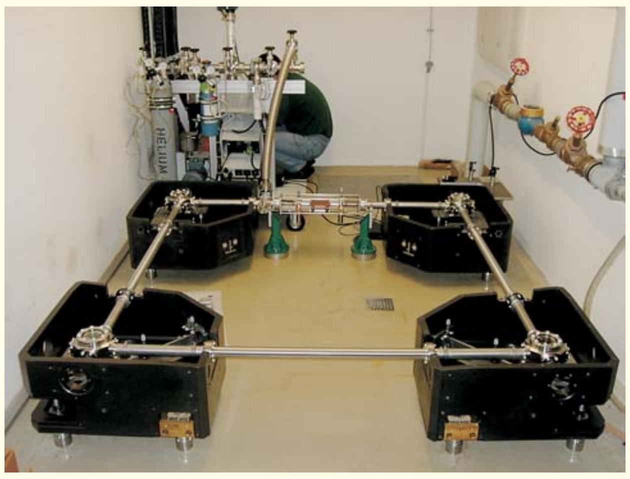
where $V_{i,}$ $i=x,y,z$ are the components of the velocity field *V*, the time derivative of the deformation field. Assuming plane transversely polarized seismic wave propagation, an estimate of rotation rate can be obtained by dividing the transverse acceleration by two times the horizontal phase velocity V_H. In theory, under this assumption both rotation rate $_S$ and transverse acceleration A_T signals should be equal in phase and amplitude.

$$\Omega_S = \frac{1}{2V_H}\cdot A_T$$

The comparison of the measured rotation rate and translational motion has been done for the recorded earthquakes. It demonstrates that the ring laser measured rotational signals are in phase with the translational motions and their absolute amplitudes are also within expected range.



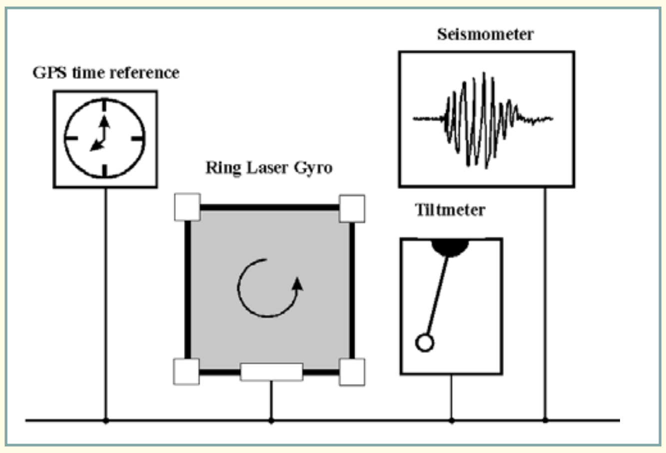




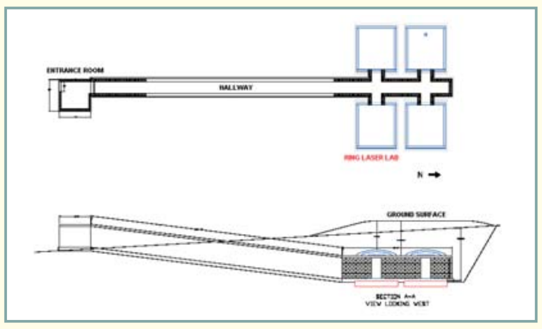
The Geosensor gyroscope at its test site in Wettzell

The demonstrator system named GEOSENSOR has been developed for particularly seismical applications. It consists of several major components; a large perimeter one-axis ring laser gyroscope, a conventional three axis broadband seismometer, a tiltmeter to monitor changes in the orientation of the ring laser component and a GPS-station to provide time and reference frequencies for the data acquisition system. In order to match standards used in seismology a high 20 Hz data acquisition rate is realised via a frequency demodulation technique. The ring laser component of this system posses resolution of f = 8 x 10^{-11} rad/√s . The goal of this project is to investigate the potential of the ring laser technology for theories of seismic wave propagation and earthquake source processes.

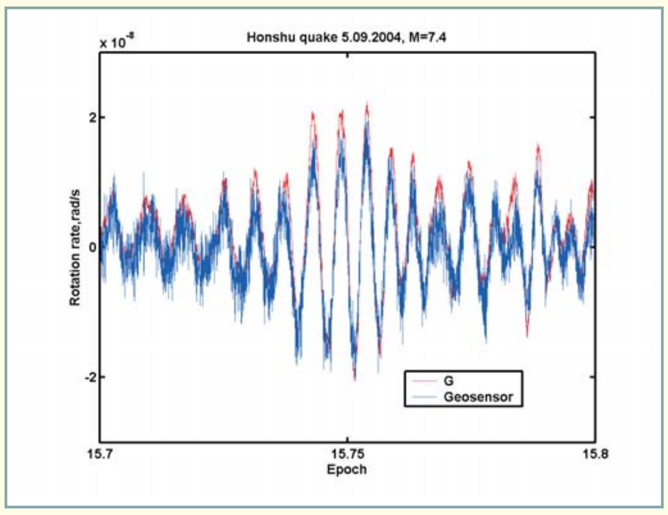
Since the most interesting datasets for seismic studies are expected in the areas of high earthquake activity the instrument must be relocatable. Once this hybrid sensor is completed, it can be set up in any suitable observatory, which provides sufficient infrastructure namely a solid monument with as little temperature variations as possible, power and Internet connectivity.



Principle scheme of the Geosensor



Sketch of the seismic vault at Pinon Flat Observatory, California



The 5.09.2004 earthquake in Honshu, Japan with magnitude of 7.4 was recorded by GEOSENSOR at its temporal location in Fundamentalstation Wettzell office building. The comparison with the G data shows good agreement of both sensors despite the noisy environment. Currently the GEOSENSOR is shipped to the Pinon Flat Observatory, California, USA to be installed in a seismic vault along with broadband seismometers to monitor the seismic activity of the region.

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