Recording Rotational Motions at a New Set-up Uses ‘Earthquakes Simulation’
(simple modification of typical shaking table to cover rotation)

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Fiber - Optic Seismograph for Rotational Events Monitoring (FOSREM)

- **Optical part:**
  5 km SMF-28, $\alpha_{\text{total}} = 16.37$ dB, $P = 11$ mW, min. FOG configuration $\rightarrow$ sensitivity: $2.06 \cdot 10^{-8}$ rad/s/Hz$^{1/2}$, max. rotation rate about 10 mrad/s

- **Electronic part:**
  Open-loop, digital processing, remote control via internet, passband from DC to $2.56 \cdot 2^n$ Hz ($n=1,..,7$)

- **Mechanical part:**
  size: 47x36x23 cm, weight: 7 kg, power supply: 230V AC + 14.4V/20Ah Li-On battery (12 hours system work)

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FOSREM-SS

FOSREM-BB for strong motion (see example)

- **Optical part:**
  5 km SMF-28, $\alpha_{\text{total}} = 16.89$ dB, $P = 0.5$ mW, min. FOG configuration $\rightarrow$ sensitivity $2.18 \cdot 10^{-6}$ rad/s/Hz$^{1/2}$, max. rotation rate a few rad/s

- **Electronic part:**
  Open-loop, digital processing, remote control via internet, passband from DC to $2.56 \cdot 2^n$ Hz ($n=1,..,7$)

- **Mechanical part:**
  size: 36x36x16 cm, weight: 10 kg, power supply: 230AC PCU, PoE 48V from PCU (3 AFORSs)
The Fiber Optic Gyroscope’s 40th Anniversary

- Prolific field launched by pivotal paper by Vali and Shorthill published in May 1976
  - Raport first use of an optical fiber for measure a rotation rate
  - Sensitivity to rotation is enhanced by the number of turns in a multi-turn, single-mode fiber coil

\[ \varphi_s = \frac{2 \pi L D}{\lambda c} \Omega \]

„This experiment show that a ring interferometer gyroscope having sufficient sensitivity for navigation can be built.”

A.Vali nad R. Shorthill, „Fiber ring interferometer,”

The Sagnac – Von Laue Effect in Vacuum

The FOSREM is based on Sagnac-Von Laue effect
- Light beams propagating in opposite directions in a rotating frame experience a different optical path length.

• At rest, the time of flight through the loop is

\[ T_0 = \frac{\text{Circumference}}{\text{Speed of light}} = \frac{2\pi R}{c} \]

• When rotated at rate \( \Omega \)
- Cw beam travels farther to catch up with the moving beam splitter, and its time of flight becomes:
- Ccw beam travels a shorter distance:

\[ T_{cw} = \frac{2\pi R + \Delta L}{c} = \frac{2\pi R + R\Omega T_0}{c} \]
\[ T_{ccw} = \frac{2\pi R - \Delta L}{c} = \frac{2\pi R - R\Omega T_0}{c} \]

• Difference in times of flight:

\[ \delta T = |T_{cw} - T_{ccw}| = 2 \frac{R\Omega T_0}{c} \]

• Phase difference (Sagnac-Von Laue phase shift):

\[ \varphi_s = 2 \frac{R\Omega T_0}{c} = \frac{8\pi^2 R^2 \Omega}{c\lambda} = \text{Scale factor} \times \Omega \]

The two beams experience a Sagnac-Von Laue phase shift proportional to the rotation rate and the coil area:

\[ \varphi_s = \frac{4\pi RL}{c\lambda} \Omega = \frac{1}{S_o} \times \Omega \]

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IWGoRS, Tutzing, Germany
The FOSREM contra FOG

- Applied depolarized light for cost minimisation,
- ESPU optimised for detection rotation rate instead of angle (FOG) up to 10 [rad/s]

\[ \Omega = S_o \tan^{-1} \left( \frac{u(t)}{S_e} \right), \quad u(t) = \frac{A_1\omega}{A_2\omega} \]

- \( S_o, S_e \) – optical and electronic constant determines during scaling on Earth rotation,
- Detection \( \Omega \) on „drifting signal” by special numerical procedure

FOSREM accuracy

FOSREM thermal instability

\( \Omega \) of Earth for Warsaw \((4.45 \cdot 10^{-5} \text{ [rad/s]} \)

\( \text{DC – 2,56 [Hz]} \)

\( \text{DC – 54,63 [Hz]} \)

\( \text{DC – 109,38 [Hz]} \)

\( \text{DC – 328,12 [Hz]} \)

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Measurement with bias phenomena

Ideal approach (without drift connected with bias phenomena)

Real situation ‘drifting signal’ (bias connected with enviroment)

K – defined Ω level for start to recording data

K’ – defined local Ω level for start to recording data
Set-up for `Earthquakes Simulation`  

\[ \Omega = \frac{d\phi(t)}{dt} = \frac{1}{1 + \left(\frac{x - dx}{H}\right)^2} \frac{dx}{dt} \quad dx \ll x = \frac{H}{H^2 + \left(\frac{x}{H}\right)^2} \quad v(t) = \frac{H}{l^2} \quad v(t) = 0.0365 \cdot v(t), \quad L = 3.7 \text{ m}, H = 0.5 \text{ m} \]

v(t) from digitalized data of Earthquakes  

\[ \Omega = 0.0365 \cdot v(t) \quad (1) \]
El Centro Earthquake

Digitalized data

Simpson method

used formule (1)

#1 - Error connected mainly with frame end positioning in different position
El Centro Earthquake

Digitalized data

Simpson method

used formule (1)

Accelerometer mounted on frame
calculation with correction

from formule (1) with correction
El Centro Earthquake

Digitalized data

FT(Rotation Rate) used formule (1)

Accelerometer mounted on frame

FT(Rotation Rate) from formule (1) with correction

#2 – Measured values have different amplitude (accelerometer data will be used in future investigations)
Sine 1 Hz (50% of amplitude)

#1 HORIZON – Before shows noise connected with linear bearing
#2 All seismometers are same different calibrated
Sine 1 Hz (50% of amplitude)

Accelerometer

FOSREM-SS (DC- 10 Hz)

FOSERM-BB

Rotation from accelerometer

FOSREM-SS (DC- 100 Hz)

FOSERM-BB

#3 FOSREM with passband to 100 HZ is too noisy but lower cutting amplitude (HORIZON probably has 500 Hz)

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Sine 1 Hz (100% of amplitude)

Accelerometer  FOSREM-SS  (DC-10 Hz)  FOSERM-BB

Rotation from accelerometer  HORIZON® “before”  HORIZON® “after”

#1 HORIZON – Before shows noise connected with linear bearing
#2 all seismometers are some different calibrated
Sine 1 Hz (200% of amplitude)

Accelerometer

FOSREM-SS (DC-10 Hz)

FOSERM-BB

Rotation from accelerometer

HORIZON® "before"

HORIZON® "after"

#1 HORIZONs have limited amplitude below above)
The existence of resonant characteristics of beam for about 8 Hz is well observed.
El Centro Earthquake

Accelerometer
FOSREM-SS (DC – 10 Hz)
FOSERM-BB

Rotation from accelerometer
HORIZON® “before”
HORIZON® “after”

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FT analyse

FOSREM-SS (DC – 10 Hz) FOSERM-BB

Rotation from accelerometer

HORIZON® „before” HORIZON® „after”

The spectrum are the same with additional component in range of 7 Hz \((300 \times 0,023= 6,9 \text{ Hz})\) connected with linear bearing works
Loma Prieta Earthquake with 100% amplitude

Accelerometer

FOSREM-SS (DC – 10 Hz)

FOSERM-BB

Rotation from accelerometer

HORIZON® „before”

HORIZON® „after”
The FOSREM System includes two parts: FOSREM-BB sensor(s) (FOS-3) and Power & Communication Unit (PCU). The connection provides data transmission and power supply over only one, standard STP cable within the distance of 100 meters.
Dozens of sensors can operate in one worldwide network, transferring data to a central cloud-based system. The data can be viewed and analyzed from anywhere in the world via the Internet.