Plan for Monitoring the Level Variations of the Tunnel Floor

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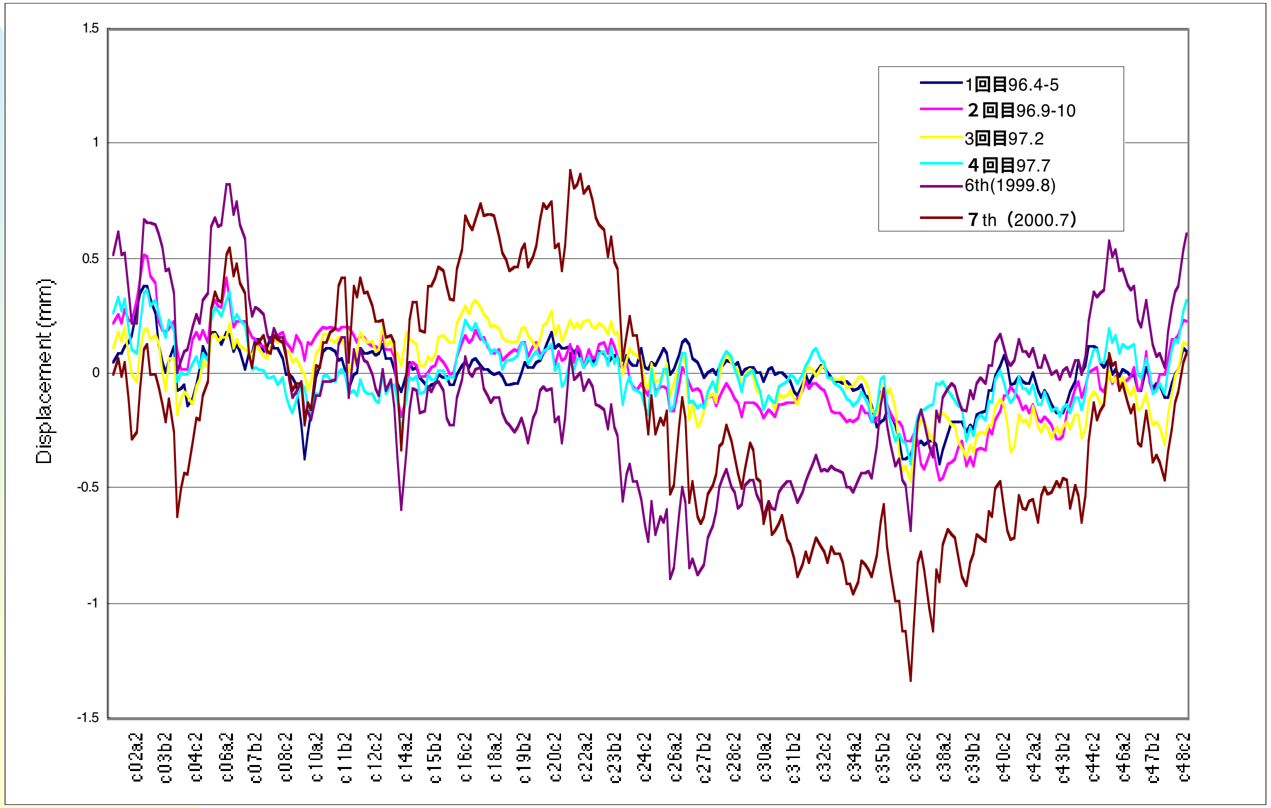
- Introduction
- Plan for the System of HLS (hydrostatic leveling system)
- System experiments

(Introduction)

Vertical Displacements of Magnets

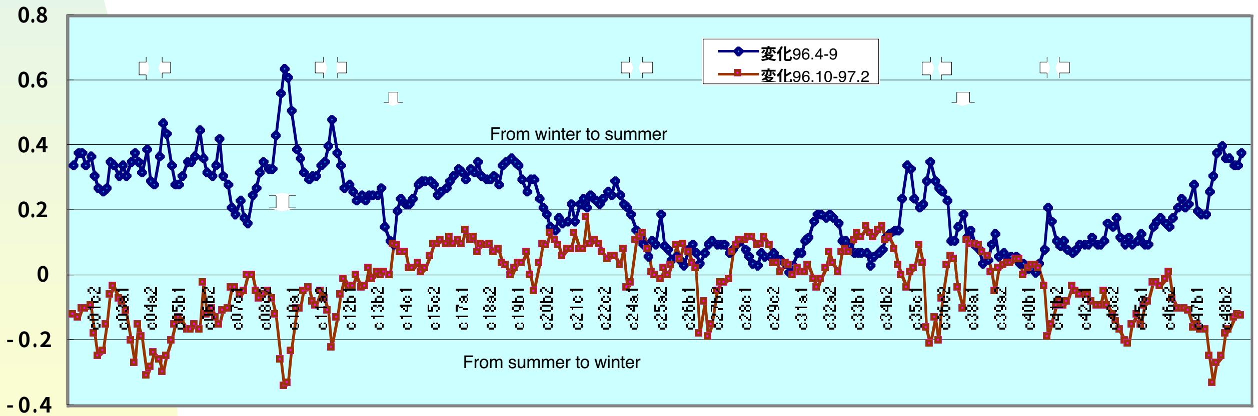
- The levels of the magnets are measured every summer, except for the first three times which were measured successively within one year.



(Introduction)

Features of Level Variations

- Overall level movements are less than ±1 mm since the tunnel was constructed. Uneven movements depend on the underground geology of the building.
- Local level variations are typically in a length of 1-2 cells (30-60 m). They are sensitive to atmospheric temperature because of the underground structures. Daily change of ~2 μm is predicted in certain places.

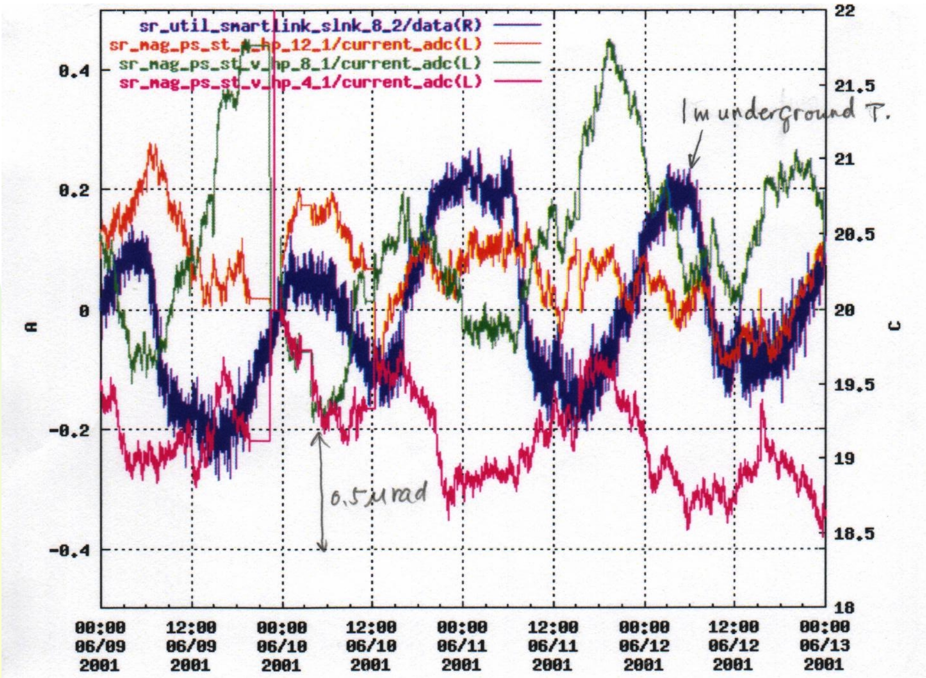


junction of constructing zone; RF waveguide pit; underpass

(Introduction)

Beam Variations And Temperature of the Ground

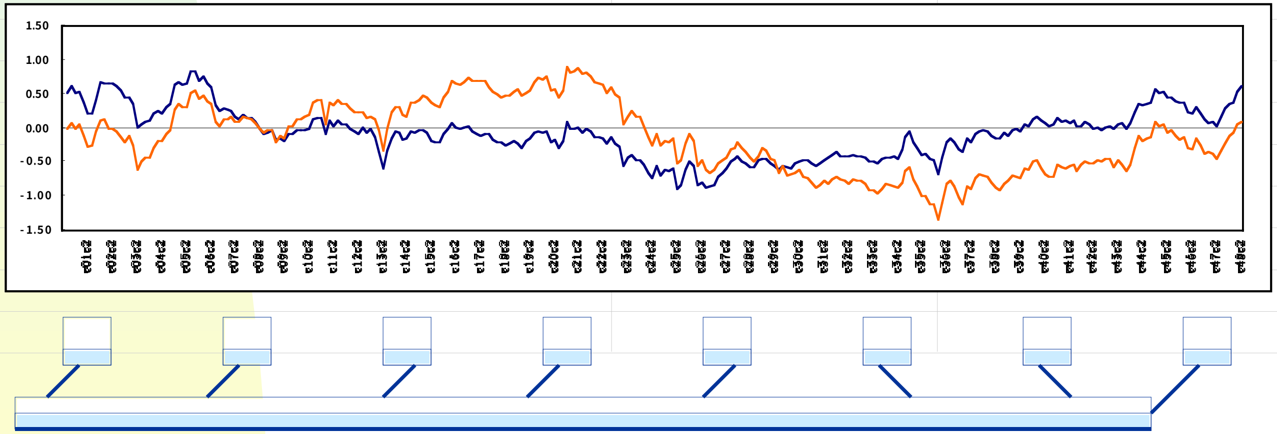
- High precision steering magnets are used to correct periodically the movement of the orbit. The variations of their current indicate a coherence with that of the atmospheric temperature measured one meter underground.



(Plan for the System of HLS)

The Targets of the Leveling System

Target	Sensibility Nedded	Response Time Needed
Local variations:		
Underpass, Junctions, RF pits etc.	1 um ～ sub-um	30 min
Gound movement caused by the rain:	1 um ～ sub-um	1～2 hours
Correlation between the locals and the beam:	1 um ～ sub-um	
Global variations:		
Deformation of the construction by insolation:	several um	several hours
Deformation caused by the tide:	10 um	1～2 hours
Seasonable change of the ground:	several um	
Yearly uneven settlement along the tunnel:	several um	

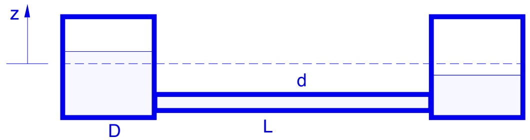


Full-filled Hydrolevelling System

The motion of water in full-filled system is a damped oscillation:

$$\frac{d^2z}{dt^2} + 2\beta\frac{dz}{dt} + \omega^2 z = 0$$

with damping coefficient: $\beta = \frac{16\mu}{\rho d^2}$, eigenfrequency: $\omega = \frac{d}{D}\sqrt{\frac{2g}{l}}$



when β=ω, one obtains critical diameter:

$$d_c = \alpha(lD)^{\frac{1}{6}} \qquad (\alpha : const = 2(\frac{\mu}{\rho})^{\frac{1}{3}}(\frac{2}{g})^{\frac{1}{6}})$$

where,

l: length of the pipe, d: diameter of pipe,
D: diameter of sensor, μ: coefficient of viscosity

For the scale of the SPring-8, the pipe should be around φ20 to get the minimum damping time of 150 seconds.

- Features of full-filled system:
  - Relatively high response
  - Linear motion
  - Easy installation
  - The expanse of the water
  - Evaporation and re-filling
  - Air bubble

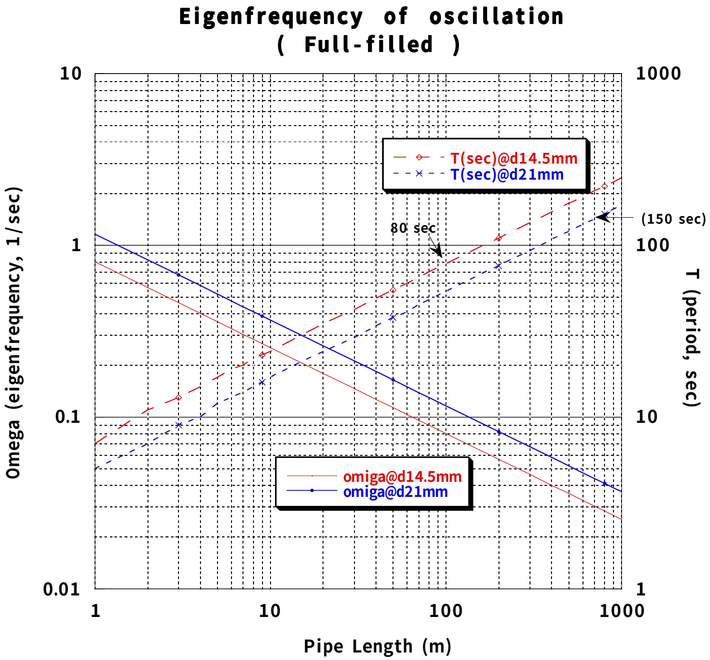


Figure: The eigenfrequency and period (2π/ω) of the oscillation. Their indicate the response time of the system.

Half-filled Hydrolevelling System

The motions of water with free surface are different according to boundary conditions and initial conditions. On the assumption of ideal fluid and small amplitude wave, the oscillation of half-filled is derived to have dispersed eignfrequencies:

$$\omega_m = \sqrt{m\frac{\pi g}{l}\tanh(m\frac{\pi h}{l})} \qquad (m = 1, 2, \cdots)$$

which correspond to different modes of motions. The shapes of free surfaces are:

$$\eta = c\frac{\omega}{g}\cosh(kh)\cos(kx - \omega t)$$

where, l: length of pipe; h: the depth of water; k: wave number; and c: constant.

The dominant component of tilted water is:

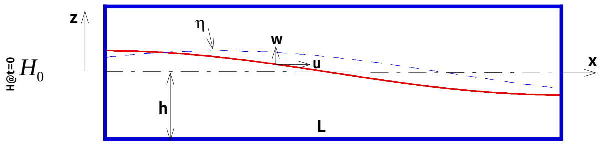
$$\eta_1 = H_0 \cos(\frac{\pi}{l}x - \omega t)$$

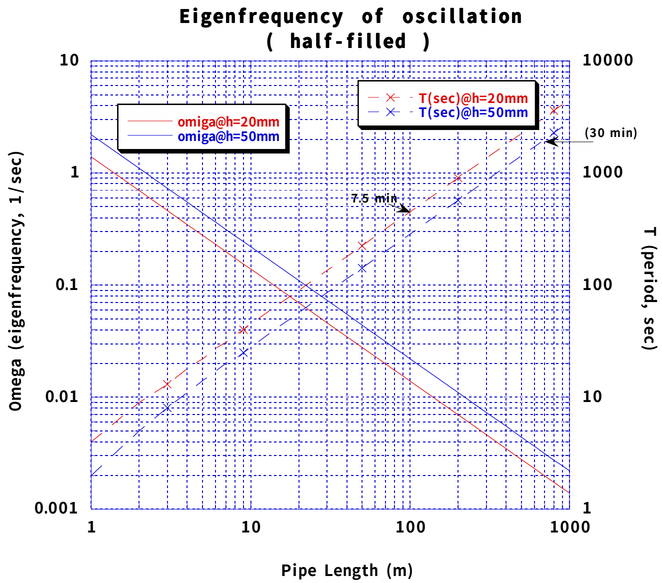
which determines the damping time

$$T = \frac{2\pi}{\omega_1} = \frac{2l}{\sqrt{gh}}$$

Because the velocity of u is much larger than w ($\frac{w}{u} = \frac{\pi h}{l} << 1$), the damping coefficient could be deduced using one-dimension flow theory, and the critical depth (radius of pipe) for circular pipe will take the form of:

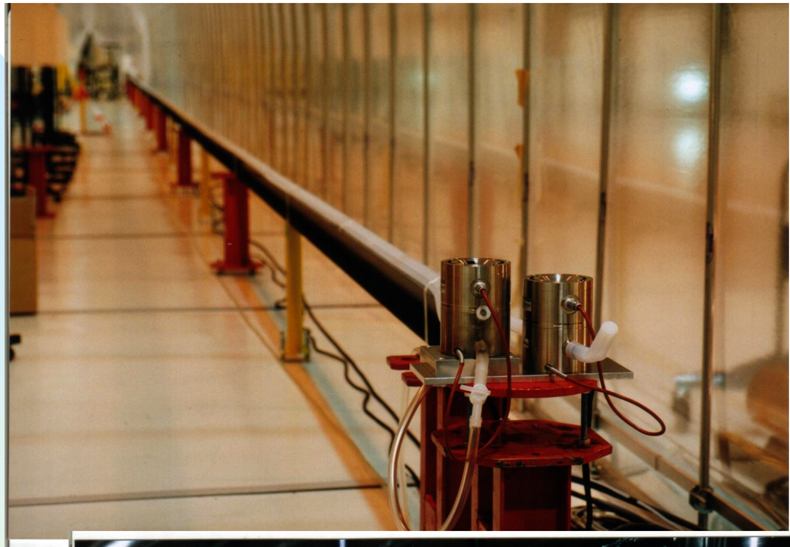
$$h_c = (\frac{\psi 4 \mu l}{\pi \rho \sqrt{g}})^{\frac{2}{5}} \qquad (\psi \approx 1.4)$$

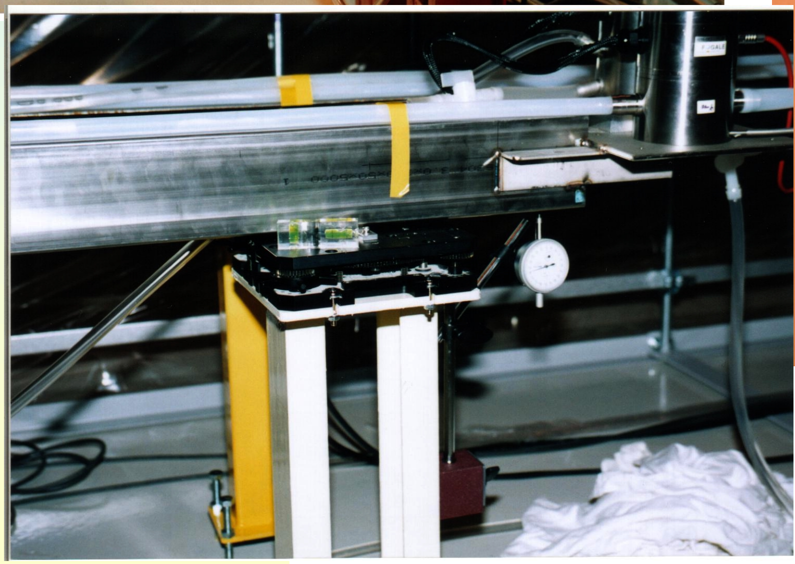




For the scale of the SPring-8, the depth of water should be around 50mm to get the minimum damping time of 30 min.

System Test-benches





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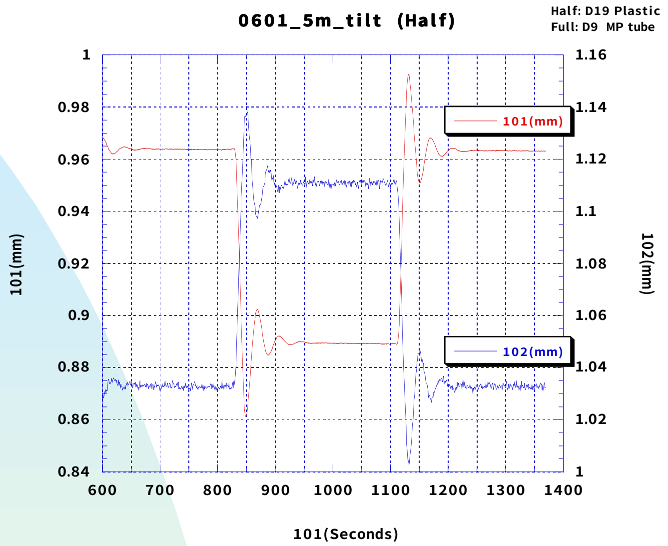
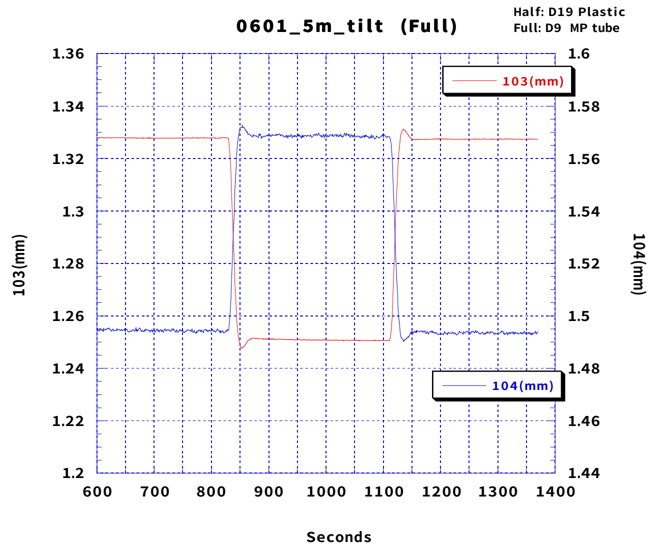
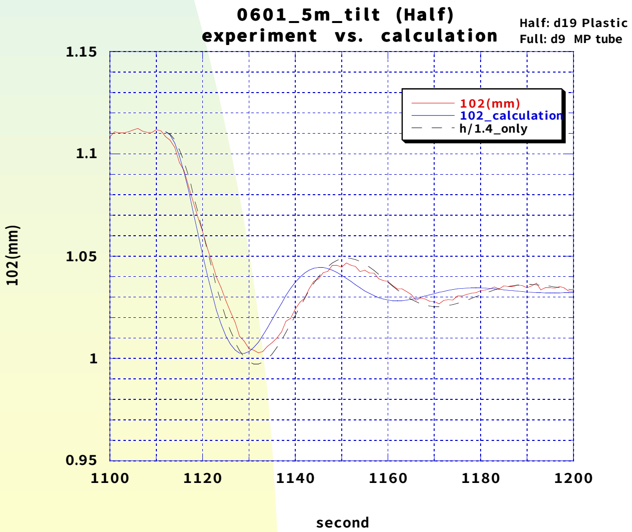
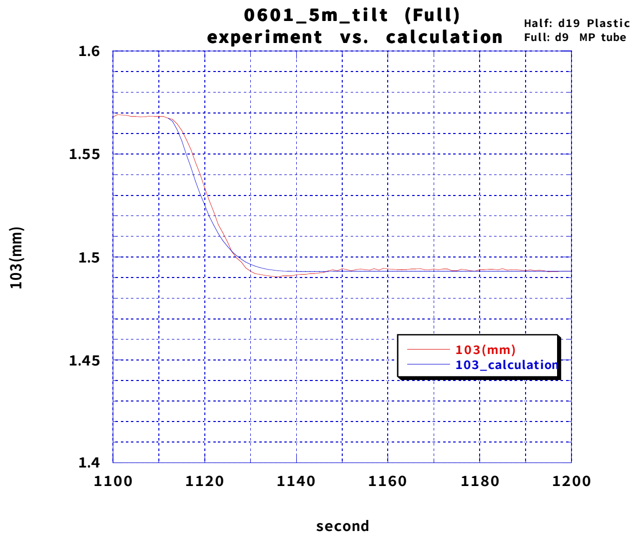
Measurement range	2.5 mm
Precision	1 um
Resolution	0.2 um

Tests for Tilted Movements (experiment vs. calculation, 5m)

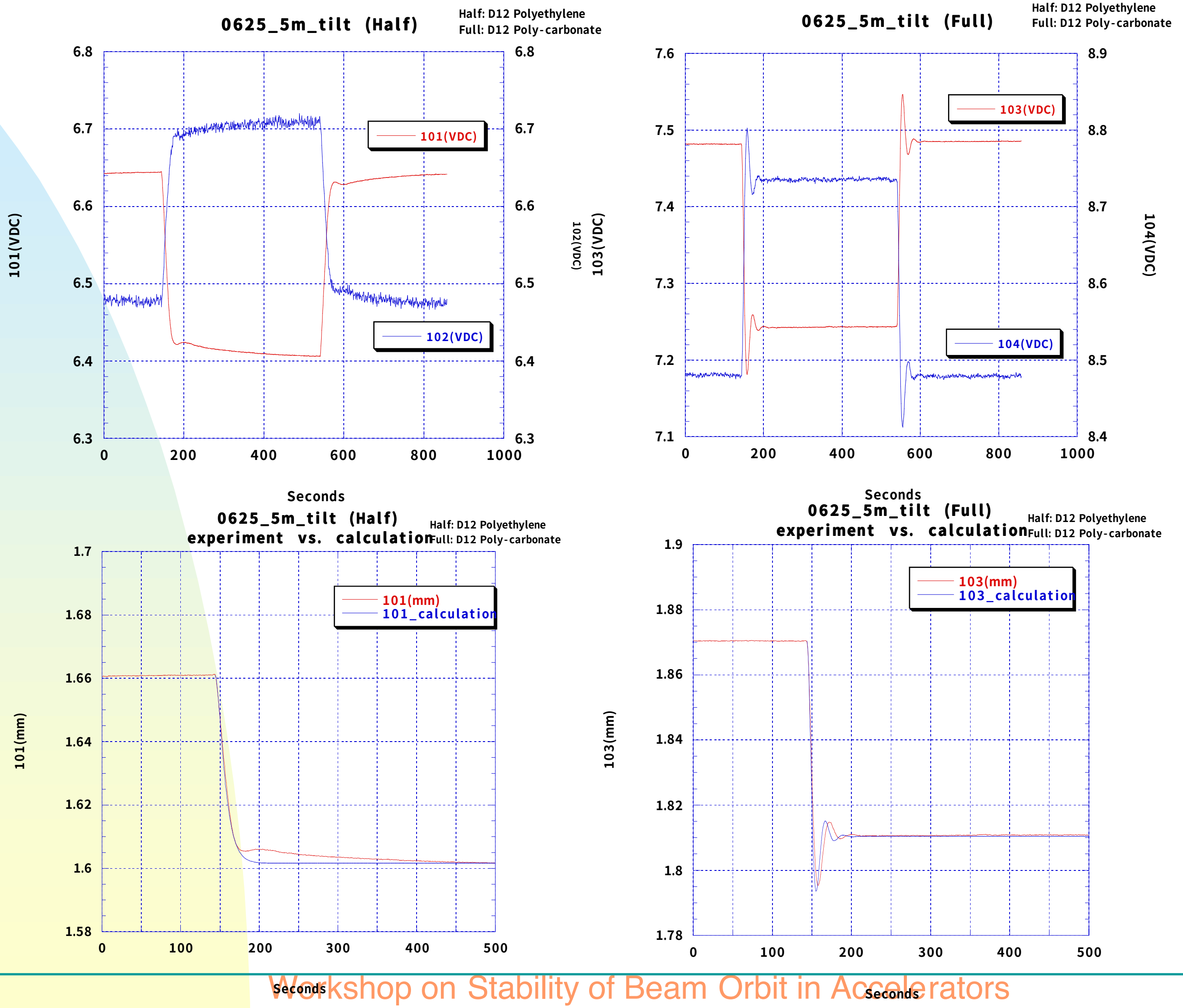






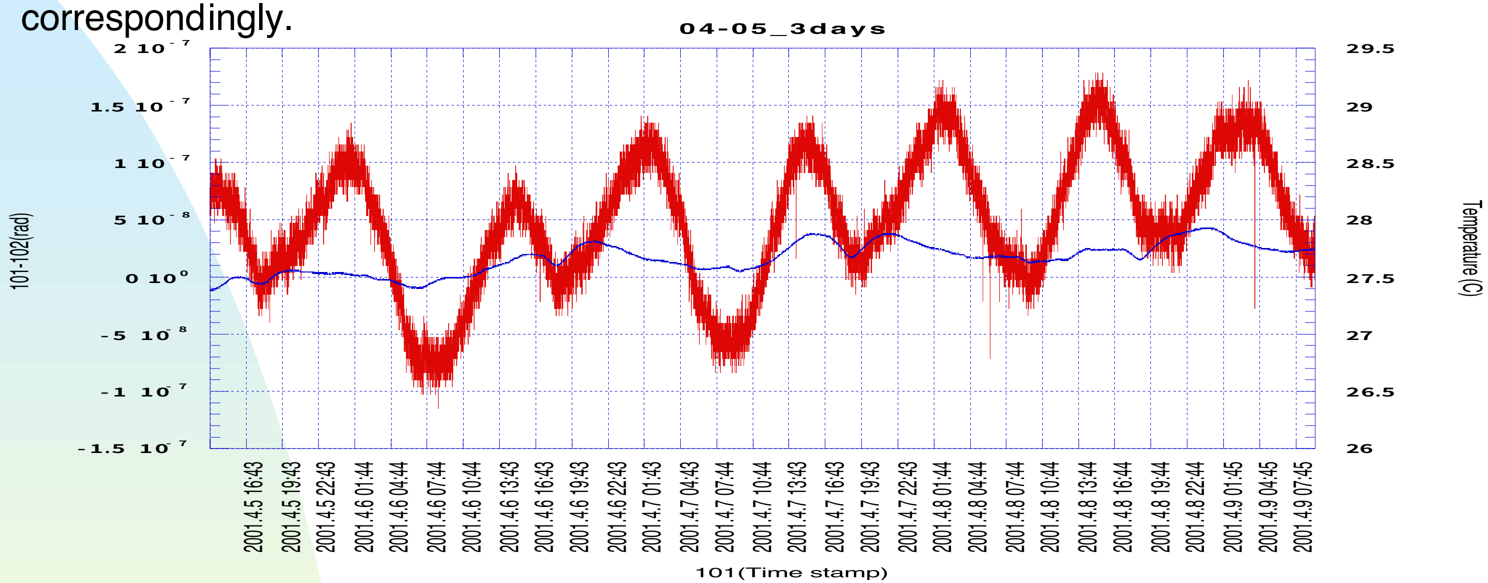


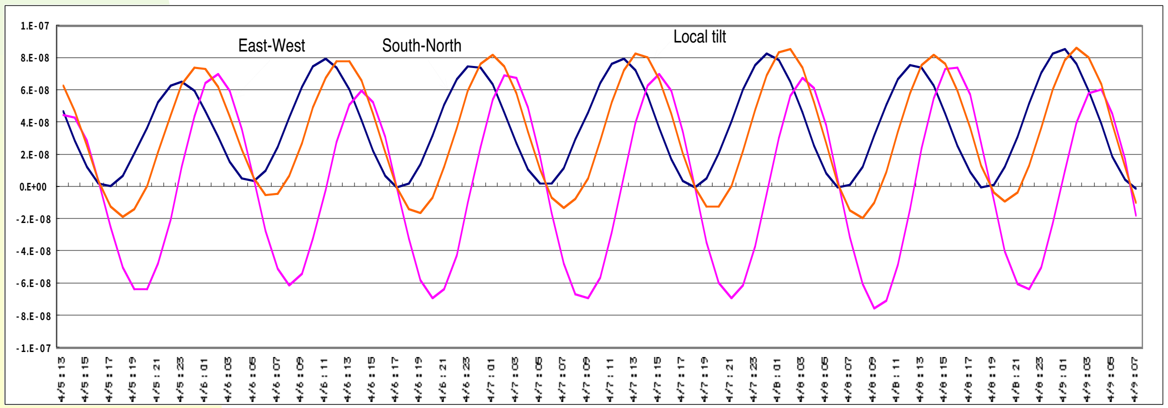
Tests for the Tilted Movements (continue)



Measurement of the Earth Tide (System experiment: sensibility)

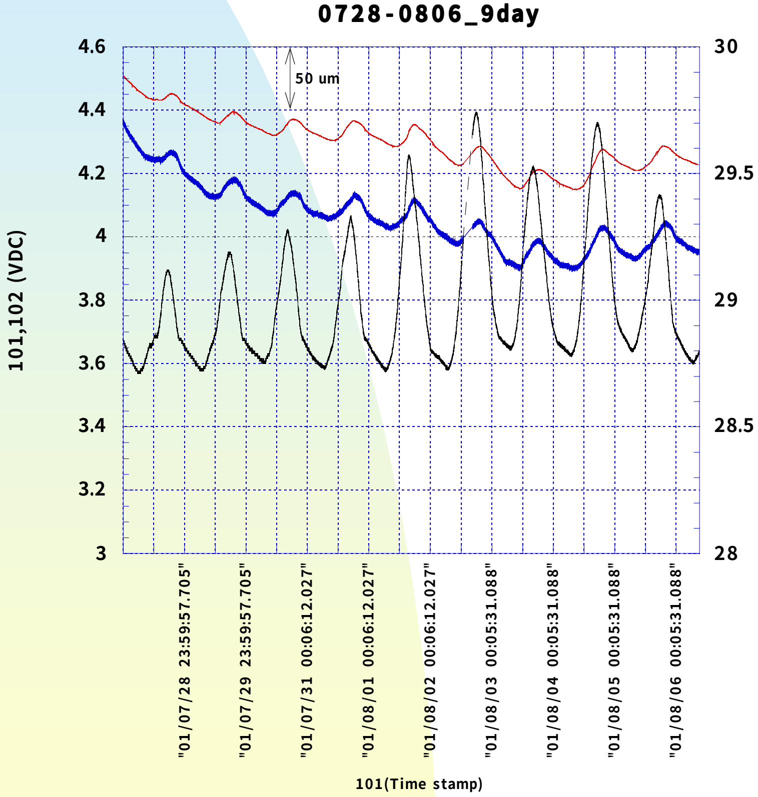
- In the condition of room temperature, the earth tide has been recorded using 40-m half-filled system. The upper: measurement of ground tilt for three days; the lower: calculated earth tide correspondingly.

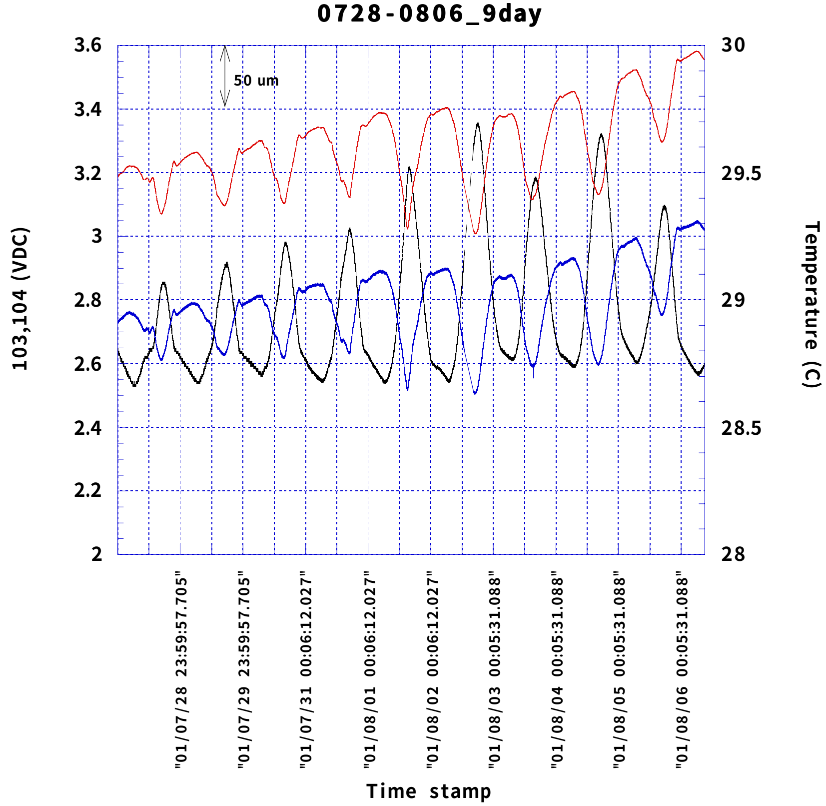




Sensor’s Readings and Temperature (System experiment: stability)

- The system stability of nine days is observed using the 40-m test bench. The left figure: half-filed; the right: full-filled. The half-filled is less influenced by environmental temperature .





Plan of the Water Communicating System

- Overall system (perimeter of the storage ring)
  - Half-filled (50×100 SUS).
  - 16 sensors (in the first stage).
  - Full-filled at the entrances of the tunnel.
  - Corresponding utilities (circulating and re-filling).
- Local system (90 meters)
  - Half-filled (ϕ40 SUS).
  - 9 sensors (each for one girder)
  - Moveable