FROM THE HLS MEASUREMENT FOR GROUND MOVEMENT AT THE SPRING-8

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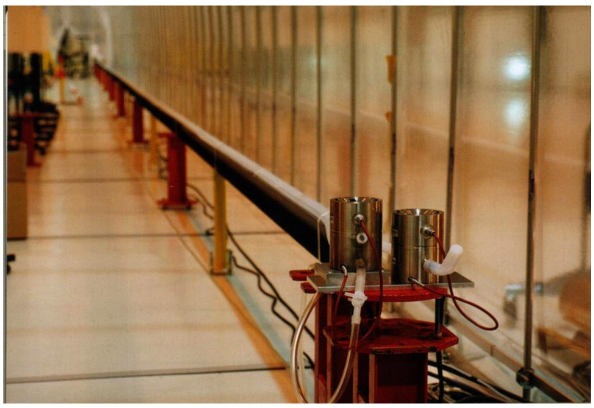
1. INTRODUCTION

The SPring-8 storage ring (SR), with a circumference of about 1.5 kilometers, is constructed on hard rock and partially artificial rock. The variations of the magnet levels are surveyed each year with the precision level Wild N3 or Zeiss DiNi11. These observation data show that some areas in the storage ring tunnel had comparatively subsided. Such areas usually have special underground structures, for instance, RF wave-guide pit, vehicle underpass, junction of constructing zones, and drain pipe.

On the other hand, such atmospheric phenomena as temperature, pressure or rain also cause the movement of the ground. And, the level changes of the tunnel floor in certain areas are several hundred micrometers between summer and winter. The HLS (hydrostatic Leveling system) is studied and two sets of moveable systems are tentatively installed to the tunnel of the storage ring. The purposes of them are to find and monitor the plots of the ground movement or the magnet level variation, and to evaluate the influence of these movements to the beam obit.

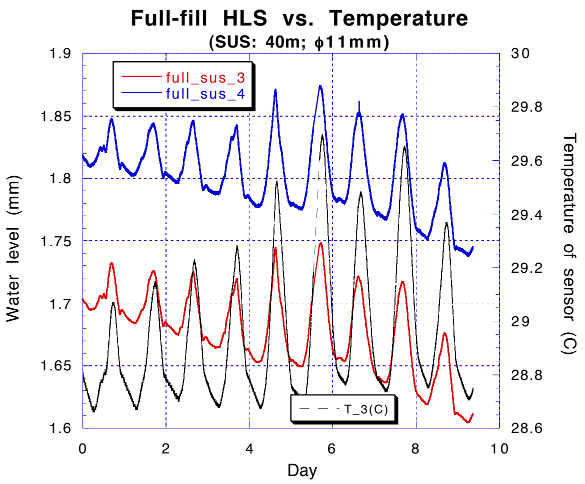
Most of the variations mentioned above are in the order of micrometers or tens of micrometers. Therefore our requirement to the HLS system is sub-microns for the resolution. For this target we had done some studies in the past years. Hereinafter, some experiments on the features of the HLS, especially the temperature response, as well as the measurements with a moveable HLS are illustrated.

2. EXPERIMENTS WITH 40-METER TEST BENCH



In the experiment hall of the storage ring we make a test bench in 40 meters long. On the bench we set up two pipes paralleling with each other. The HLS sensors are at the two ends. With this bench we compared two types of the HLS of full-fill and half-fill systems. And, the communicating pipes of various materials were examined. The sizes of pipes we used are close to their optimum diameter [1].

Figure 1a is the measurement of the HLS with full-filled stainless steel pipe of 11 mm in diameter. It shows the variation of the water level in the sensors and the temperature. The temperature was measured at the bottom of sensor, which can represent the room temperature. In the experiment, with the temperature changes the water level fluctuated for about 0.1 mm/°C. Figure 1b is a system with a full-filled polyethylene pipe. Its response to temperature change was about -0.2 mm/°C. That is, the water level became low when temperature rises. The different response behaviors to temperature for the two could be explained by the different expansion rates between the pipe and water.



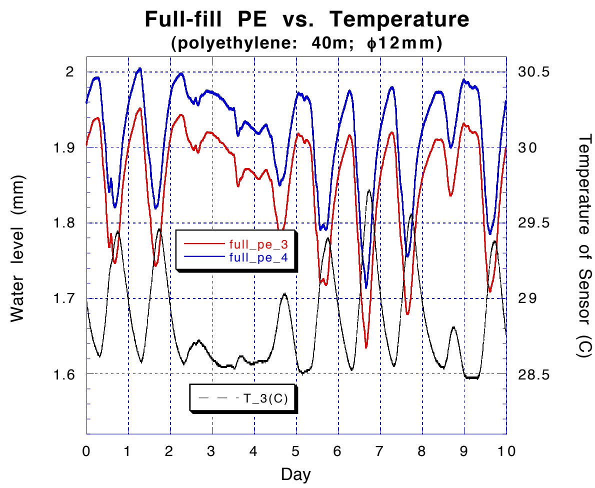


Fig.1a Measurement of HLS with full-filled stainless steel pipe

Fig.1b Measurement with full-filled polyethylene pipe

The volume expansion coefficient of water is the function of temperature and can be obtained from its density curve.

$$\beta = -\frac{1}{\rho}\frac{d\rho}{dT}$$

where ρ is the density of water. At 25°C, β is 2.6×10^{-4}.

The difference of volume variation between water and pipe is direct proportional to the difference of their expansion coefficients

$$\Delta V = (\beta_{water}-\beta_{pipe})\, V_{water}\, \Delta T$$

This variation will make the level of water surface change. For the case of full-fill, it will causes the water level rise by $\Delta h=\Delta V/S_{sensor}$, where, S_{sensor} is the area of water surface inside sensor.

Table 1 Materials used in the experiment

	Expansion coefficient (β)	Diff. of expan. coeff. (Δβ)
Water	$2.6\text{X}10^{-4}$ (at 25° C)	(ref.)
Stainless steel (SUS)	$4.5\text{X}10^{-5}$	$2.1\text{X}10^{-4}$
Polyethylen (PE)	$4.5\text{X}10^{-4}$	$-2.0\text{X}10^{-4}$
Polycarbonate (PC)	$2\ \text{X}10^{-4}$	$0.6\text{X}10^{-4}$

The expansion coefficients for some materials used in the experiments are listed in table 1. For the full filled pipe we have

$$\Delta V = sl\, \Delta\beta\, \Delta T$$

where, s and l are the area of cross section and the length of pipe respectively. The rise of water level is therefore

$$\Delta h = sl\ \Delta\beta\ \Delta T\ /S_{sensor}$$

It is calculated of 0.1 mm/°C for above full-filled stainless case. The water level became higher when temperature rises. That is coincident with the experiment.

For the polyethylene pipe, because of its larger expansion rate than water, it is expected that the water level decrease as the temperature rising, for about -0.1 mm/°C. While in the experiment the variation is two times of this value.

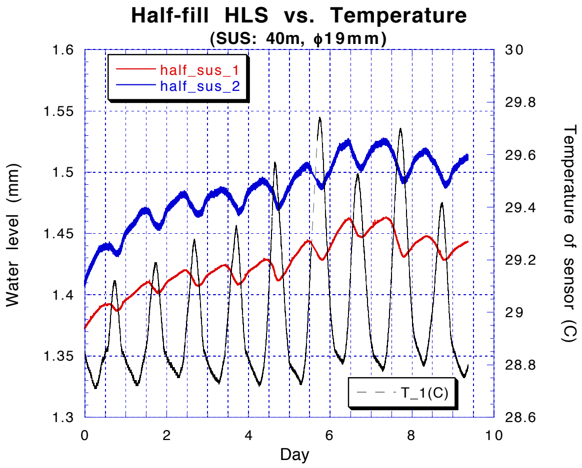


Fig.2a Measurement of the HLS with half-filled stainless pipe

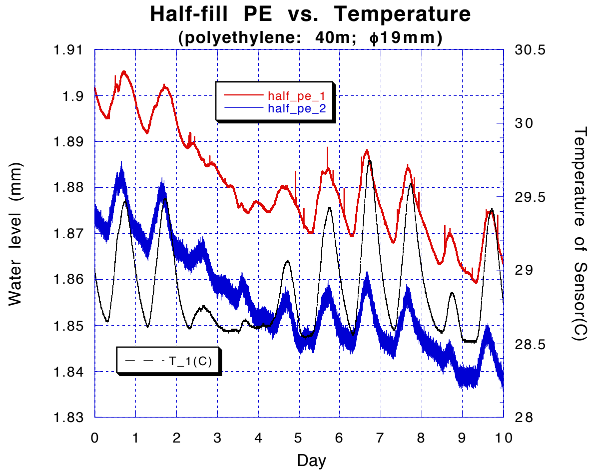


Fig.2b Measurement with half-filled polyethylene pipe

On the other hand, Figure 2 show the measurement of half-filled system. Figure 2a is the HLS with half-filled stainless pipe of 19 mm in diameter. The variation of water level owing to temperature change was a fifth part of the full-filled one, about -0.02 mm/°C. With polyethylene pipe (fig.2b), the system's response to temperature was dramatically reduced comparing to its full-filled case, to about 0.015 mm/°C.

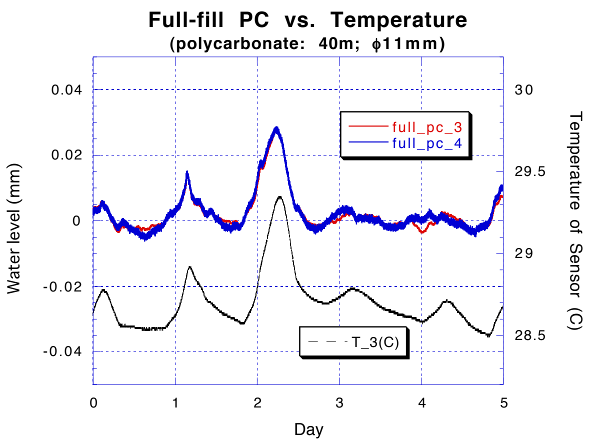
Because the free surface of water is large, the half-filled system is less sensitive to the temperature change. It is considered that the different volume variation between water and pipe causes the water level raised by

$$\Delta h = \Delta V/S_{pipe}$$

where, S_{pipe} is the area of free surface of water in pipe. Accordingly, the water level change is calculated of 1.6×10^{-3} mm/°C for stainless pipe and -1.5×10^{-3} mm/°C for polyethylene pipe. They are usually in quite small amount. While the results in the experiments was much larger. That may possibly be caused by other reasons, for instance, the pipe's supports were moved as the room temperature changes.

As the different expansion of water and pipe causes the variation of HLS measurement, it should exist the materials that are less affected by temperature. We had tested the material of polycarbonate. Figure 3 is the measurement with full-filled polycarbonate pipe. As seen in fig.3a the temperature induced water level fluctuation was about 0.04 mm/°C, much smaller than that of stainless or polyethylene pipe, because the expansion rate of polycarbonate is nearer to water. Unfortunately, the evaporation of water from the pipe is a problem for the polycarbonate. One can see in fig.3b that the water level dropped rapidly for 0.5 mm (about 3 cubic centimeters) in 5 days.

Results of the experiments illustrate that the response of half-filled HLS to the temperature change is basically much small comparing to full-filled one. Any of materials in above table can be used in actual HLS system.



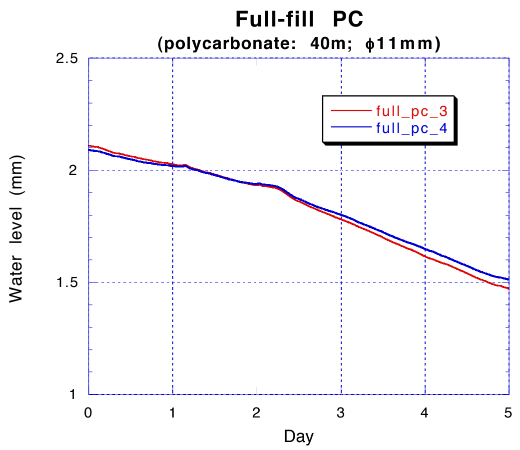


Fig.3 Measurement with full-filled polycarbonate pipe

3. MOVEABLE HLS SYSTEM

A moveable half-filled HLS system is made in the SPring-8. It is composed of many segments of 5-meter communicating pipes, which are connected using flexible tubes. Each segment is made of dual pipes. The inner pipe is filled with the water, with a cross section of 40×40 mm^2, and the outer is support. The FOGALE sensor [2] are used and connected to the pipes with full-filled way. This system can be combined into any length as we wish and moved to any site in the tunnel to measure the ground movement.

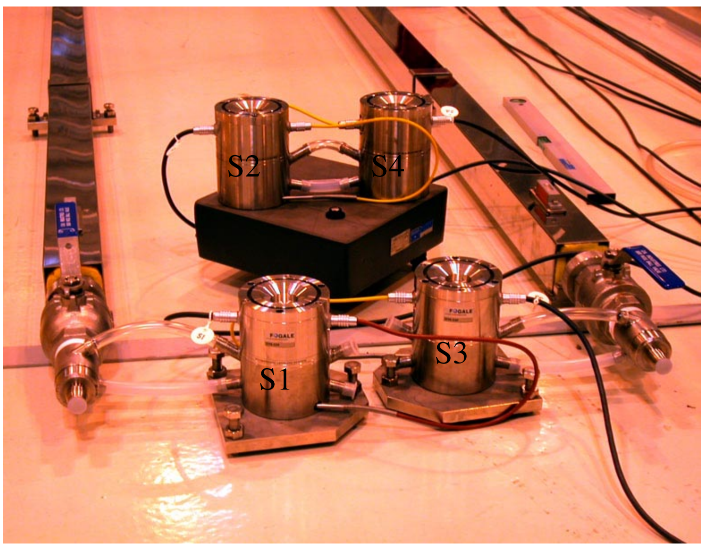


Fig.4 System testing with a fold back pipe

Measurement accuracy of this system was checked at the SR experiment hall by folding back the communicating pipe. As shown in figure 4, two sensors were set in same place. The sensors were not directly connected to each other, but to the two ends of the pipe. For reference measurement, two other sensors were put in same place, with very shot communicating pipes. The measurement result is shown in fig.5. The water level decreased because of

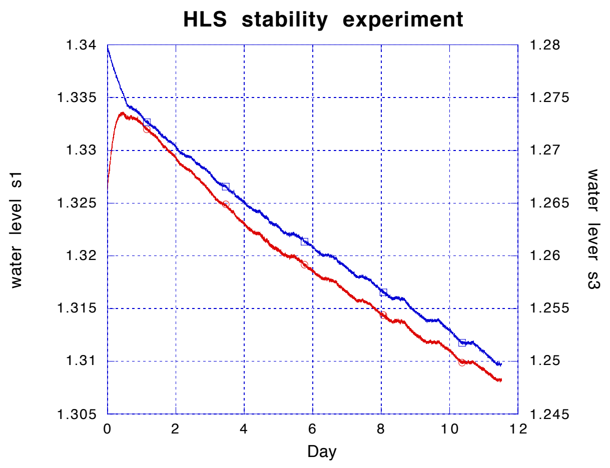


Fig.5 Water level measured with two sensors.

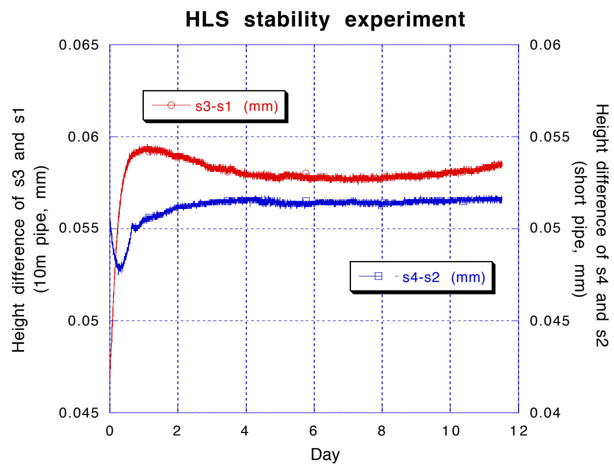


Fig.6 Difference of two sensors' measurement

evaporation. The influence by such phenomena as the drift of sensor, the fluctuation of atmospheric temperature or pressure should be reflected on the measurement with modifications. Taking the difference of the two sensors' measurements, we get the stability of the system for the level measurement, as shown in fig.6. The slow drift for about 1 μm is most likely due to the sensor.

3.1 System Performance and Data Processing

Figure 7 shows the set up of the moveable HLS at the maintenance passage, where shares the same concrete base with the tunnel while temperature fluctuation is over one degree in one day. So, it is a good spot to examine the system. Figure 8 are the floor movements measured with 10-meter HLS for one month and the temperature. The measurement data is a modulation of ground movement, temperature effect, and earth tide etc. Fourier analysis shows that its spectrum (fig.9) appears the peaks of tidal components. We use a tidal program BAYTAP-G (Bayesian Tidal Analysis Program) [3], which is usually used in Japan concerning

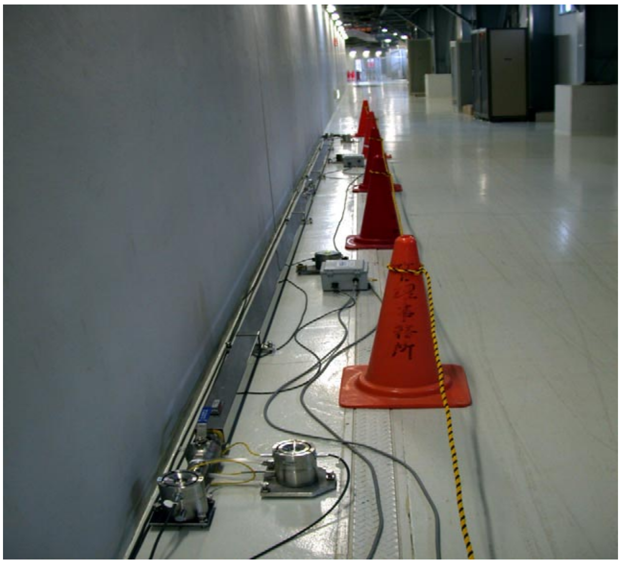


Fig.7 Moveable HLS at maintenance passage

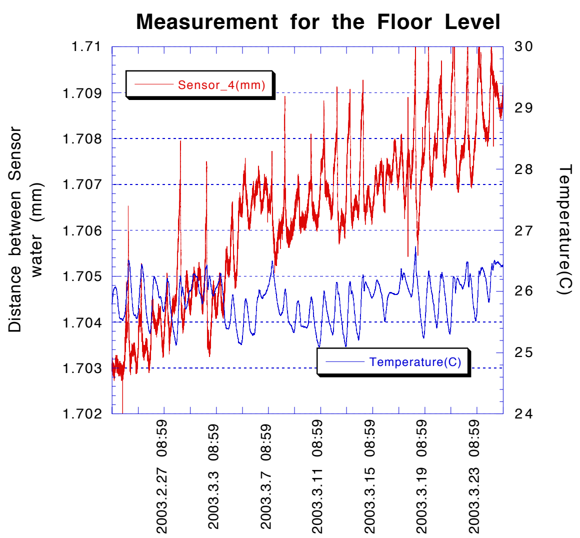


Fig.8 Floor movements of one typical sensor.

the astronomical observation, to analyze the data, and decompose it to four parts of the earth tides, the response to atmospheric temperature, the irregular part and the trend as shown in fig.10. The tidal components are calculated from theoretical value. The response component shows how much the system is affected by the temperature. Here it is 0.6μm/°C, which is less than calculated value of 2 μm/°C. The irregular component is uncertain of the measurement. It shows that the measurement resolution of the system is 0.3 μm for 1σ. The trend component shows the long-term movement of the ground.

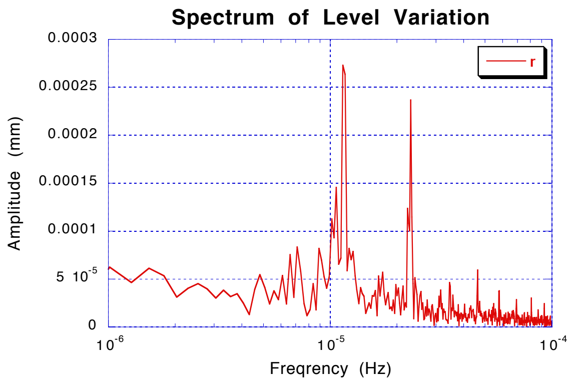


Fig.9 Spectrum of the measurement at maintenance passage

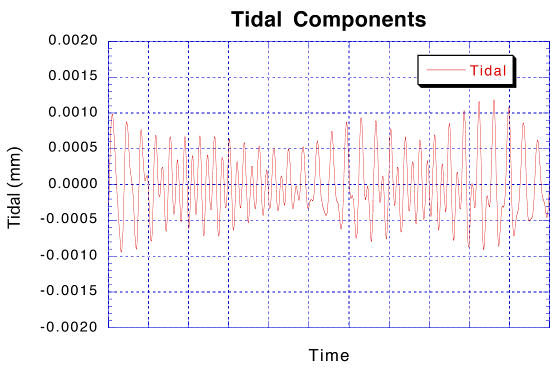


Fig.10a Tidal component in the measurement

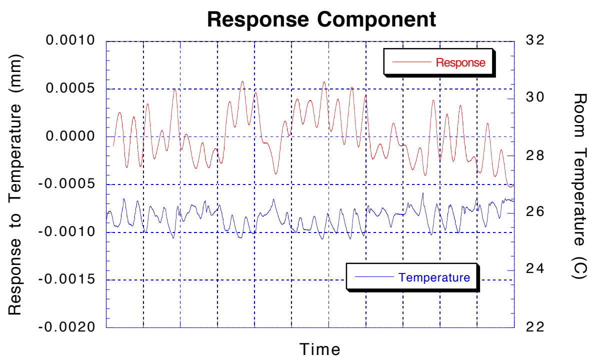


Fig.10b Response of atmospheric temperature

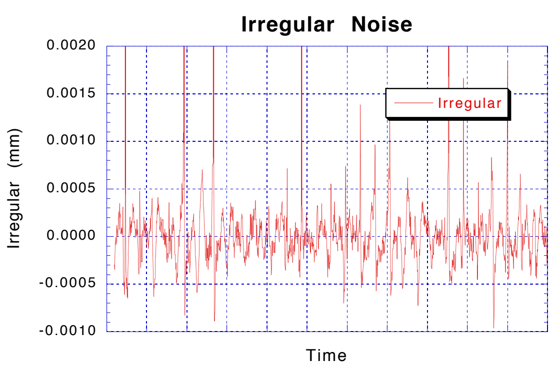


Fig.10c Irregular noise

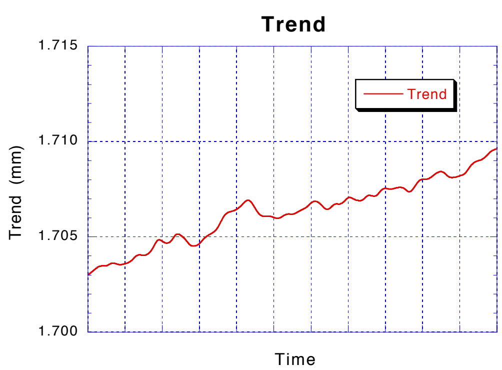


Fig.10d Trend of the ground movement

3.2 Measurement in SR Tunnel

Two sets of the moveable HLS systems have been set up in the SR tunnel. One is on the floor where has vehicle underpass below. Another is at the junction of two constructing zones.

Fig.11 50m Moveable HLS on the underpass

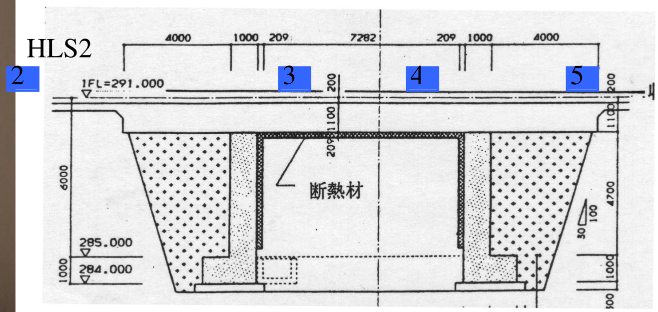


Fig.12 Sensor arrangement

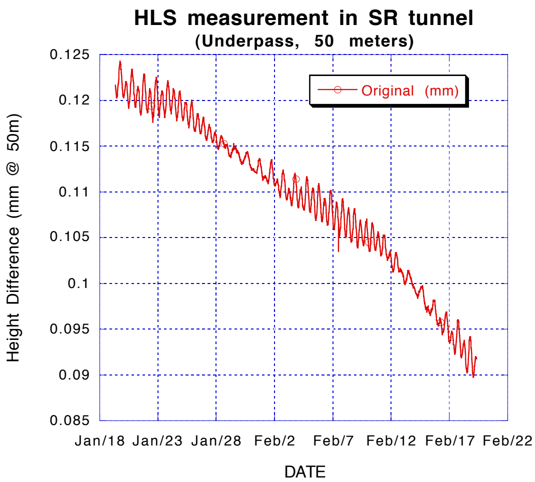


Fig.13 Typical of the measurement for 1 month

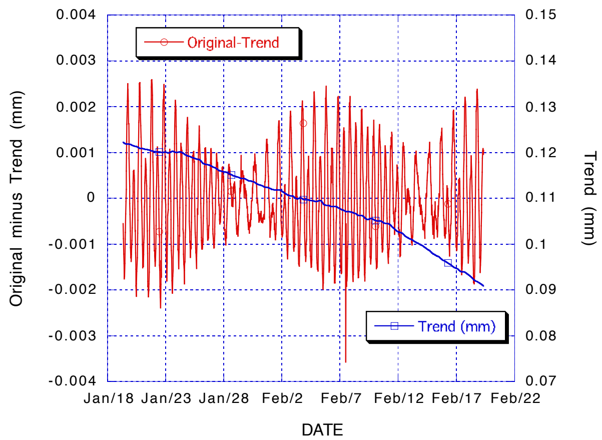
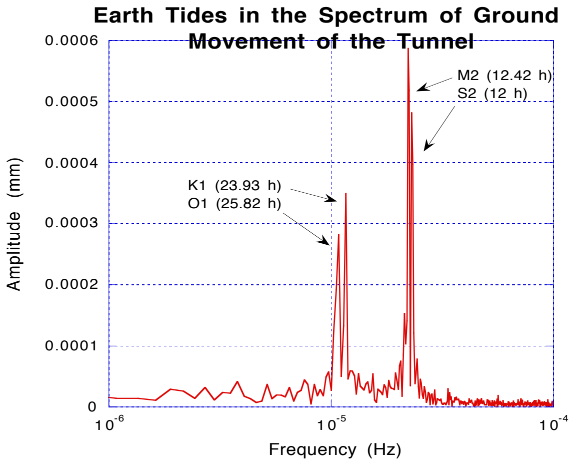


Fig.14 Subtracting trend from the measurement

The system that on the top of the underpass is 50 meter long, with 6 sensors at intervals of 5 or 10 meters (fig.11, 12). Measurement data are collected with VME system and uploaded to SR database via Ethernet. Figure 13 is the typical of the measurement for one month. Subtracting the slow movement of the ground, most part of it isn't other disturbance but the tidal component (fig.14) and many tidal components of diurnal and semidiurnal appear in the spectrums (fig.15). As shown in figure 16, the short period variation of ground is correspondent with that of RF frequency, which is adjusted to compensate the change of SR circumference owing to the tidal effect in machine operation [4]. Long-term ground movement



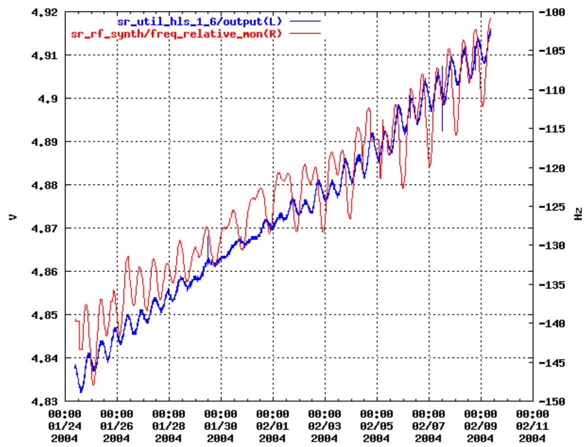
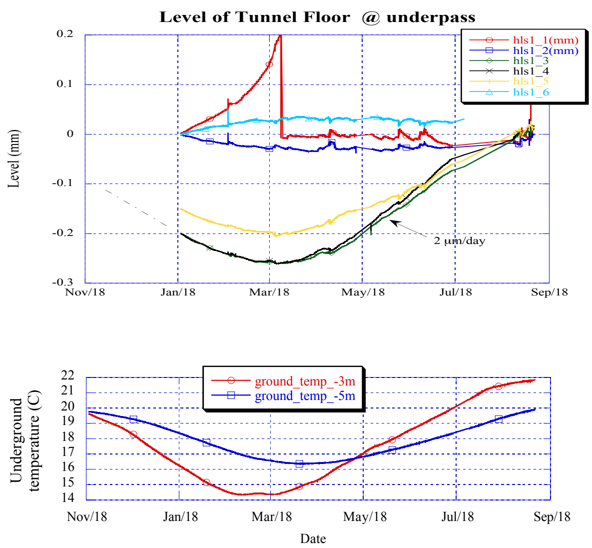


Fig.15 Spectrum of the measurement at SR tunnel

Fig.16 RF frequency and the ground tilt



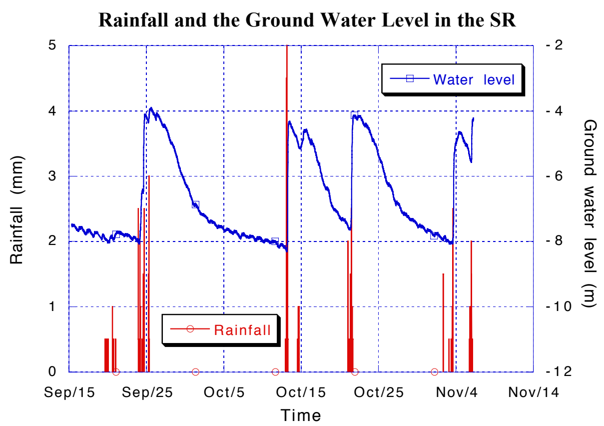


Fig.17 Long-term ground movement in the area of the underpass

Fig.18 Ground water level near the tunnel and the rainfall

in the area of the underpass from January through September is given in figure 17. It is cleared that the tunnel floor has seasonable variation. As the underground temperature change, the level of floor goes down and up for more than 0.25 mm, from the bottom in March to the top in September. The change rate is 2 μm per day for several months.

The ground water level of SR usually rises for 4 meters when it is rains (fig.18). It is also observed with the HLS that the tunnel floors are raised by underground water. Figure 19 shows sudden changes of the tunnel floor in the area of the underpass caused by rainfall. These changes are usually in tens micrometers and make the beam obit drifted in the meantime. Figure 20 shows the drift of the electron beam obit measured by rf beam position monitor, and the correspondent changes of the floor level nearby measured by the HLS.

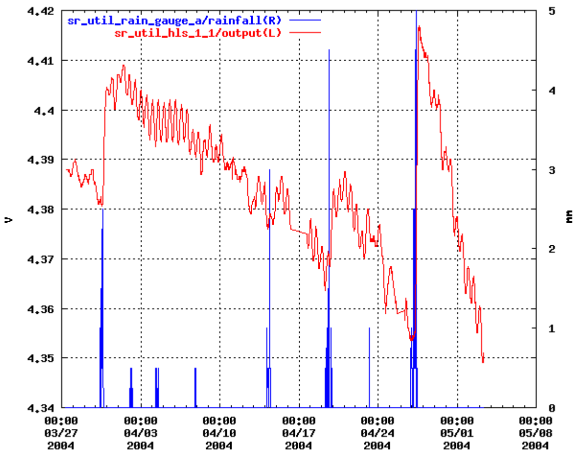


Fig.19 Changes of tunnel floor level caused by rainfall

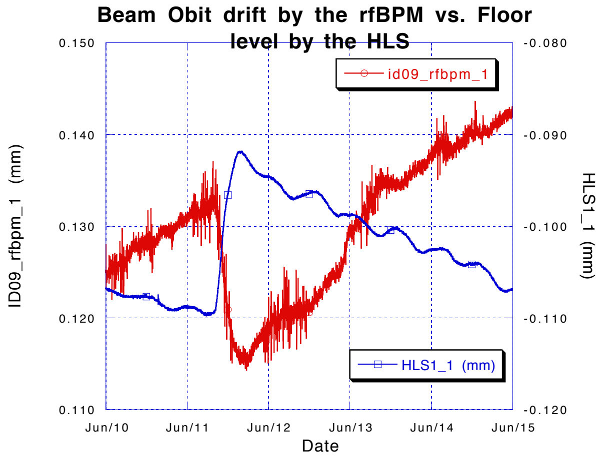


Fig.20 Beam obit with rf BPM vs. the floor level with the HLS

4. CONCLUSION

To understand the characteristics of the two types of HLS systems, a test bench in 40 meters long was made. With this bench we set up two pipes in parallel and compared full- and half-filled systems. In the meantime, the communicating pipes with various materials were examined.

Systems with different communicating pipes are differing in the behavior for their response to the temperature variation. This could be explained by the different volume expansion rate between the pipe and water.

To measure the ground movement in certain areas of the SR tunnel, the moveable HLS system is made. The performance testing shows that its measurement resolution is in sub-micro of 0.3 μm in rms and its response to atmospheric temperature is about 0.6μm/°C.

The moveable HLS are tentatively installed to the tunnel of the storage ring. It is understand that the level of the floor on the underpass has seasonable variation. The ground is also raised or lowered by underground water as it is raining. The drift of the electron beam due to the movement of the ground is observed.

5. REFERENCES

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