DEVELOPMENT OF NEW HLS AND THE RELATED PROBLEMS

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ABSTRACT

The Hydrostatic Leveling System (HLS) are installed and commissioned in many laboratories, in order to attain severe requirements of the vertical alignment on the accelerator components. We have several problems, however, in the application of HLS for an accelerator operation. HLS is not always making up for beam position monitor, for example. We have developed a new type of HLS for the large future accelerator. The important designing points as followings:

1) Best signal quality being free from environmental EM noise,
2) Decreasing the environmental temperature influence,
3) Digital signal transmission system for long distance.

These three points are very important factors to apply the leveling system to large next generation accelerator in order to obtain good temperature stability and being free from the environmental electronic noises. In addition to these three points, we have to take care of the lowest cost for mass-production. Typical resolution of the new HLS is less than 0.05micron-meters and its signal to noise ratio is better than ten times comparing usual HLS in worst case. We worried out many problems, however, in the process of development and a few problems are now open. These problems will be described in detail to give important information for future developers of HLS. The slow ground motion observed by the new HLS for the latest Japanese large earthquakes is also shown.

1. INTRODUCTION

HLS is one of the useful equipments for the pre-alignment or re-alignment of the accelerator components. Almost all of the leveling systems use water to provide an absolute elevation reference for measuring distance between equipotential surface of the water and the surface of the sensor. Some of the liquid, such as mercury and silicon oil, however, are used in another application of the leveling system [1]. Mercury is used to get the easy floating target for the leveling sensor. They are using silicon oil in order to avoid corrosion or fungus and moss gathering in water, though the thermal expansion coefficient of silicon oil is about five times larger than water. Our experience being more than ten years, however, shows that there is no problem for application of water surface to the elevation reference, after using distilled and deionised water for the reference.

Usually, the vessel of the water is made by quartz glass to eliminate the levelling error by the thermal expansion and contraction of the vessel. It gives us mechanically fragile problem, then they make the vessel using stainless steel in the application for the accelerator. The present new sensor's vessel is composed by hydro-carbonate material. This material and water have similar thermal expansion coefficient, that is, we can expect to decrease the incidental error to the environmental temperature. Application of the half filled water level sensing method, instead of the usual full filled type, increases reliability of the observed data [2].

In the geological application of HLS, they use combination of a float and LVDT or eddy current sensor to detect the ground distortion, at least in Japan. These combinations give us, however, severe problem about the temperature dependent error signal and environmental EM noises, if we use them in the accelerator tunnel. Non-contact capacitive sensor or light reflection detector [3, 4] are preferable sensor for the detection of equipotential surface on the application of the accelerator.

2. DESIGN OF NEW HLS

The general requirements for the new HLS are summarized in Table 1. Condensation of the vaporized water on the surface of the capacitive sensor becomes one of the error sources of the measured value. We adopt an integrated heater and its controller to control the temperature of the saturated vapor pressure.

Table 1: Technical Requirement Data

Measuring method	Non-contact capacitive displacement measuring system
Measuring range	± 2 mm
Offset distance	2 mm (between sensor surface and the highest water surface)
Non-linearity	± 5μm
Resolution	± 0.1μm
Target	Distilled and deionised water
Output signal	Digital, CAN bus
Maximum data rate	5 messages/sec
Connector	9 poles D-sub

The principle of the capacitive distance measurement is based on the parallel plate capacitor, as shown in Fig. 1 using a simple equivalent circuit.

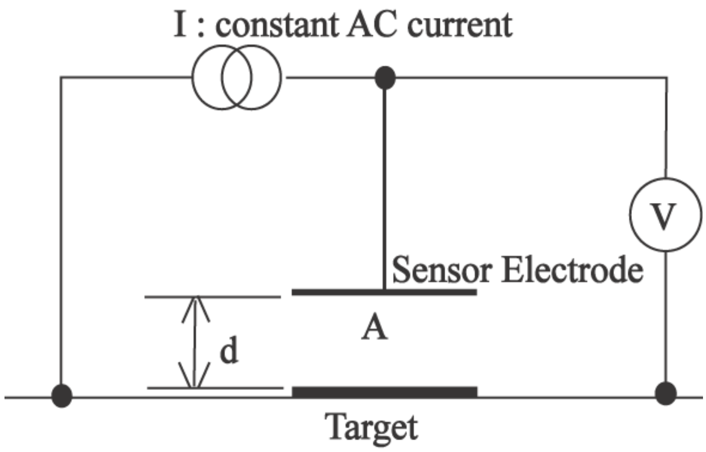

Figure 1: Equivalent circuit description for measurement principle.

Constant AC current I flows through the capacitor, that is the sensor, the amplitude of the AC voltage V at the sensor becomes,

$$V = \frac{Id}{\omega \varepsilon A}$$

where ω is frequency of AC current; ε is dielectric constant of the air; A is the sensor plate area and d the gap. If the electric field were perpendicular to the water surface by cooperative effect of the guard ring being set on the sensor surface, the sensor electrode and the opposite water surface form two ideal electrodes of the capacitor. Carefully considering the above equation, critical error sources for the value of V are tilt of the sensor plate and adsorption of water vapour onto the sensor plate. But in our case with large offset gap, we can ignore the effect of the tilt. The value of ε depends on the partial pressures of the materials between the sensor plate and the water surface. According to L. Essen and K. D. Froome, we can estimate the effect of the partial pressure of the materials. In practice larger changes than this estimation are reported about the adsorption of the vapour on to the sensor [5].

Fig. 2 shows a schematic description of the present new HLS. The surface of the capacitive sensor is protected by anti-vapour absorbing material and the top surface attached by a heating circuit. In order to avoid the change of sensor position by environmental temperature, an invar rod supports the sensor plate.

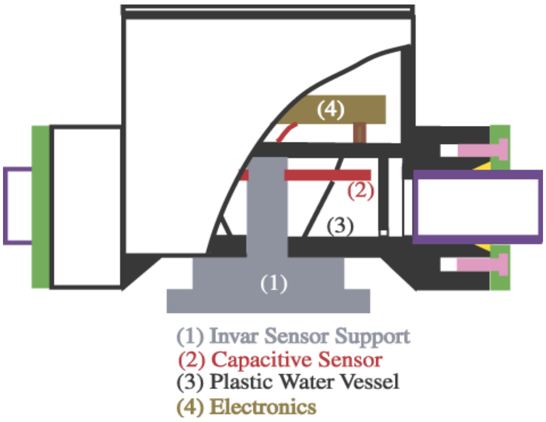

Figure 2-1: Schematic description of the new HLS.

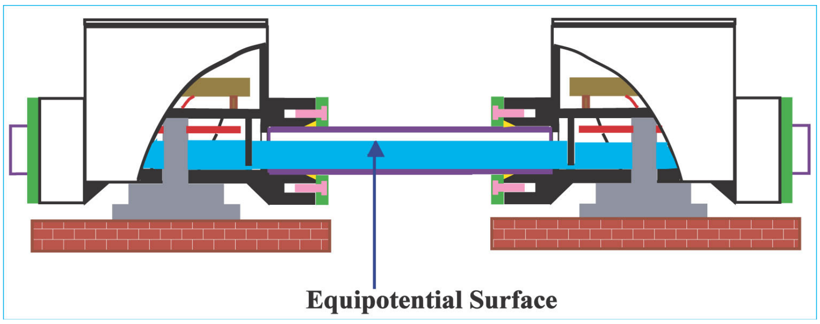

Figure 2-2: Schematically partial cross-sectional drawing for the setup of new HLS.

The water vessel has special inner walls working as a breakwater. The walls of inlet/outlet side of the vessel have small openings and the both sides have trapezoid windows as shown in Fig. 2. This structure of the vessel is very effective to prevent the direct touching of the surges for the sensor plate. Separated upper side of the vessel is equipped by the electronics. The electronics is composed by circuit boards of *V* detection, 24bit A/D converter being MSC1210 of Burr-Brown Products, and the CAN controller with Philips SJA-1000. DC 24 volts power is supplied through 9-pin D-sub connector's reserved pins, the pin No. 9 for +24V and the pin No. 5 for power GND. CAN specification is found in the ISO11898/11519 being originally developed for use in automobiles and now used in industrial field bus systems. CAN is adaptable to the accelerator field because of similarities of requirements, such as low cost, the ability to function in a difficult environment of electrical noises and real time capability.

3. TEST RESULTS

3.1. Fundamental Function Test

The first test of the present HLSs were set up as shown in Fig. 3 and gave us a few problems about the resolution related to the noise and the long-term drift of the data. The resolution as shown in Fig. 4, is considerably worse than the designed one.

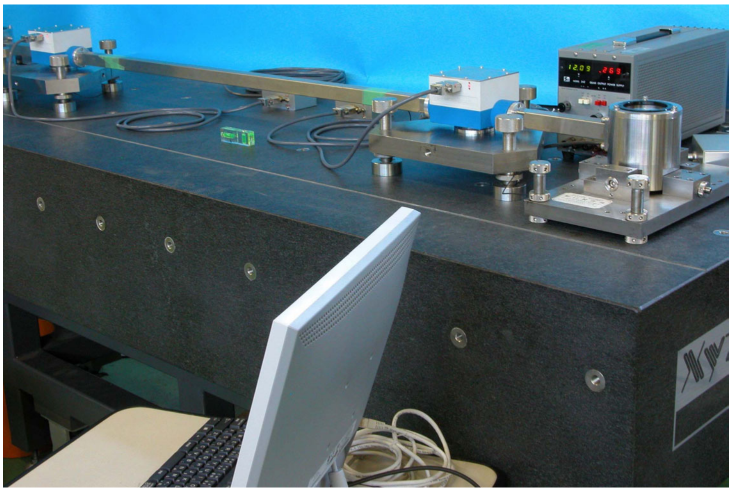

Figure 3: Experimental setup of HLS. Both sides are attached water level monitors with water level changer. We set up HLS's 1.2 meters apart.

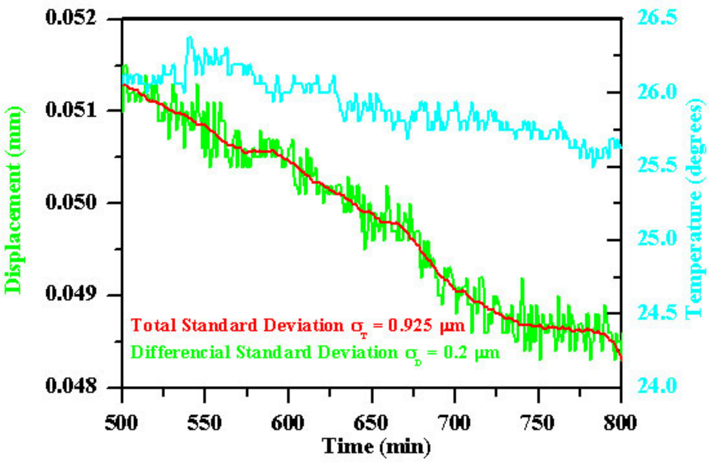

Figure 4: Resolution obtained by the first experiment.

An improvement on the V detection circuit gives better resolution than the designed one, as $0.05\mu m$ or more. The second problem was more serious. This problem has been cleared by reproduction of the sensor plate with careful coating method for anti-diffusing water vapour.

3.1.1 Noise issues

We have experiences of degradation of SN ratio for usual analogue signal transmitting method as an example shown in Fig. 5, though the signal was transferred using shielded twisted pair lines. In this case, the HLS was set in the high EM noisy place and the root mean square [rms] noise width becomes $0.18\mu m$.

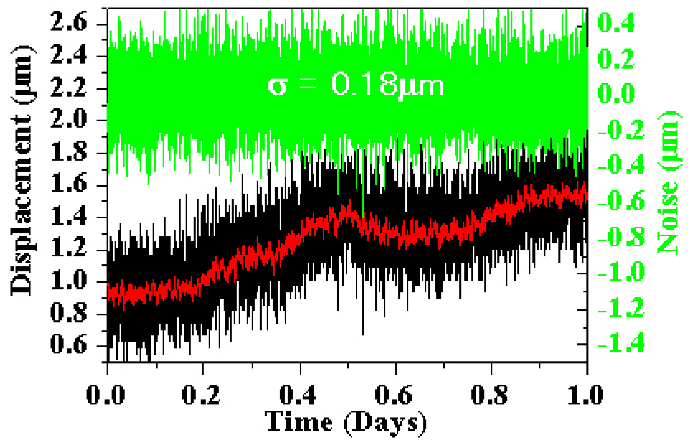

Figure 5: The signals observed in the EM noisy place; cable length is 50m and HLS made by FOGALE.

We have also checked the SN ratio in the quiet place of EM noise using the same experimental set-up. The observed rms noise width becomes $0.02\mu m$ as shown in Fig. 6. The rms noise for this case shown in Fig. 6 gives a contrasting result with that of Fig. 5, though the cable length was longer than the above bad case. These two results indicate clearly that wide range voltage analogue signal transmission is severely interfered with the external EM noise along the transmission line, even if the twisted pair lines are applied.

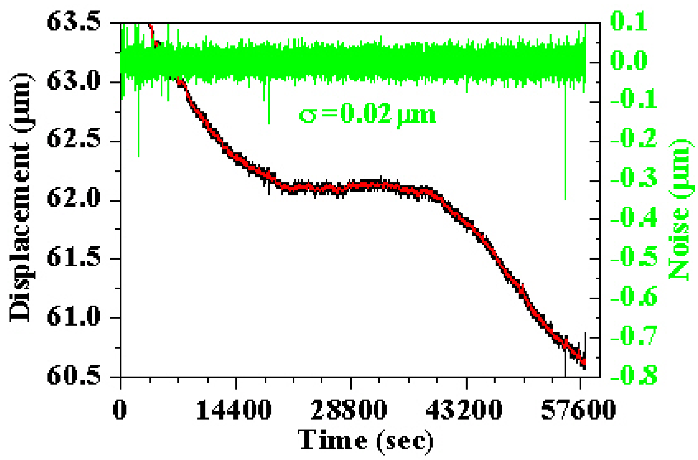

Figure 6: Observation in the quiet place; cable length is 100m and HLS made by FOGALE.

3.1.2 Digitisation Effect for Noise Figure

On the present HLS, the analogue signal from the capacitive sensor is digitised using ADC and converted to serial CAN signals at the very near place of the sensor to obtain the best SN ratio. In this situation, we have to take care in setting the electronic parts on the circuit board in order to avoid the digitising noises. At first test of the HLS, we found a slightly high noisy result as shown in Fig. 4, comparing the designed resolution. As mentioned above, the source of the noise was depending on the *V* detection circuit and a little change of the circuit gave large reduction of the noise as shown in Fig. 7.

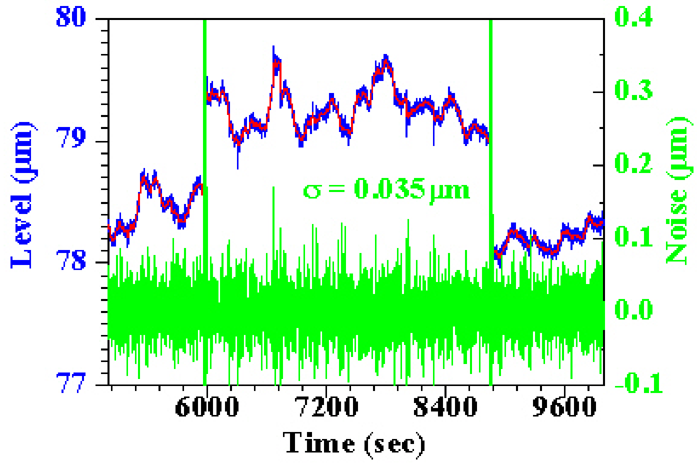

Figure 7: The signal observed in the EM noisy place; C-band klystron and its modulator are operated at the very near place: Cable length is 60m and HLS made by Micro-Epsilon.

Fig. 7 shows one of the measuring results of the new HLS. In spite of the high EM noise environment being incidental to the operation of C-band klystron and its modulator near the test station of HLS, the obtained rms noise width is very small as $0.035\mu m$ being shown in Fig. 7. This figure includes also about $1\mu m$ step change by adding 0.1 cc drops of water and extracting the same volume of the water. Fig. 7 shows some waving signals instead of a straight line, though the amplitude is small. These phenomena may correspond to the ground motion noise in KEK site. Although we have much information of the ground motion in KEK site and this site shows very large *ATL* value [6], this waving slow ground motion is new information. We are going to study this ground motion in detail using the present HLS.

3.2. Earthquake Observation

In the long-term testing of the present HLS, we could observe large earthquakes in the distance and the behaviour before and after the earthquakes shows very significant phenomena, then the result will be shown in detail. The earthquake has occurred at midnight on September 5th 2004 and in the morning, 7th [7, 8]. Fig. 8 shows the hypocenter of the earthquake being in the Philippine-Sea Plate using a map of the main island of Japan. The distance from the seismic center to KEK is about 380km. Fig. 9 shows waveforms of the three large earthquakes in about three days including the information of magnitude, date-time and locations. Fig. 11 shows the second largest earthquake expanding the time scale in order to clear the observed waveform in detail. Using this figure, we can find out that the period of the large amplitudes is about 12.5sec.

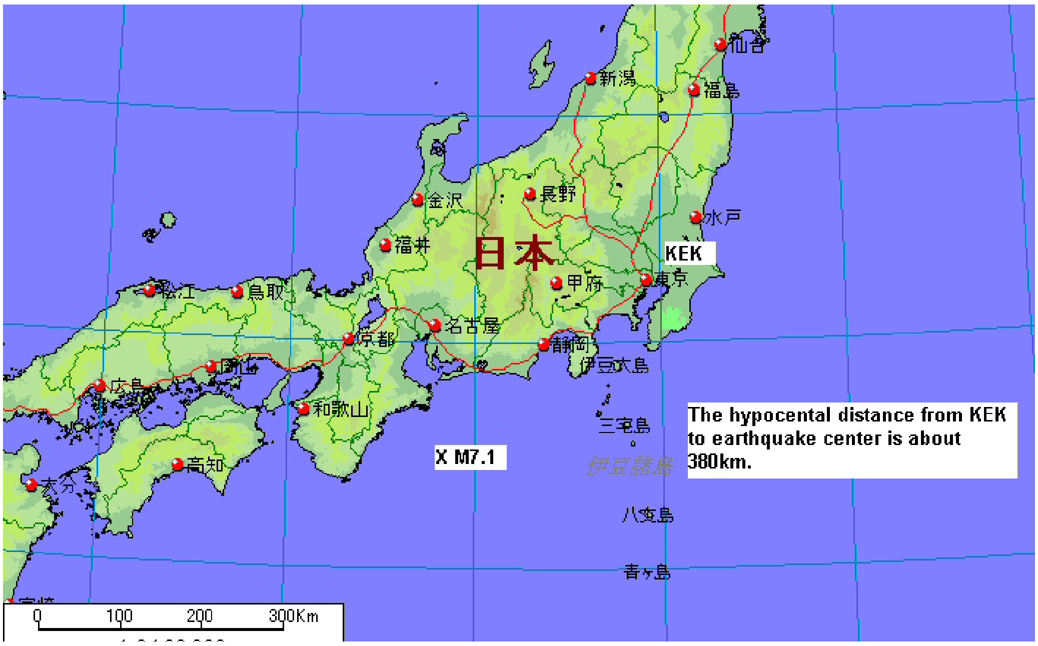

Figure 8: The earthquake center [X] and KEK observation point for the latest large earthquake.

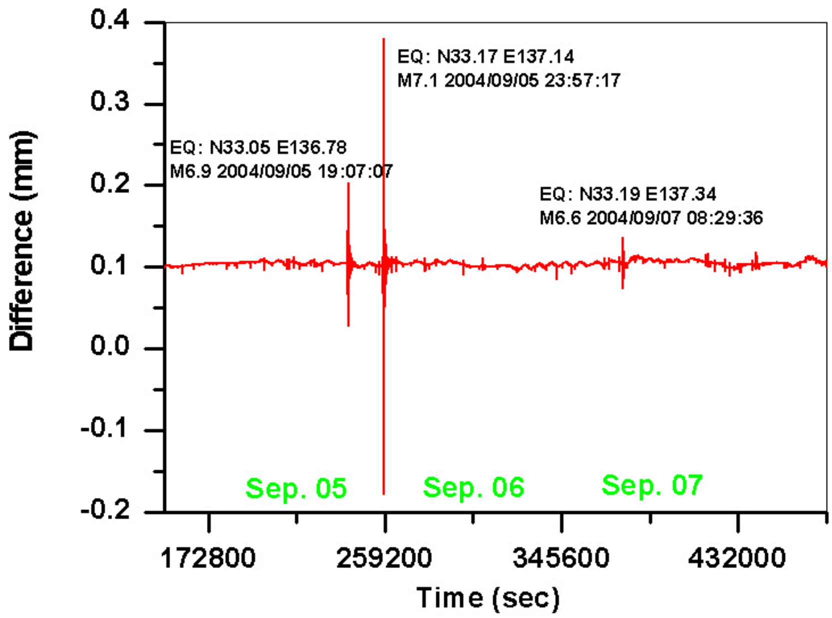

Figure 9: Recent big earthquakes observed in KEK using the new HLS.

Surveying carefully Fig. 9 and Fig. 10, we can find very slow ground motion, its period is about 1.5 hours, has been continued during at least 8 hours before the severe shock. This phenomenon for the large earthquake may give us new and important information in the region of prediction of earthquake. In other words, we had better to introduce new broadband observation system for predicting large earthquake instead of the present narrow band and event driven pre-trigger methods such as taking the data after the earthquake had been there. The present HLS may become one of the compact and convenient tools on the region of predicting large earthquake.

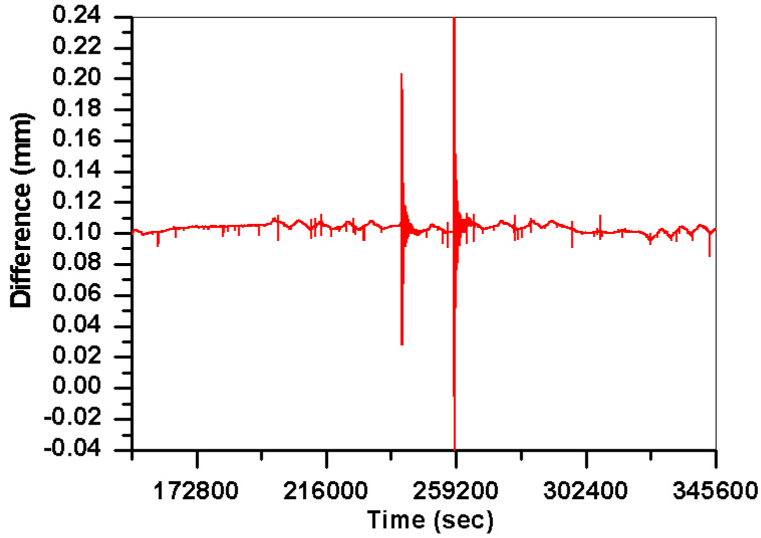

Figure 10: Partially expanded graph of Fig. 9 to show clearly details of the slow ground motion.

HLS or so-called water tube tilt-meters have been applied, for a long time, to geology and geodesy in order to detect very slow ground motion or drift. However they were introduced low-pass filters having the time constants being about 1min. to 30min. in order to remove fast ground motion noises and electronic noises. Then they cannot observe the signal of the earthquake since the signal is attenuated and filtered out the fast component of the signal, even if they give a sign of the earthquake. An organic combination of the present HLS and the broadband seismometer will give us new development on the prediction of large earthquakes.

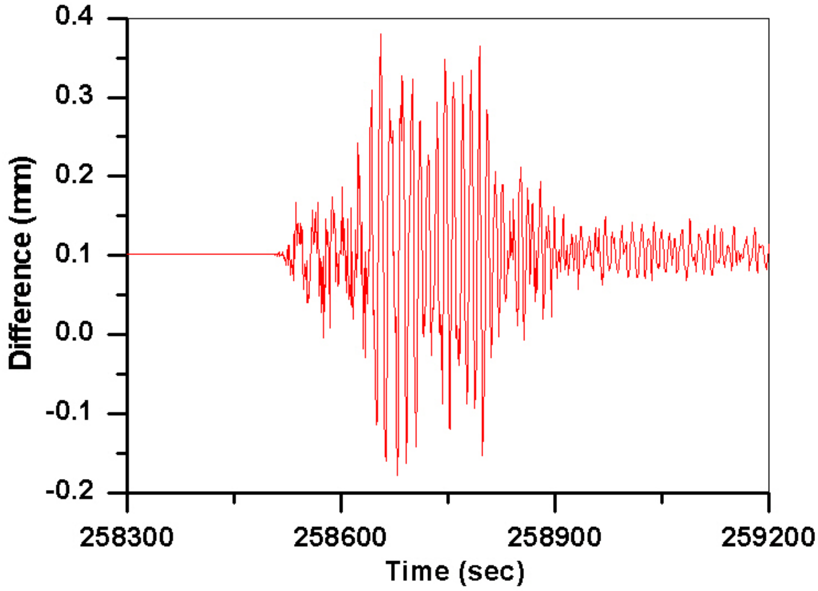

Figure 11: Detailed earthquake waveform observed in KEK. This figure corresponds to the 2nd earthquake of the Fig. 9 expanded in the time scale.

In the accelerator alignment, we have to take care to those insensible but large amplitude ground motion extended over a long period of time, since they may become one of the sources of large alignment error.

4. SUMMARY

We have designed and produced the new HLS as the following concepts to obtain the low temperature drift and low noise system:

- Introduction of the half filled water level sensor instead of the usual full filled level sensor.
- Introduction of the capacitive sensor being supported by an invar rod to decrease the environmental temperature influence.
- Integration of the related circuit board into the very near place for the capacitive sensor.

Typical resolution of the New HLS is less than 0.05 micron-meters. Better resolution will be possible after the improvement for EM noise shielding around the vessel. The present new HLS has not satisfied our requirements on the offset distance (1.4mm instead of 2mm) and the measuring range (± 1 mm instead of ± 2 mm). These requirements will be satisfied in the next version.

Accidental observation of the large distant earthquake, using our HLS, gave us very important information for the prediction of large earthquake.

Our next progress is to be clear the waving ground motion as shown in Fig. 7 and to check the temperature dependence of the HLS doing long term observations.

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References

[1] T. Tsubokawa, private communication, NAO (1999).

[2] S. Takeda et al. “Slow Ground Motion and Alignment System”, Proc. EPAC94, London, June 3 (1994) pp. 2564-2566.

[3] M. Taino, private communication, KEK (1995)

[4] L. A. Kivioja et al. IWAA (1997) ”A New Hydrostatic Levelling System Developed for the Advanced Photon Source” IWAA’97, Argonne, Oct. 1997.

[5] L. Essen and K. D. Froome “The refractive indices and dielectric constants of air and its principle constituents at 24,000 Mc/s” Proc. Phys. Soc., LXIV, 10B 1951: “The Nano-Positioning Book”, Queensgate Instr. Ltd., 1997.

[6] S. Takeda et al. “Ground Motion Studies for Large Future Linear Colliders”, Proc. PAC97 May 12-16(1997), Vancourver.

[7] http://www.hinet.bosai.go.jp/.

[8] http://quake.wr.usgs.gov/.