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# LONG TERM STABILITY STUDY AT FNAL AND SLAC USING BINP DEVELOPED HYDROSTATIC LEVEL SYSTEM*

A. Seryi, R. Ruland   SLAC, Stanford, CA, USA
V. Shiltsev, J. Lach, D. Plant   FNAL, Batavia, IL, USA
A. Chupyra, A. Erokhin, M. Kondaurov, A. Medvedko,
V. Parkhomchuk, E. Shubin, S. Singatulin   BINP, Novosibirsk, Russia
A. Kuznetsov   Novosibirsk State University, Russia

*Abstract*

Long term ground stability is essential for achieving the performance goals of the Next Linear Collider. To characterize ground motion on relevant time scales, measurements have been performed at three geologically different locations using a hydrostatic level system developed specifically for these studies. Comparative results from the different sites are presented in this paper.

## INTRODUCTION

Small emittances and nanometer size beams of the Next Linear Collider set tight requirements on alignment and motion of its components. While fast motion affects beam separation in the interaction point, slow ground motion may cause beam emittance growth, as its short wavelength components result in accumulated misalignments and deviation of the beam trajectory from a smooth line.

This article summarizes two-years studies performed in collaboration of BINP, FNAL and SLAC to investigate slow ground motion in three different geological conditions: in the shallow Main Injector tunnel in glacial till (Fig. 1), in the deep Aurora mine in dolomite, and in shallow SLAC linac tunnel in sandstone.

For these studies, BINP has developed a special Hydrostatic Level Measuring System (HLM System). The HLM System is based on principle of communicating vessels and capacitive measurements of the water level. Each sensor is equipped with a temperature sensor. The capacitance - to - frequency converter has specially clocked calibration procedure that allows avoiding influence of many factors on measurements accuracy. As a result, the accuracy of sensors is better than a micron and resolution is better than 0.1 micron with 5 mm dynamic range. The SAS-1 sensor model has separate pipes for connecting the water and air tubes. The SAS-2 sensor model (used for these studies) is built to use in a system with "half-filled" single tubes. A principle advantage of a single tube system (with continuous free water surface) is that the relative water level does not depend on temperature variations, as it is defined only by gravity, in contrast to a double tube system, where temperature difference cause change of water density and change of water height in the sensors. The sensors have digital output via the standard RS-485 interface. A special atmospheric air pressure monitor is an integral part of the system. A test device (TD), to programmably vary the water level (e.g. for tests of water dynamics or tests of calibration), is a part of HLM System as well.

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## RESULTS OF STUDIES

The slow motion most worrisome for a linear collider is believed to be the diffusive ATL motion, because of its short "wavelength" character. The variance of the relative misalignment for ATL is proportional to elapsed time and spatial separation $\Delta X^2 = A \cdot T \cdot L$. The coefficient $A$ depends strongly on geology, and its clarification, for the chosen geologies, was one of the main goals of the study.

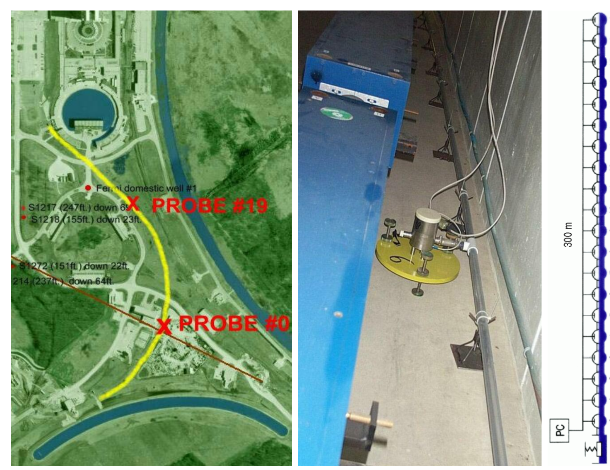


Figure 1: FNAL areal photo with marked locations of the first and the last SAS sensor and location of the water well – cause of the "2-hours puzzle"; photo of HLM system installed in MI8 tunnel; system layout.

For study at FNAL Main Injector tunnel, 20 SAS-2 sensors were installed over 300 m distance in the MI8 transfer line. The very first measurements immediately gave a surprise dubbed "2-hours puzzle" – the motion looks quasi-periodic with amplitude of about 10 $\mu m$ near one end of the system, smoothly vanishing to the other end of the system. The period was not constant, but slowly varied by about 30% (see Fig.2 where one can also see a spike due to earthquake in Alaska, which caused quench of the Tevatron and was also detected by a seismometer at Northern Illinois University). Sudden disappearance of the motion on January 3, 2002, for about one day, hinted to the man-made character of the phenomenon. After extensive search, in August 2002, Duane Plant found the cause – domestic water well located 219 ft deep and several hundred feet away which slowly and periodically change ground water level

Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309
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and pressure and caused ground to move, see Fig.3. (We appreciate suggestion by Rainer Pitthan who proposed that a sump pump may be a cause – a very close hit).

The "2-hours puzzle" is probably the first observation of cultural ground motion on such a low frequency scale. (Traditionally, cultural noise is man-made vibrations above 1Hz). Such cultural slow motion is worrisome, because it has poor spatial correlation. This underlines importance of more careful attention to shallow tunnels in sedimentary or glacial geology in populated areas.

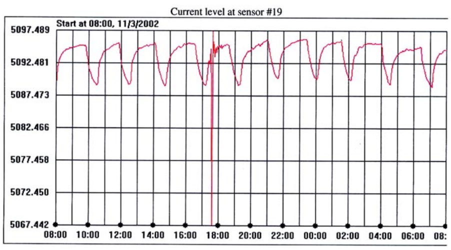


Figure 2: Level at sensor 19 in MI8. The periodic motion is due to 2-hours puzzle. The spike is earthquake in Alaska.

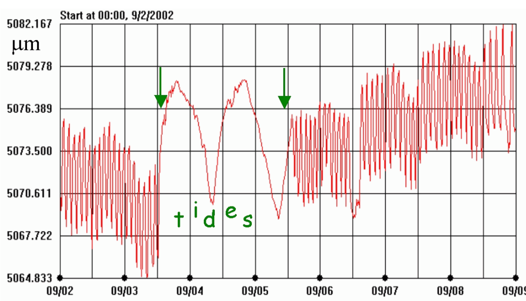


Figure 3: The "2-hours puzzle" is switched off and on.

As the "2-hours puzzle" could not be turned off for sufficiently long time, analysis of natural ground motion was hampered. The sufficiently long puzzle-free data came only from the month of February 2003. Diffusion coefficient $A$, calculated for this month, is shown in Fig.4 (calculated using three sensors, to remove the irrelevant common change of ground tilt). One can see that the envelope of $A$ corresponds to previously found values (from the PW on surface tunnel [1]) and roughly constant with $\Delta L$ from 15 m to 90 m. The mean value of $A$ however appears to decrease with $L$, as if it shows not $\Delta X^2 \propto L$ but rather $\Delta X^2 \propto 1$ behavior. To find if it is a reality, one would need more 2 hrs puzzle-free data and also better understanding of the effects of viscous damping in the HLM System pipes (see further discussion below).

For further study of slow ground motion in Aurora mine, the existing HLM System [1] was augmented with four new BINP sensors on May 2002 (see Fig.5). Though with less statistics (both in time and space), the SAS sensors appear to show about twice smaller diffusion: about $(6 \pm 3) \cdot 10^{-7}$ $\mu$m$^2$/(m·s) is observed with Fogale-based system and about $3 \cdot 10^{-7}$ $\mu$m$^2$/(m·s) is observed with new SAS sensors. This underlines the importance of low electronic drift in a measuring system – well known headache of instrumentation developers.

Hydro-dynamics of water motion in long half filled tubes

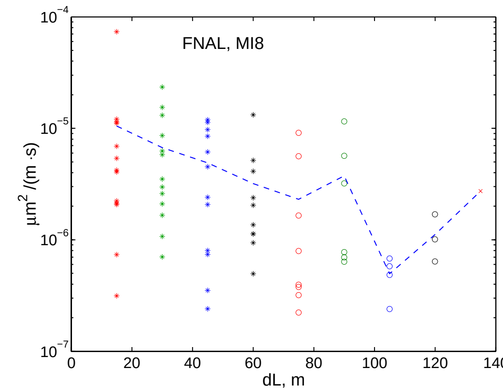


Figure 4: Diffusion found on three sensors for 2 hrs motion-free data from the MI8 tunnel.

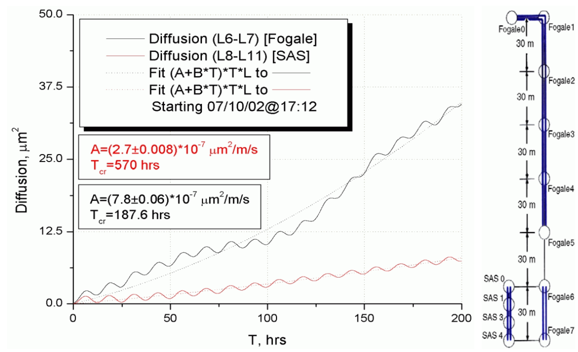


Figure 5: Example of diffusion found in Aurora mine with Fogale and new SAS sensors, and location of sensors.

plays important role in measurements with HLM System and should be taken into consideration. Neglecting, for a moment, viscosity, the phase velocity of propagation of long gravity waves in half-filled round pipes is $V = (\pi g R/4)^{1/2}$, see [4]. For our case of 1" pipes, it is $V \approx 0.3$ m/s and for a periodic 15 minutes motion excited by a test device, a $0.4\pi$ phase shift would be observed after 50 m, corresponding well with observation, see Fig. 6.

Note that these long gravity waves in tubes have no dispersion. However, if viscous damping is taken into account, dispersion appears. The viscous damping affects dynamics strongly: the damping coefficient is $\gamma = 1/R\,(\nu\omega/2)^{1/2}$ (for water $\nu \approx 0.01$ cm$^2$/s ) [4]. For example, for 15 min period, we have $\gamma/\omega \approx 0.7$, i.e. the motion is strongly damped! We do not have an exact solution for

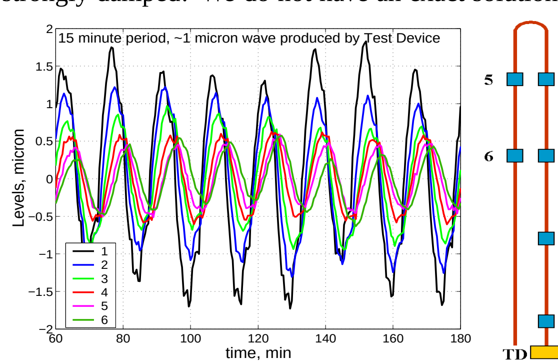


Figure 6: One micron wave excited by test device in 2x30m HLM System at Sector 10 lab in SLAC linac tunnel.

water dynamics in large damping case, but it appears that in many cases the motion would exhibit aperiodic damped flow, as observed in Fig. 7, where equilibrium is reached several hours after a TD step change, in a 300 m system.

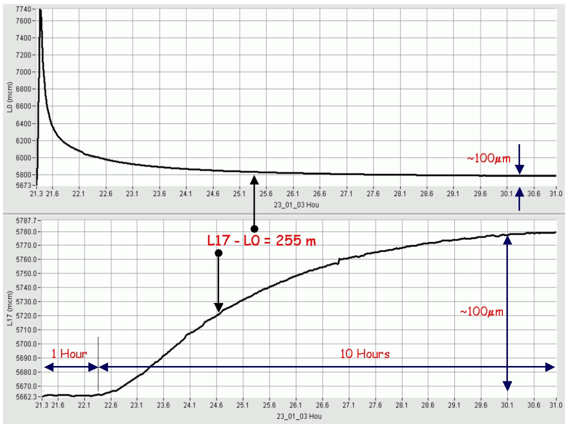


Figure 7: Reaction of sensors #0 and #17 to a level step change by a test device in MI8 HLM System.

It is very important to stress, that though the viscous water dynamics may affect measurements by HLM System of the long wavelength ground motion, measurement of the important (for linear collider) ground motion with wavelength of tens of meters is still accurate, as it involves only one sensor and water redistributes only near this sensor. Tests performed with MI8 system have shown that if one sensor is displaced, it reacts within about one minute. For this reason, application of HLM system for ground motion study, and for machine alignment, is appropriate.

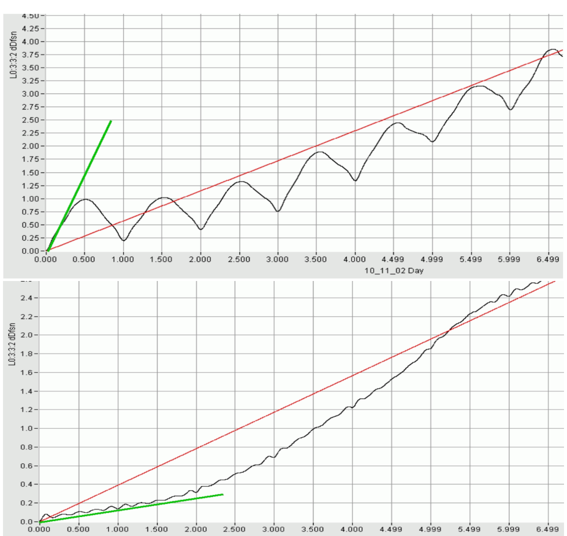

Figure 8: Diffusion found on three sensors without (top) and with (bottom) filtering out the components with period equals one day. Sector 10 HLM System.

The 2x30 m HLM System in Sector 10 alignment lab in SLAC linac tunnel is configured in such a way, that two pairs of sensors are located together, for cross check of their stability, see sensor location in Fig. 6. It is also planned to later install hydrostatic sensors of alternative design, and also install a stretched-wire system, for triple cross-check. The two sensors located close together follow each other with about 3 $\mu$m for 4 month (within $\sim 1$ $\mu$m if one compensates for temperature correlation). The rms of difference of this two sensors was found to be about 55 nm (for time difference less that one day), corresponding to resolution of about 40 nm.

Details of installations of water tubes were found to be very important and may allow for further improvements. At MI8 the tubes are installed loosely. Variation of temperature do not cause transverse variation of tube position, and so there is no observed significant correlation of temperature and mean level at FNAL MI8 HLM System. However, studying motion with Sector 10 HLM System, we found unexpectedly large correlation of the mean water level with mean temperature – about 33 $\mu$m/°C. We explain this by the fact that, at Sector 10, tubes are rigidly fixed to the floor, and so the variation of temperature may cause large transverse deflection of tubes (as $\Delta h \approx \ell(\alpha \Delta T)^{1/2}$), and as a result, large correlation of temperature and mean level. And though we use relative levels (w.r.to the mean) for ground motion analysis, this temperature sensitivity may be suppressed mostly but not entirely.

The mentioned temperature sensitivity is clearly seen as daily variation in diffusion analysis plots form Sector 10 HLM, see Fig. 8, where apparently the motion of the tubes, and not ground, artificially dominates the picture (see Fig 8, top, where the red fit line corresponds to $3.3 \cdot 10^{-7}$ $\mu$m$^2$/(m·s)). Fourier suppression of daily harmonic, produces, we believe, more accurate estimation of about $2.3 \cdot 10^{-7}$ for the red line fit and about $0.7 \cdot 10^{-7}$ for the small time part (see Fig 8, bottom plot).

As a summary, the diffusion coefficients $A$ (in units of $10^{-7}$ $\mu$m$^2$/(m·s)) are: (10-100) for MI8 shallow tunnel in glacial till (in absence of dominating cultural motion); about 3 or below in deep Aurora mine in dolomite and in Sector 10 shallow tunnel in sandstone (irrelevant motion of the tube may still be a large contribution in the Sector 10 $A$ value). Previous studies for FNAL surface and at SLAC tunnel are confirmed, and new measurements in Aurora mine are about factor of two below the previously found values.

## CONCLUSION

The study performed have confirmed the strong dependence of slow ground motion on geological conditions – a competent geology is beneficial for NLC.

Hydrostatic Level Measuring System, as a slow ground motion and alignment monitoring tool, has been studied and several important factors affecting its performance have been found and investigated.

## REFERENCES

[1] V. Shiltsev, et al., in Proc. of PAC2001.
[2] A. Seryi, et al., in Proc. of PAC2001.
[3] V. Shiltsev, FERMILAB-FN-0717, March 2002.
[4] L. Landau, E. Lifshitz, Fluid Mechanics, 1959.