RECENT GROUND MOTION STUDIES AT FERMILAB*

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Abstract

Understanding slow and fast ground motion is important for the successful operation and design for present and future colliders. Since 2000 there have been several studies of ground motion at Fermilab. Several different types of HLS (hydro static level sensors) have been used to study slow ground motion (less than 1 hertz) seismometers have been used for fast (greater than 1 hertz) motions. Data have been taken at the surface and at locations 100 meters below the surface. Data of recent slow ground motion measurements with HLSs, many years of alignment data and results of the ATL-analysis are presented and discussed.

FERMILAB'S HLS SYSTEMS

Over the past several years Fermilab in collaboration with Budker INP (Novosibirsk, Russia) has developed [1] and installed a number of HLS systems on- and out-of the Fermilab site: a) 18 Budker sensors on the Tevatron low beta quads at B0 and D0 interaction regions; b) 204 Tevatron style sensors one on each Tevatron quadrupole, 29.6 meters apart; c) 5 Budker sensors in the LaFarge mine North Aurora Illinois (30 m apart); d) 7 Budker sensors in the near MINOS hall Fermilab (30 m apart); e) 11 Tevatron style sensors on floor in NMS hall photo injector test(6 meters apart); f) 6 sensors of various types for comparative stability test at the MP-8 line at Fermilab; g) 12 Tevatron style sensors 200 ft level Homestake Gold mine Lead (South Dakota) 60 meters apart; h) 12 PoE and 3 Capacitive "hot" spares at MP-8; i) 9 Legacy Fogale sensors from old installations and 8 Fogale sensors on loan from Argonne Lab. These probes have been extensively used in various ground motion/stability studies [2].

In January 2009 there 12 Tevatron style HLS installed at 2000 ft in the Homestake Gold Mine – proposed site for DUSEL. In the summer 2009 we will install 12 HLS at the 4100 ft (1242 m) to monitor tilt during dewatering process. Montana Tech has ordered 12 Budker Capacitive and 12 Budker Ultrasonic Sensors to install in DUSEL. We also will install 32 Tevatron Style sensors in the Fermilab Main Injector tunnel to monitor motion during construction this summer.

In 2009 we plan to re-work the Tevatron low beta quad systems and MINOS at Fermilab and continue LaFarge (Aurora, IL) mine and MINOS data collection.

SLOW GROUND MOTION ANALYSIS

Tevatron B-sector HLS: since early 2004, a system of 20 HLS sensors with half-filled water pipe was installed in the Tevatron tunnel on top of the accelerator focusing magnets spaced 29.6 m apart.

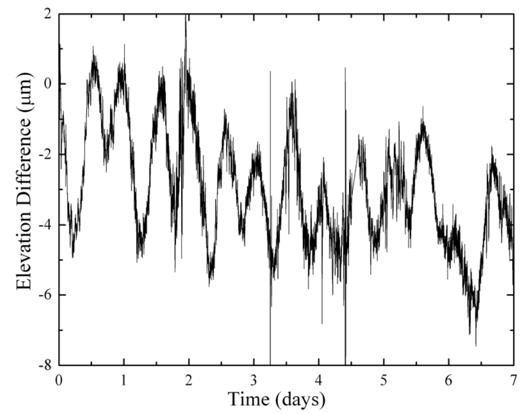

Figure 1: One week record of elevation difference of two neighbor focusing magnets in the Tevatron tunnel as measured by HLS (starts midnight Feb.7,2004).

Environment of a working accelerator had its own peculiarities, e.g. regular ramping of the electromagnets resulted in few micron relative magnet position changes – see spikes in Fig.1 – on top of regular tidal variations and diffusive drifts. Fig.2 shows a snapshot of the magnet elevation changes after 23 days of observations. One can see that the differential movements over the ~600 m section of tunnel could be as big as 30-50 μm.

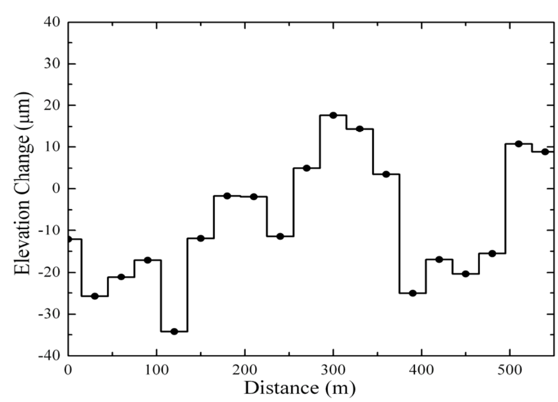

Figure 2: Change of the elevations of 20 Tevatron magnets after 23 days of observations (Jan.7-Feb.1,2004).

Variograms of the second differences $SD_{nmml} = Y_n - 2Y_m+Y_l$ have been analyzed, linear dependence on the time interval T confirmed and the variance $<SD_{nmml}^2(T)>/T$ are plotted in Fig.3. The indexes (n,m,l) indicate triples of the sensors distanced by L and T=7

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days – the week of Feb. 7, 2004. One can see that the variance increases with L up to 90-120 m and then flattens out. That indicates lack of coherence (independence) of the motion of the pieces of the tunnel distanced by more than 120 m apart – at the time scale of 1 week. For shorter distances, the ATL law $<dY^2(T,L)>=ATL$ with coefficient $A_{TevB} =(2.2\pm1.2)\cdot10^{-6}$ μm²/s/m gives a good approximation of the data.

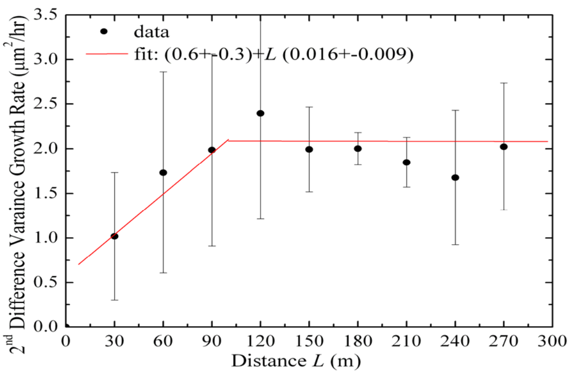

Figure 3: Dependence of the growth rate of the variance of the 2nd difference vs distance between the HLS probes (the Tevatron tunnel, the week of Feb 7,2004).

MINOS Hall Data: seven HLS probes had been installed in 2006 in the MINOS experiment underground hall some 100 meters below grade on top of the Galena Platteville dolomite (also on the site of Fermilab). The probes are set 30 m apart and connected in two double-pipe (air/water) systems – the first one with 4 probes are orientated along a North-South line and the other system of 3 oriented along an East-West line. One month long record of the HLS readings of the level difference $Y_0 – Y_3$ (probes #0 and #3, 90 m apart in NS direction) is presented in Fig.4. One can see that some 6 μm amplitude periodic variations due to the Earth tide dominate few μm scale slow drifts over weeks.

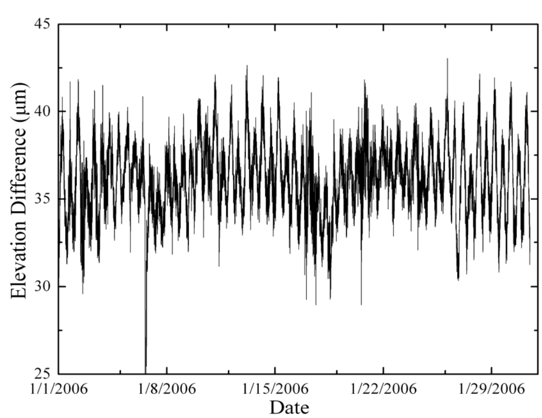

Figure 4: January 2006 record of elevation difference for two HLS probes 90 m apart in the FNAL MINOS hall.

To remove the systematic effects due to the tides, the FFT of the 1 month long record of the level difference Y_0 – Y_3 data has been calculated (see Fig.5). The power law fit *1/f* indicated by the red line in Fig.40 corresponds to the ATL diffusion coefficient of $A_{MINOS} =0.18\cdot10^{-6}$ μm²/s/m.

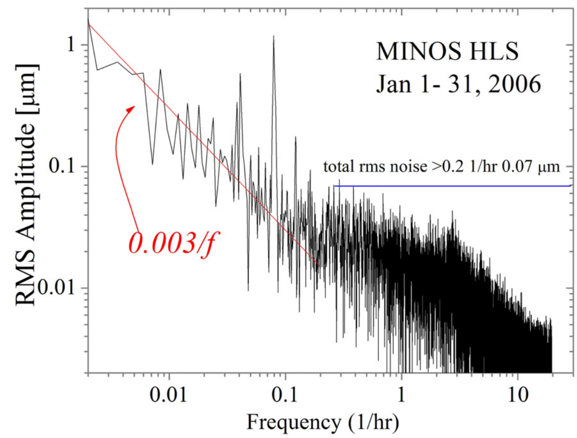

Figure 5: FFT of the elevation difference for HLS probes 90 m apart as measured in the Fermilab's MINOS all.

Tevatron Alignment Data Analysis: alignment system of the Tevatron Collider employs more than 200 geodetic "tie rods" installed in the concrete tunnel wall all over the ring , approximately 30 m apart.

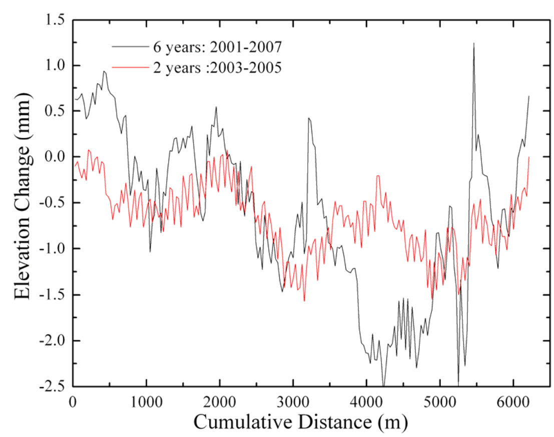

Figure 6: Vertical displacement of more than 200 "tie rods" in the Tevatron tunnel over the period of 2003-2005 and a 6 year period of 2001-2007 (courtesy of FNAL Alignment Group).

Position of the magnets is regularly locally referenced with respect to the rods while positions of the rods are routinely globally monitored. The rods elevations data are available for the years of 2001,2003,2005,2006 and 2007. Fig.6 shows the change of the elevations around the ring accumulated over two intervals – 2 years (2003-2005) and 6 years (2001-2007). One can see that longer term motion has larger amplitude. The variance $<dY^2(L)>=<(dY(z)-dY(z+L))^2>$ of the displacements has been calculated and averaged over all possible time intervals. E.g. there are two 1-year intervals (that is 2005-2006, 2006-2007), three 2-year intervals (2001-2003, 2003-2005, 2005-2007), etc, and one for the 6-year interval 2001-2007.

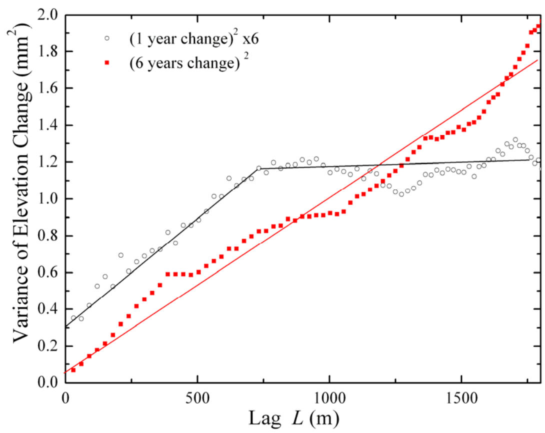

Figure 7: Variances of the averaged Tevatron tie rod vertical displacements over time intervals of 1 (multiplied by 6) and 6 years vs the distance L.

The results for 1-year changes and for the 6-year change are shown in Fig.7. A remarkable difference between the two plots is that 1 year variance scales linearly only up to L≈900 m and does not depend on L beyond that scale, while the 6 years variance grows all the way to distances as large as 1800 m. Such behaviour indicates independence of the displacements of the rods located more than 900 m apart on the time scale of a year, and existence of a significant level of interdependence of the motion of distanced rods at the times as long as 6 years. The calculated variances for all possible time difference can be well approximated by linear fits $<dY^2(L)> =a+bL$ over distances less than 900 m and the slopes (fit parameters b with the error bars) are plotted in Fig.8.

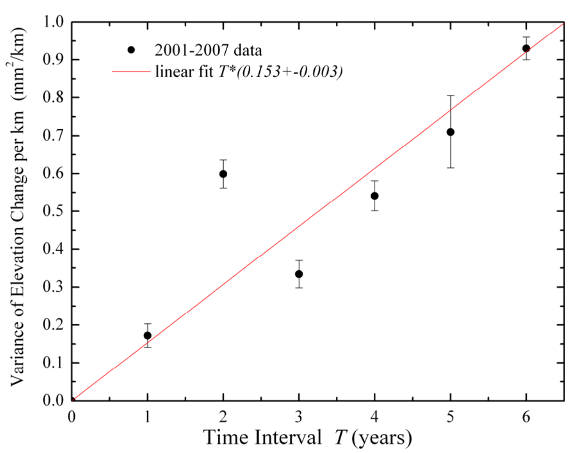

Figure 8: Variances of the Tevatron alignment rods displacements per unit distance vs the time interval between the measurements (see text).

One can see that the variance per unit distance grows with the time interval between the measurements, and can be approximated by a linear fit $b(T) =cT$ with $c=0.153\pm0.004$ *[mm^2/km/year]*. Such dependence is in accordance with the ATL law with coefficient $A_{Tevatron} =c=(4.9\pm0.13)\cdot10^{-6}$ $\mu m^2/s/m$.

SUMMARY

Table 1 below summarizes the observations of the ground diffusion presented above and compares the diffusion coefficients *A* found in these and previous studies. It also cite the time interval *T* of the observation or analysis, the spatial scale (e.g. the tunnel length, of the total length of the HLS system), and corresponding reference. The last two lines correspond to measurements at the depth of ~100 m , contrary to all other results obtained in the tunnels of less than 10 m depth. One can see that the diffusion coefficient at larger depth is about an order of magnitude smaller.

Table 1: Diffusion coefficients in units of 10^{-6} $\mu m^2/s/m$.

Tev Align. Vert.	4.9±0.1	1-6 yr	6.3km	
Beam Orbit Vert.	2.6±0.3	15 hrs	6.3km	[3]
Horiz.	1.8±0.2	15 hrs		
PW line	6.4±3.6	3 mos	180m	[4]
MI8 line	1-10	1 mo.	285m	[5]
Tev B-sector	2.2±1.2	1 wk.	600m	
MINOS hall	0.18	1 mo.	90m	
Aurora mine	0.6±0.3	2 wks	210m	[6]

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