Hydro Static Water Level Systems at Fermilab

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Several Hydrostatic Water Leveling systems(HLS) are in use at Fermilab. Three systems are used to monitor quadrupoles in the Tevatron and two systems are used to monitor ground motion for potential sites for the International Linear Collider (ILC). All systems use capacitive sensors to determine the water level of water in a pool. These pools are connected with tubing so that relative vertical shifts between sensors can be determined. There are low beta quadrupoles at the B0 and D0 interaction regions of Tevatron accelerator. These quadrupoles use BINP designed and built sensors and have a resolution of 1 micron. All regular lattice superconducting quadrupoles (a total of 204) in the Tevatron use a Fermilab designed system and have a resolution of 6 microns. Data on quadrupole motion due to quenches, changes in temperature will be presented. In addition data for ground motion for ILC studies caused by natural and cultural factors will be presented.

1. MOTIVATION FOR WATER LEVELS

Hydro static water levels (HLS) are based on the principle that water seeks its own level. By using communicating vessels connected with 12.7 mm external diameter polyethylene tubing the relative vertical displacement with respect to gravity can be determined. Distilled water is used since it is safe and the physical properties are well known so that measurements data can be corrected for. In all cases a two pipe system is used at Fermilab. One pipe is full of water and connects each vessel or pool. This pipe is always below the desired level of water in each pool. The second pipe is elevated above the pools and is full of air. There is only one place where the entire system communicates to atmospheric pressure. The advantage of a two pipe system over a single half filled pipe is the ability to maneuver over or around obstacles between each pool. A half filled pipe system must be level throughout the installation.

Capacitive sensors are used to determine the distance to the top of the water in the pool. As an individual sensor shifts in the vertical the distance changes and is recorded. For large shifts there can be movement of water between the pools causing levels in adjacent pools to also change. This depends on the total displacement and the impedance of the water carrying tube. Resolution is dependent on the system used. The Budker Institute of Nuclear Physics (BINP) devices have a resolution of 1 micrometer; the commercial proximity sensors used by Fermilab have a resolution of 6 micrometers.

2. BINP SYSTEM

2.1. General Layout

At each interaction region (B0 and D0) there are eight low beta quadrupole magnets arranged as a triplet and a single quadrupole on each side of the interaction regions. These are high field strong focusing quadrupoles used to reduce the beta of the Tevatron beam and thereby increase the luminosity delivered to the detectors. Given the strength of these quadrupoles any misalignment magnet to magnet or with the entire set can cause the interaction vertex in the detectors to be improperly offset or cause orbit distortions around the Tevatron.

On each low beta quadrupole as near the center of the magnet as possible a BINP HLS sensor is mounted. Each sensor is attached to a stainless steel plate with epoxy. There is a second plate with threaded rods that allowed for height adjustment of the sensor. The sensor pools are connected with 12.7 mm O.D. polyethylene tubing fully filled with water. In addition there is a separate air line made of Tygon tubing. The entire system is sealed with one opening to atmosphere. The sensors on each side of the interaction region are wired in series for power and signal. A separate PC is used to read out the data. Figure 1 shows a BINP hydro static water level. Note the sensor head is up side down to show the active area.

Figure 1 BINP water level showing sensor and pool

2.2. Electronics

The BINP HLS is a PC based system simultaneously collecting level, temperature in the SAS version. There is a modified version SAS-T that also in addition collects rolls and tilts. The Data Acquisition Software System presents results on the computer and stores data on the hard drive. The Software operates under Microsoft Windows

95/98/2000/XP operating systems and is compatible with FNAL network. Up to 30 sensors (level, tilt, temperature channel in each) and 2 air pressure channels can be accommodated.

The interface board is a commercially available standard RS485 PC card controlling data transfer to and from remote level and tilt sensors. The sensors use +48 VDC and draw less than 50 mA per sensor. All Sensors are connected by commonly used for Ethernet LAN cable with two pairs used for duplex data exchange and two for power. Data sampling frequencies are up to 0.5 Hz .

The Software for the slow ground motion study consists of two programs: "Level&Tilt" and "LTvisio". The "Level&Tilt" program is designed for level and tilt measurements. "LTvisio" program is designed for offline or remote data processing and can calculate, represent or export to text files for wide range of data such as spectra and diffusion. The program provides different data filters and can concatenate separated data files into one data file. This software has been in use for 9 years. During that time it was found that splitting the tasks into 3 different programs made for a more robust system. These tasks are:

a) Collecting measurement dates - hlsservice, hls monitor

b) Manager interface – hlsinterface(console of HLS;

c) Analysis and visualization applications.

All programs have GUI (graphic user interface), except hlsservice.exe working in the background under the system account. Hlsservice software runs under HLS PC, where the HLS interface board present. The core is “hlsservice.exe” program. The Program runs under service mode. This has the advantage that the program starts every this time the operating systems starts, and any authorized person could long in and access the data with out stopping data collection, and data collection is independent of other users on the PC.

“*HLS file monitor”* – is additional program, running under the HLS PC. The main function – send data with defined time interval from HLS stored files to database of ARCNET system, used in Fermilab to control TeV accelerator. ARCNET system also use as watchdog for responsible person. If date collecting process is broken, an e-mail message is sent to the managers of the system with information on the source of the error that caused the process to stop.

Manager interface – “hlsinterface.exe” program is running on remote or local computer to control HLS hardware systems on HLS PC. This program communicates with the “hlsservice.exe” program and has configuration functions of HLS system.

The Program displays also current values of data from sensors, time statistic, error events. The program communicates could to communicate with many HLS PCs by using TCP/IP protocol under LAN. Before starting to check HLS user have to choose just IP address or logic name of HLS PC.

The levisio.exe displays data in the form of graphics or/and data tables. There is specific software used to cut or merge raw data files, convert raw data files to ASCII format files, or present data in graphic mode. Analysis functions like Relative levels, Coherence/Cross Spectrum, Diffusion, FFT Filter, Diffusion averaging and many others are available. Also users generate ASCII files from “levisio.exe” program for use with other programs such as MS EXCEL and ORIGIN.

2.3. Motion of Low Beta Quadrupoles

There were two different support systems for the low beta quadrupoles used. The triplet for D0 interaction region directly supported off of the floor by the use of screw jacks. The B0 system was originally hung from the ceiling using Invar rods to support a cantilevered cradle holding the last two quadrupoles. It was determined that this system was susceptible vibration caused by traffic on the roads near the collision hall. The rods were replaced by a large column supported from the floor and thermally insulated to reduce effects of collision hall temperature changes. In both cases the system of support was driven by experimental needs and the construction of the collision halls.

Motion of the low beta quadrupoles are caused by quenches of the magnets, changes in the temperature of the collision hall or tunnel, and movement of parts of the detector. Figure 2 shows the effect of two quenches on the water level. There is a fast motion at the time of the quench followed by a continual motion as the system warms then a slow recovery as the magnet is cooled down. Data were taken at one minute intervals and the left hand side scale is in micro meters. The right hand side scale is the current in the Tevatron measured in amperes.

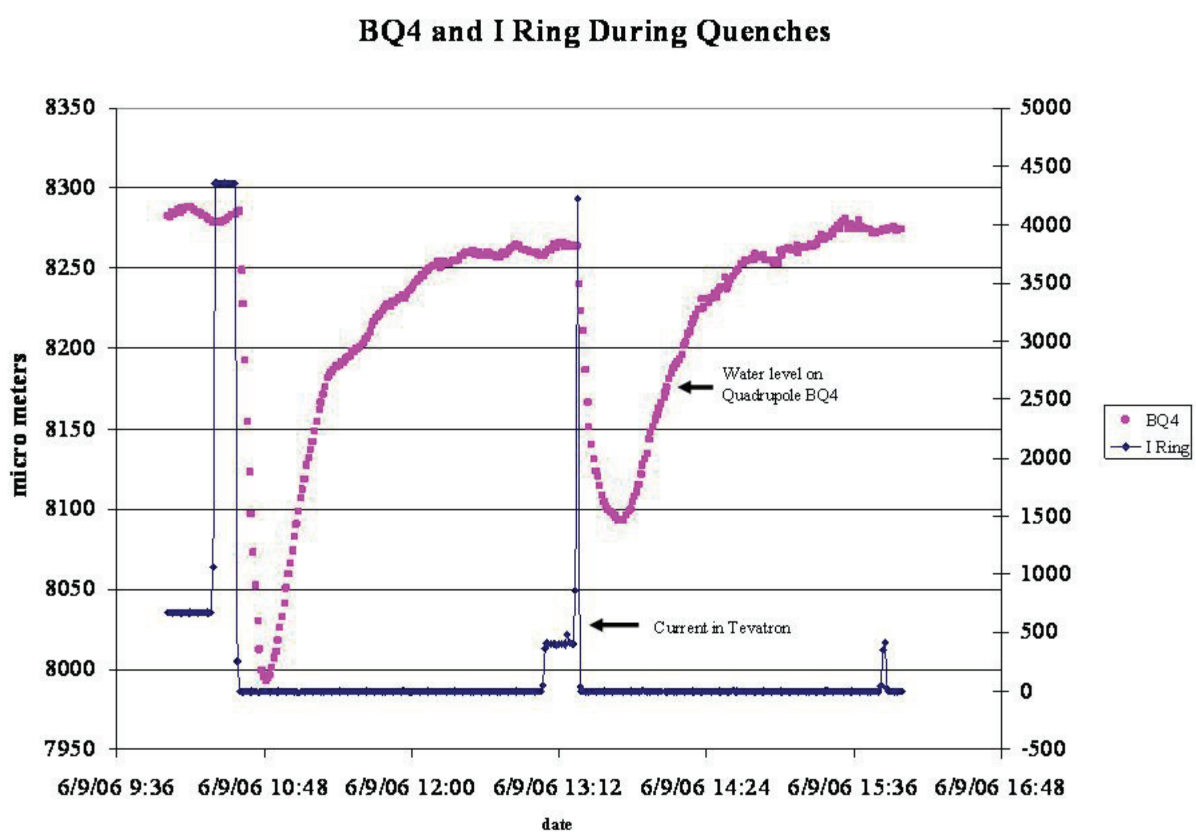

Figure 2 two sequential quenches in Low beta Quadrupoles at B0

The B0 interaction region has two moveable steel toroids for muon detection. These toroids weigh 450 tons and are moved 3 meters from time to time for access to detectors. The outer position of the toroids are within 0.5 meters of the supporting column for the low beta quadrupoles. As the toroids move the low beta quadrupoles move upward and then spring back as the toroids are returned to their normal position. Figure 3 show the effect on the water levels on the BQ3 and AQ4 low beta quadrupoles.

Temperature variation in the collision halls also have a large effect on the position of the low beta quadrupoles and the beam. Figure 4 show the motion of the DQ4 low beta quadrupole at D0 and the D0 hall temperature for several days. The experimenters were attempting to use the hall air-conditioning to regulate the temperature of their toroid. The several degree centigrade changes in hall temperature resulted in 100 micro meter movements of the low beta quadrupole. The automatic tune programs for the Tevatron were able to follow the quadrupole motion during this time and allow for continued operations of the Tevatron.

Small motion of the low beta quadrupoles from their idea position are amplified in the arc by a factor of 10. This has several undesirable effects on Tevatron performance such as higher losses all along the Tevatron, lower proton and anti-proton lifetime, tune shifts and quenches induced in the Tevatron. All of these add up to reduced instantaneous and integrated luminosity.

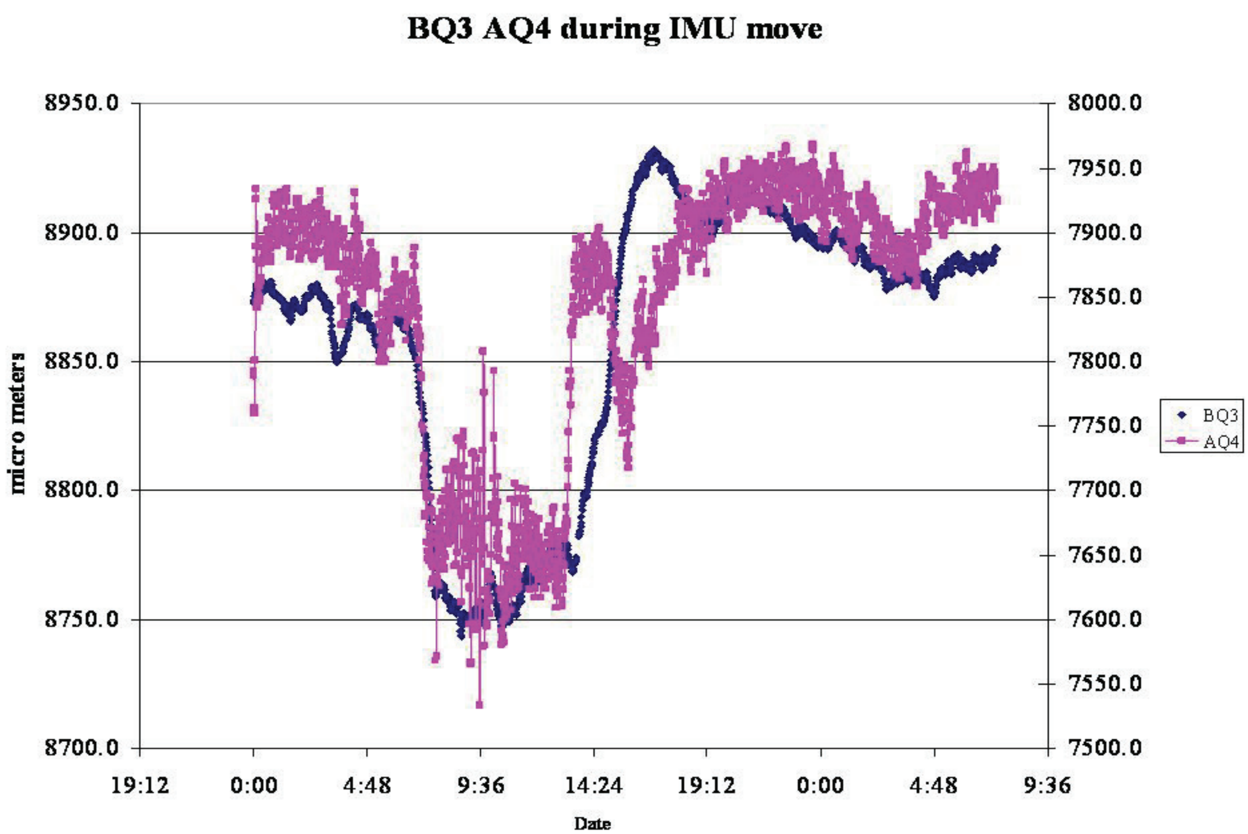

Figure 3 Toroid moves at B0 collision hall affecting the HLS sensors on the low beta quadrupoles

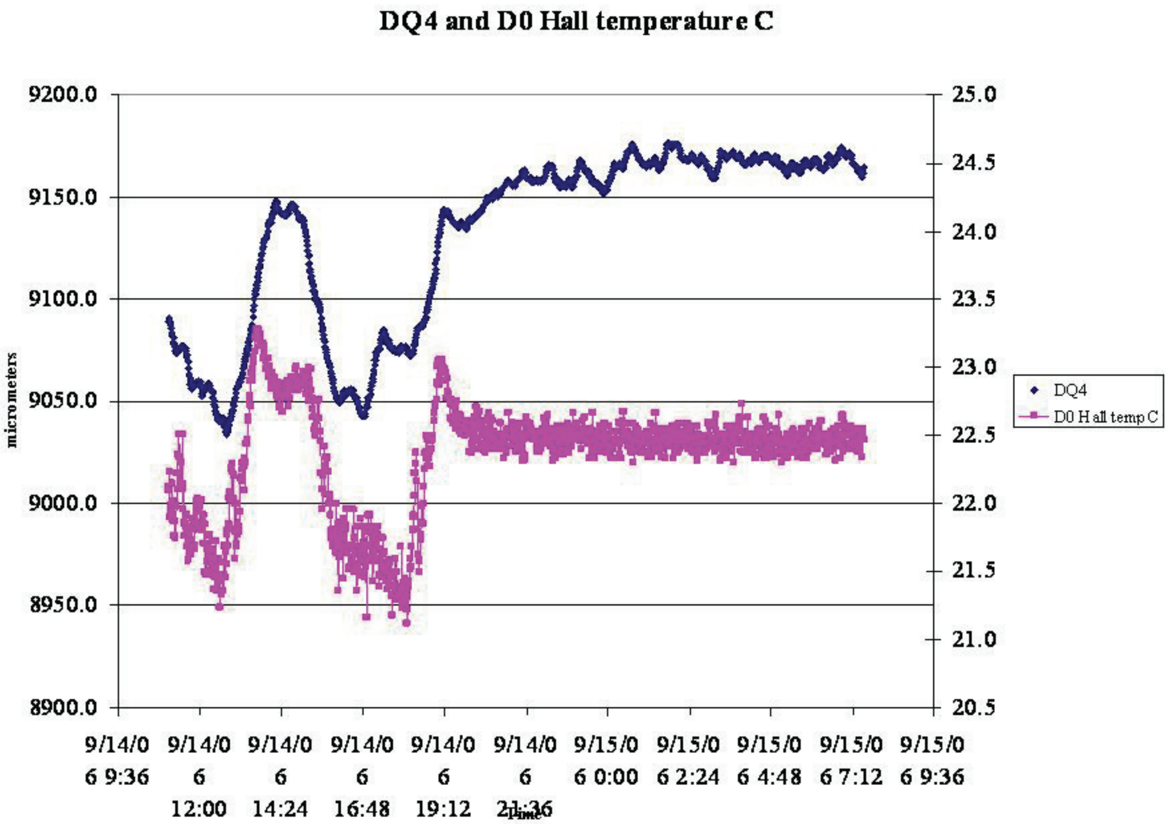

Figure 4 Motion of a low beta quadrupole at D0 and D0 hall temperature

3. FERMILAB SYSTEM

3.1. General layout

There are 205 superconducting quadrupoles in the Tevatron. To instrument these quadrupoles a simpler water level system was devised. The water pools are made of 76.2 mm ID PVC tubing cut to a length of 101.6 mm. Ends were glued into the tubing to make a sealed pool. A Balluff BCAW030NB1Y3 proximity sensor is screwed into the top plate. There are two tee connectors in the pool that are used for the water line and the air line. See Figure 5. The Balluff sensor is a commercial proximity sensor that cost $57.00. The entire cost of a sensor and electronics is $120.00 per channel.

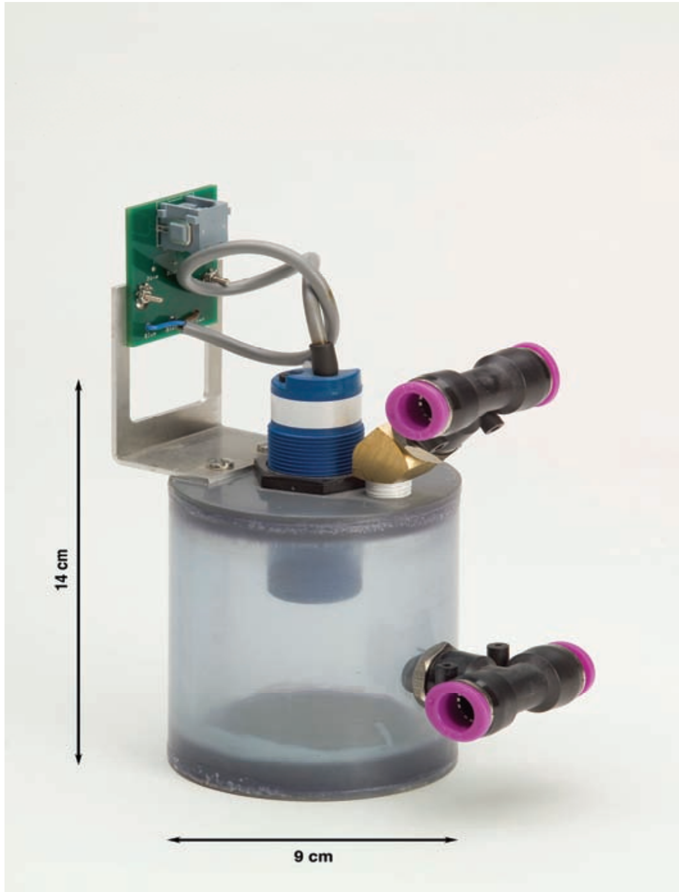

Figure 5 Fermilab Hydro Static Water Level

The number of sensors is given in table 1:

Location	Type	Separation	Elevation	Strata	Computer name
A sector	33 Balluff	30 meters	722 ft	Surface	
B sector	33 Balluff	30 meters	722 ft	Surface	
C sector	33 Balluff	30 meters	722 ft	Surface	
D sector	33 BINP	30 meters	722 ft	Surface	
E sector	36 Balluff	30 meters	722 ft	Surface	
F sector	36 Balluff	30 meters	722 ft	Surface	
B0	9 BINP	Varies	722ft	Surface	shilstev-W2k
D0	9 BINP	Varies	722 ft	Surface	D0-HLS

3.2. Electronics

The water level readout system has two control boards consisting of a Driver Board and an 8 Channel Readout Board. The driver board collects data from multiple Readout Boards on a RS485 data link. Each Readout Board has 8 channels of 4-20mA sensor interface inputs. Each sensors data is collected and stored locally using a micro controller. The sensors are attached to the 8 channel cards using a 4 conductor flat modular cable having RJ11 connectors. Each 4-20ma sensor interface board also has a temperature sensor. The Driver Board has a micro controller with RS232 and Ethernet ports. This allows for data control and display using RS232 or Ethernet. One Ethernet socket is used as a telnet connection and the second supports binary data transfers. The driver board connects to the remote 8 channel Readout Board using a 6 conductor flat modular cable. This cable supplies 24VDC along with differential TX and RX data. Hot swap controller are used on all power connection points.

The TI MSP430 micro controller is used on both cards. The Ethernet connection interface uses a Wiznet NM7010A. On power up the driver boards' firmware determines how many readout boards are connected and assigns them an incrementing board number. After this power initializing sequence commands can individually access any single board or all boards at once.

3.3. Layout on Tevatron quads

The pools and sensors were attached directly to the quadrupole magnets using a 5 minute epoxy. In most cases the pools were placed in the center of the quadrupole but in some instances there were obstructions that prevented this. All pools were connected with 12.7 mm diameter polyethylene tubing filled with distilled water. A separate air line using 12.7 mm diameter Tygon tubing was used. Each of the six sections in the Tevatron was a separate system. There was only one hole in the system to atmospheric pressure. The sensors were set in the top of the pools with a jig and no effort was made to adjust all sensors to the same level. A small wet dry vacuum cleaner was used to suck water through the tubes from one sensor to the next. This eliminated all bubbles in the tube that could cause problems. To ensure all electrical connections were correct after the system was operating each sensor was disconnected from one end of a section to the other. Data were read out showing the sequence of sensors dropping out. Any mis-cabling were found and corrected.

3.4. Motion due to quenching

When a quench occurs motion of the near by quadrupoles can be seen. There is a sudden movement as the venting of the Helium happens then a slow return to nominal position as the magnet string is cooled down to operating temperatures. Figure 6 shows a typical quench in the Tevatron.

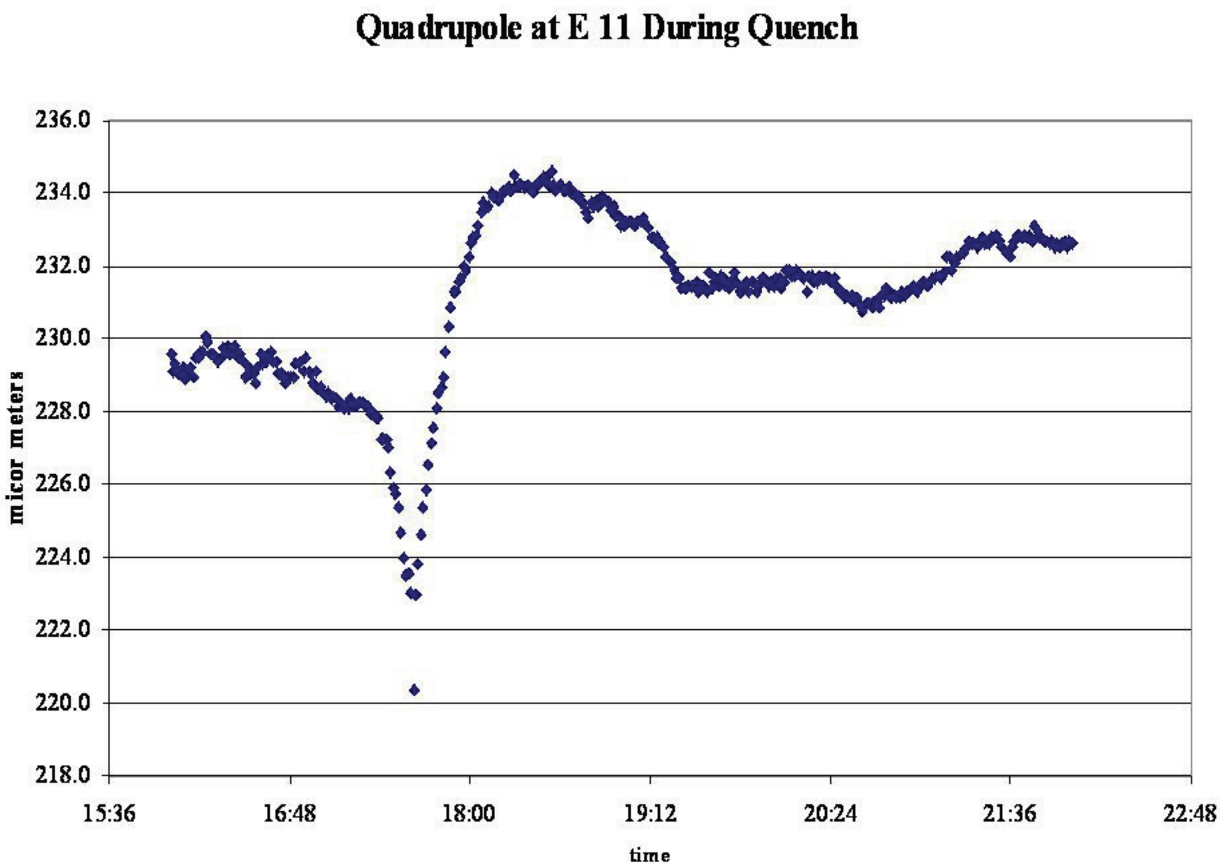

Figure 6 Quench near Quadrupole E11

3.5. Motion due to ramping

Some of the quadrupoles move when the Tevatron is ramped. Figure 7 shows water levels for B43-1 and the current in the Tevatron. There is a clear correlation between the current and the water level. During the spring 2006 shutdown the stands for this magnet were replaced. The magnet still moves with the ramp. The conclusion is for some magnets that laminations flex during the ramping process. There is no discernable effect on the beam caused by this motion.

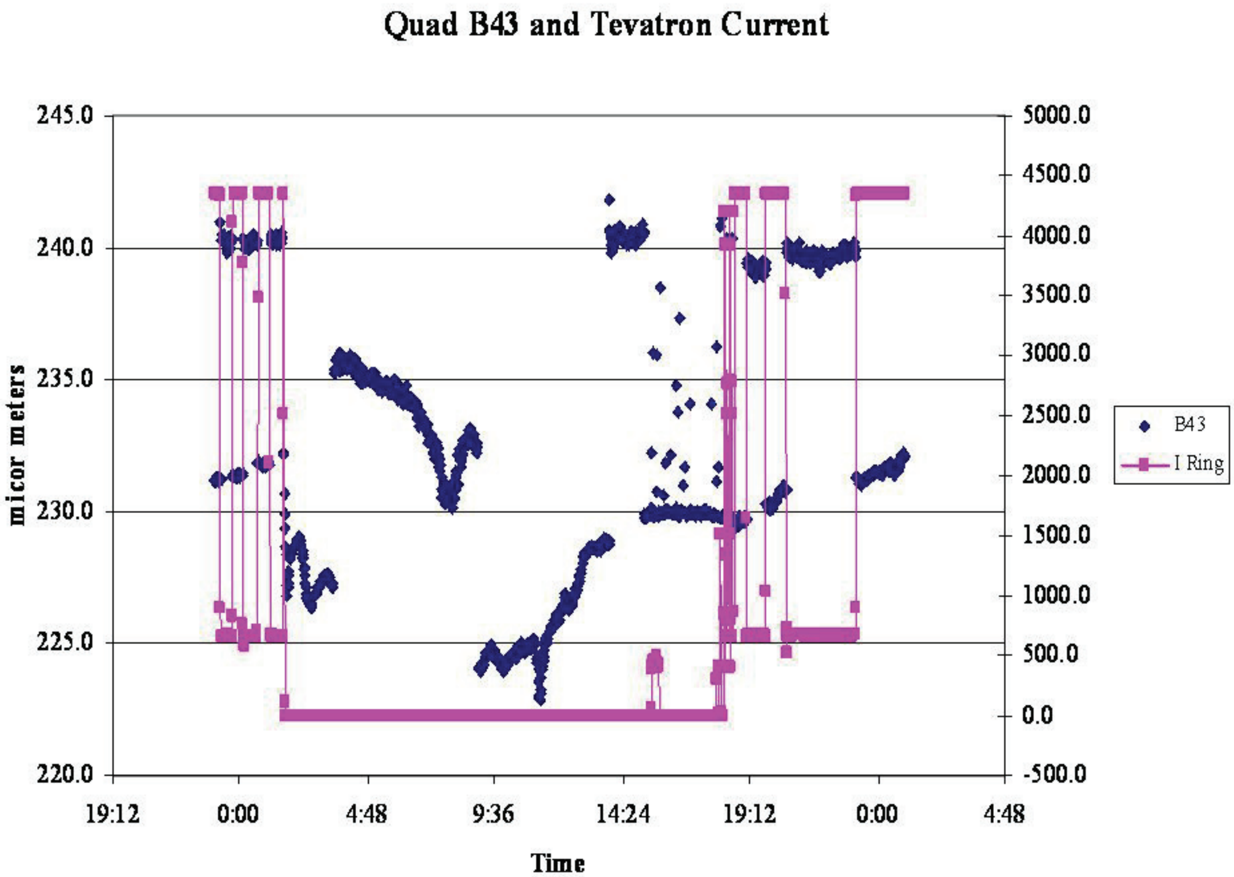

Figure 7 Motion of quadrupole B43 during ramp of the Tevatron

4. INTERNATIONAL LINEAR COLLIDER STUDIES

4.1. MINOS and Aurora mine data

There are two water level systems used to study ground motion for the proposed International Linear Collider (ILC). The first system is on the floor in the MINOS experimental hall at Fermilab. There are four BINP sensors spaced 30 meters apart. This is the similar to the spacing of quadrupoles for the ILC.

Name	sensors	spacing	Elevation Sea level	Strata	Computer Name
MINOS	4 BINP	30 meters	406 ft	Maqoketa shale	hls-minos.dhcp.fnal.gov
Conco mine	8 Fogale	20 meters	492 ft	Galena Platteville dolomite	HLS-Quarry2

The MINOS experiment is a long base line neutrino oscillation experiment at Fermilab. The near detector is located 100 meters below ground level on the Fermilab site. This is in the Maqoketa shale strata. The hall was constructed using a tunnel boring machine. There is a thin concrete cap on the floor to provide a level surface. There are no under drains in the area of the water levels.

4.2. Ground motion data

Floor motion is observed when the sump near the access shaft is pumped out. Once a month a test of the back up diesel pumps is conducted. This test removed all the water from the sump and drained water from under the floor of the MINOS hall. This caused a significant tilting of the floor toward the sump pit. Figure 8 shows data for the difference between two sensors 100 meter apart taken during the month of January. There is a seven micro meter oscillation with period of 12 hours. This corresponds to tidal motion of the earth. In addition the modulation of the tides due to the phases of the Sun and Moon (spring and neap tides) can be seen. The large spike on January 6th is caused by the monthly sump pump test. The smaller spikes are caused by running the regular sump pumps during excessive water infiltration. In these test the sump pump at the upstream end of the hall is run for extended periods of time lowering the water level in the sump pit and in the January 6th event almost totally draining the sump pit. In this case water under the floor is being removed causing the floor to tilt.

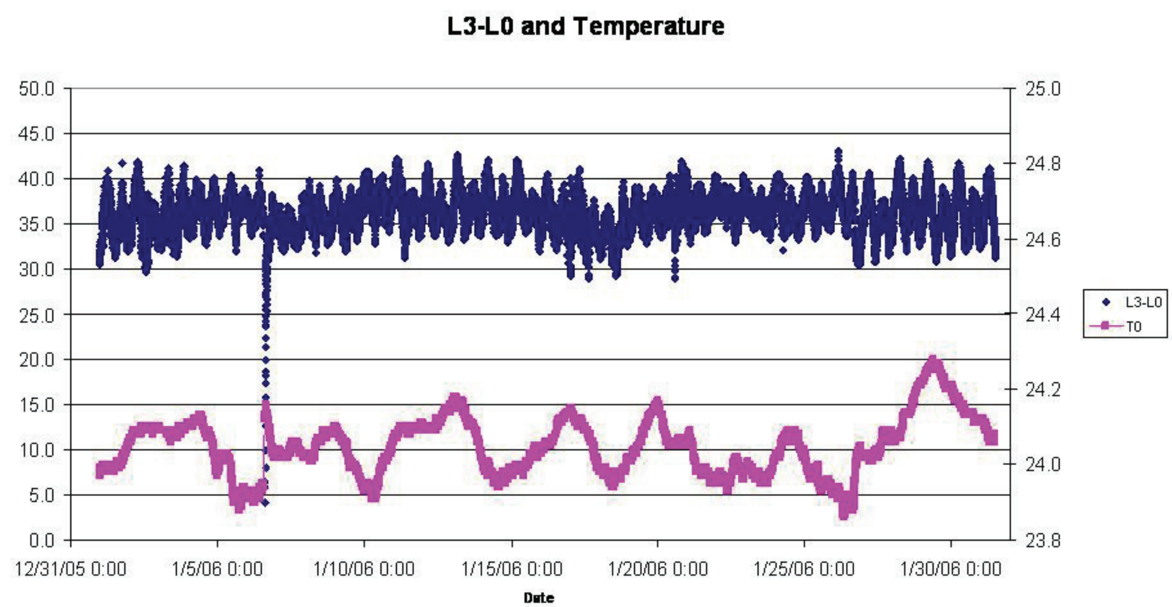

Figure 8 differences between two sensors 100 meters apart.

There are still some un explained floor motions in the MINOS hall. Figure 9 show floor data for the difference between the same two sensors as in figure 8. These sensors are 100 meters apart. The tidal motion of the floor is visible but there are also two significant motions of the floor. Air pressure (magenta) and the sump pump (red) on or off are also shown. Neither of these are correlated with the floor motion. Investigation are still underway as to the cause of this motion.

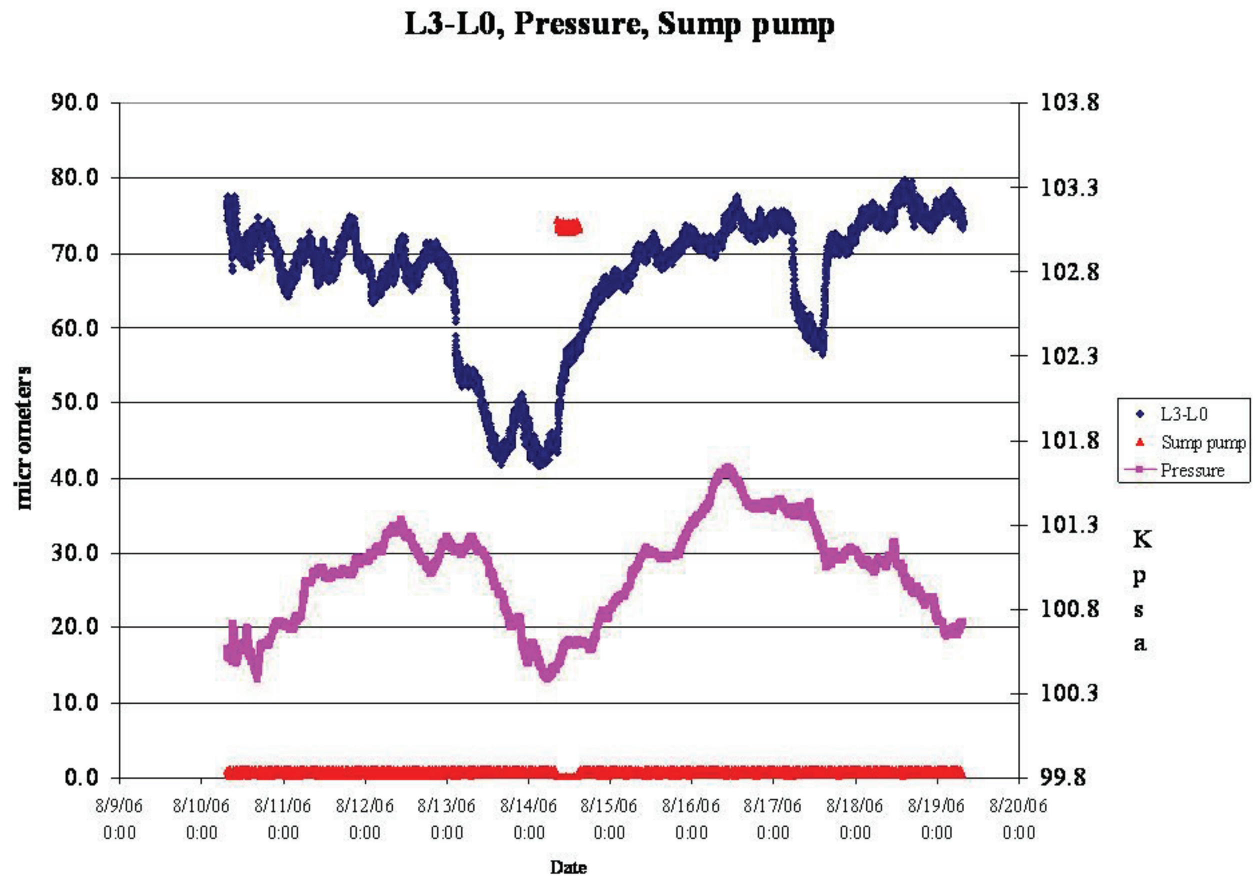

Figure 9

In 1999 a HLS system was installed in the Conco Western Mine in North Aurora Illinois. This mine is 10 kilometers from Fermilab. The HLS system had 8 sensors installed in the Galena Platteville strata. This is a dry and sable strata. In the last 7 years all but two of the sensors have failed. There are interesting cultural noise sources in this mine. Every business day at approximately 15:00 hrs local time there is a blast at the working face of the mine more than 1 kilometer away from the sensors. At 22:00 hours local time conveyors that haul the gravel to the surface start up. This conveyor system runs within 100 meters of the HLS sensors. Figure 10 shows data for a typical week of mine operations. The data is available at http://home.fnal.gov/~volk/waterlvl/.

In August of 2006 the Aurora mine system was rebuilt with new sensors and plumbing. A total of 6 sensors are now operational. Data continues to be collected at a one minute repetition rate.

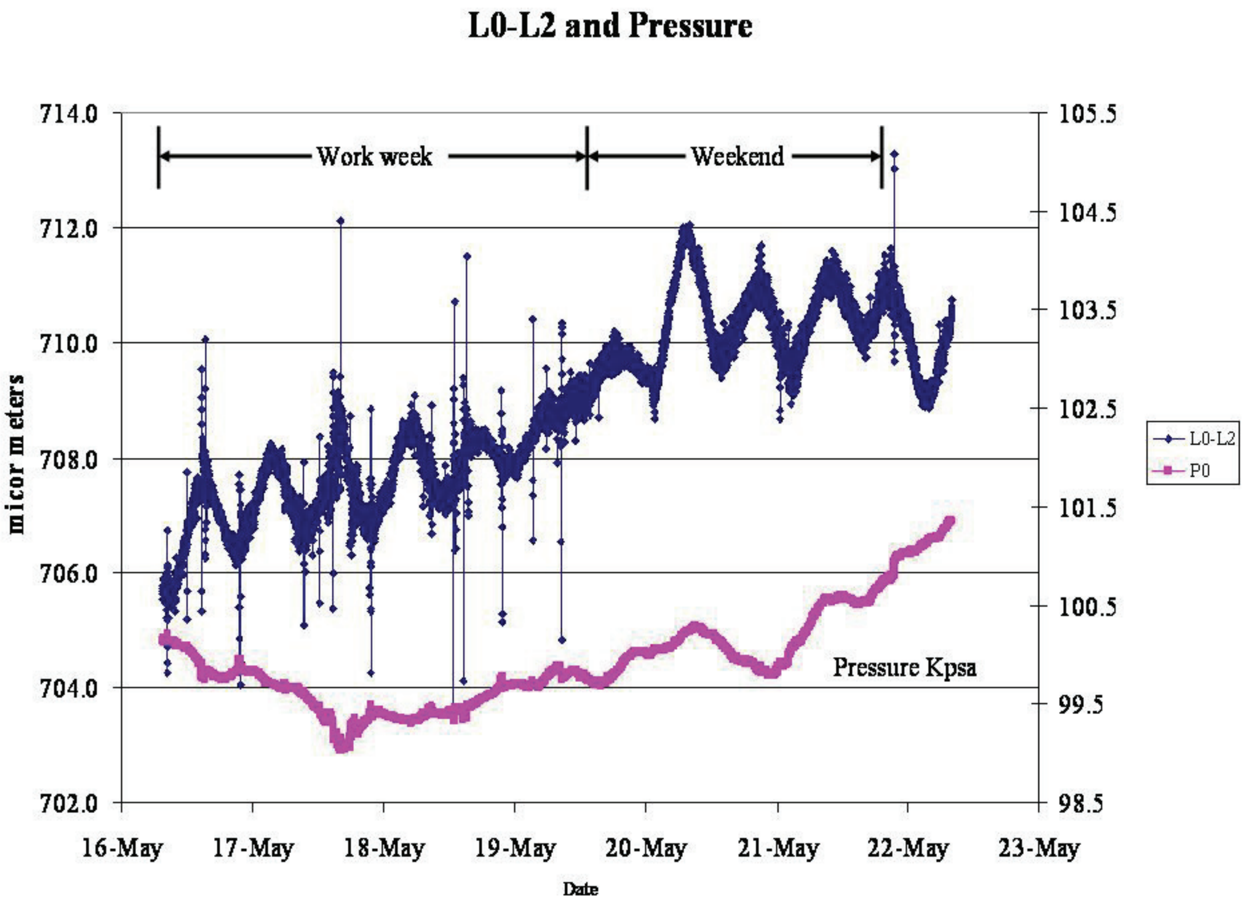

Figure 10 Difference in two sensors 30 meters apart in Conco Western mine for one week Note the cultural noise due to min operations and the quite weekend time.

5. RESULTS AND CONCULSIONS

Monitoring of the elevations of the quadrupoles in the Tevatron provides useful data to understand motion of the magnets during running and during quenches. The quadrupoles in the interaction regions are susceptible to changes in temperature and movement of large devices in the collision hall. The magnets do not always return to their original positions after the temperature returns to nominal values. This can account for the changes in position of the low beta quadrupoles that have been observed during conventional surveys. The changes in position can cause reduced running time due to quenches and reduced luminosity.

The deep mine studies for the ILC show that even bedrock moves to some extent. Cultural noise such as blasting (as much as 1-2 kilometers away) and operation of large machines can cause significant motion of the floor. In addition ground water pumping can cause shifts in the floor that are significant for ILC alignment. In locating the ILC it will be necessary to determine all possible sources of cultural noise in the general area of the tunnel and to understand the underground hydrology of the area.

Both the MINOS and Aurora mine systems continue to operate. The data collected over years will provide useful input to ILC simulations studying the effects of motion on the various ILC components. Future plans include an automatic data collection and posting so that other interested groups may use the data collected.

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References

[1] Work supported by the U.S. Department of Energy under contract No. DE-AC02-76CH03000.

[2] VLHC/NLC Slow Ground Motion Studies in Illinois V Shiltsev et. al. 2001 Particle Accelerator Conference.