BINP KEK

BINP CAPACITIVE AND ULTRASONIC HYDROSTATIC LEVEL SENSORS

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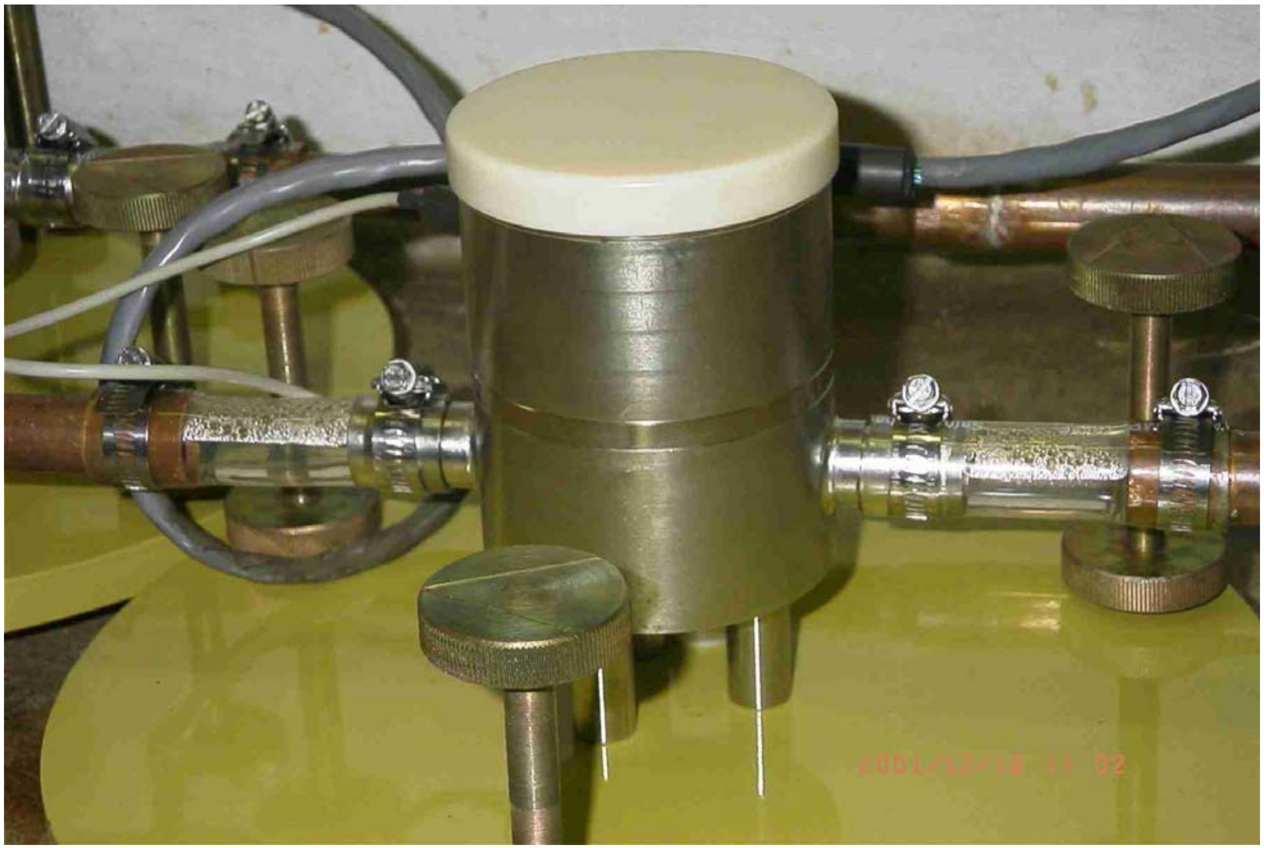
1. Introduction

Slow ground motion study for future accelerator projects and alignment of large accelerator machine components with high accuracy are important tasks now. One of the prevalent tool for solution of these tasks are Hydrostatic Level Sensors designed to work into the Hydrostatic Levelling System, which is based on principle of communicating vessels.

Since 2001 year BINP took part in development and fabrication of Hydrostatic Level Sensors in the network of team-work with FNAL and SLAC. At the beginning BINP developed capacitive HLS sensors and then in 2005 ultrasonic HLS sensors.

During last 7 years more then 200 sensors of both type were fabricated and delivered to FNAL and SLAC.

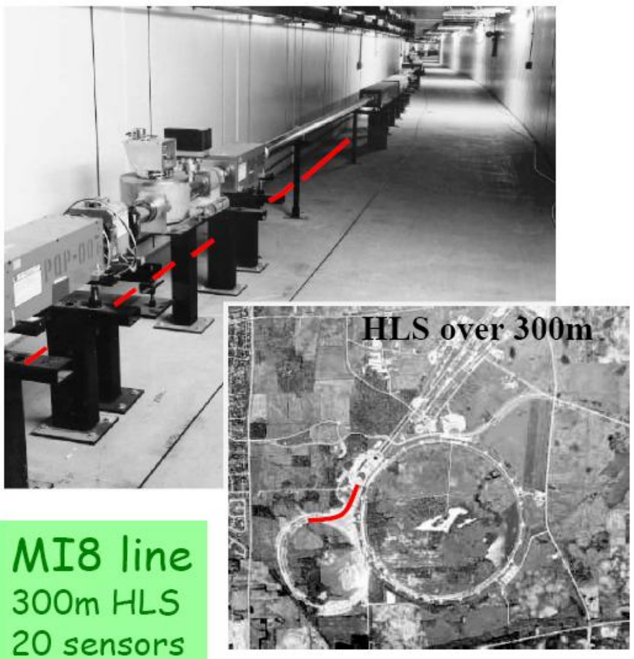
The first BINP capacitive HLS sensor SAS at SLAC, Sector 10 in the network of slow ground motion study for NLC project.



BINP-FNAL-SLAC slow motion studies and HLS R&D

NLC

BINP sensors @ MI-8



MI8 line
300m HLS
20 sensors

HLS system at sector B of Tevatron, FNAL.

The system was installed on 2003 to study online a behaviour of Tevatron magnets.

It was installed 24 capacitive sensors on quadripole magnets at sector B.

Total pipe length is about 800 meters.

In 2004 year the new modification of capacitive sensor (SAS-T) was developed. Equally with level measurement capability this sensor has a built-in two-coordinate tilt sensor. The range of tilt angle measurement is ± 17 milliradians with sensitivity better than 0.05 milliradian.

24 SAS-T sensors were delivered to FNAL in 2004. They were installed on magnet lines near detectors CDF and D0.

The SAS-T was in detail presented in our report on IWAA04 [2].

HLS system in MINOS tunnel (FNAL) to study ground motion for ILC project.

The first two prototypes of ultrasonic HLS sensor at SLAC, September 2005.

In accordance with the program of collaboration between BINP and SLAC high-resolution capacitive (SASE) and ultrasonic (ULSE) hydrostatic level sensors for the Linac Coherent Light Source (LCLS) Undulator Alignment System were developed and fabricated. The required water level working range is +/- 2.5 mm relative to the middle of the water communication pipe. The required resolution of the sensors must be not worse 1 μm with an accuracy of 5 μm over 5 mm measurement range. At first pilot series of the sensors was fabricated and tested. Then final version of the sensors was developed and fabricated.

Test stand with pilot patterns of SASE and ULSE at SLAC.   May 2006

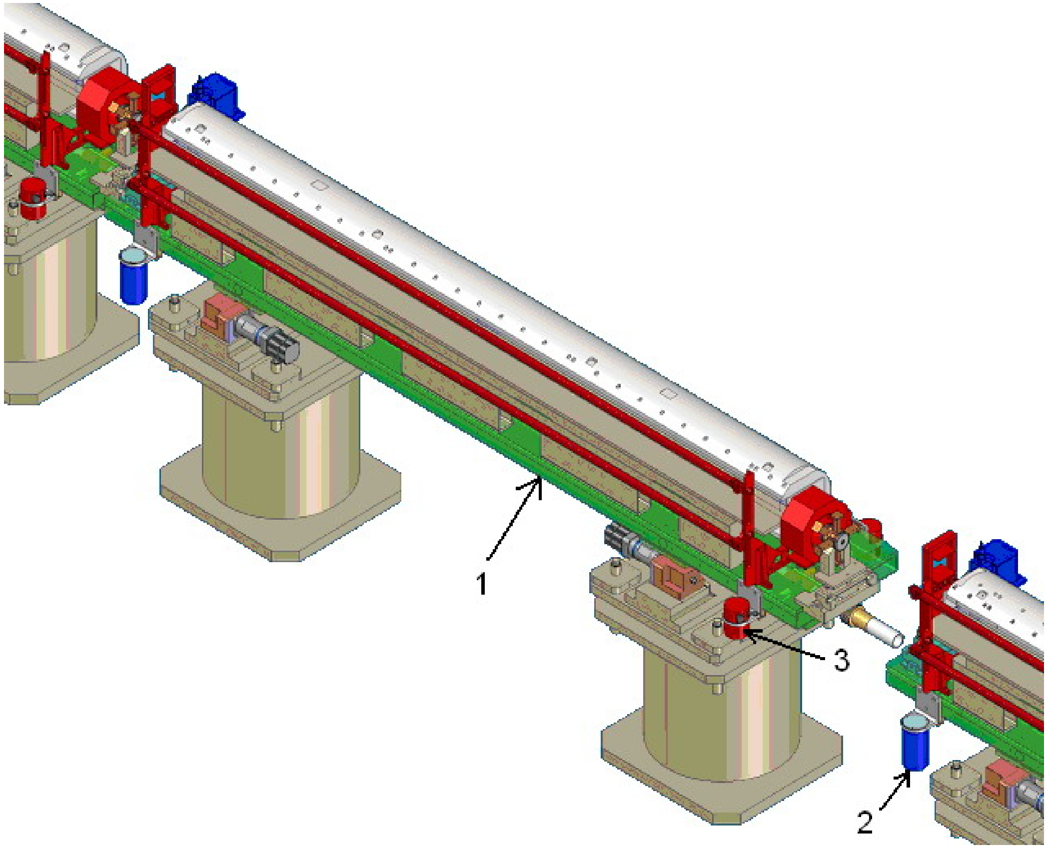
The overview of HLS monitoring system installation at LCLS undulator

(from report of Georg Gassner, SLAC - “HLS Monitoring System” August, 2006).

1 - Girder,

2 – ULSE sensor,

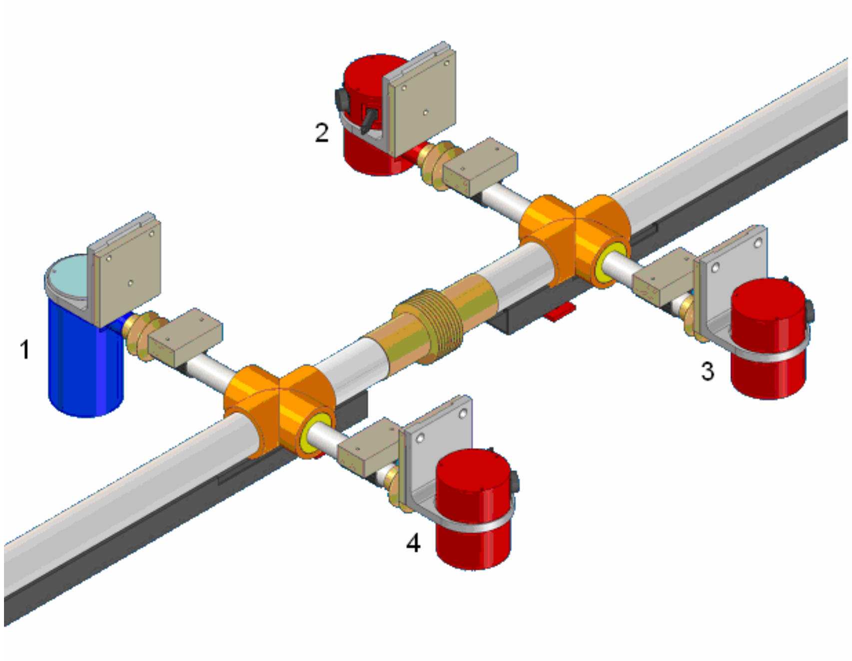
3 – SASE sensor



The detailed view of the sensor's Installation on one girder:

1 – one ULSE sensor

2-4 – three SASE sensors



Goals on last development

- *To obtain required metrological characteristics:*

  working range 5 mm,

  resolution not worse 1 μm *,*

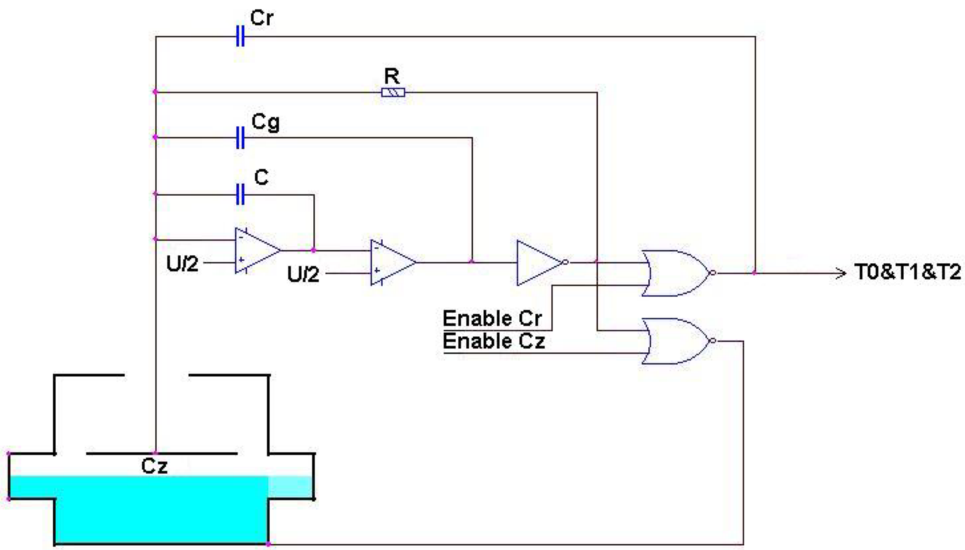
  accuracy not worse 5 μm *.*
- *Mechanical design of the sensors must fit same water pipe and same bracket*
- *The sensors must have same interface for Data acquisition system*

2 CAPACITIVE LEVEL SENSOR SASE

The presented capacitive level sensor SASE is intended for monitoring of LCLS Undulator vertical position:

- Displacement range - 5 mm ;
- Resolution – not worse 1 μm;
- Accuracy - 5.0 μm;
- Sampling rate – 0.5 Hz.

SASE works on principal of capacitance-based sensing. The principal is to create a capacitor, the liquid surface being one electrode, the sensor electrode placed in air medium upper of water surface being the second electrode of capacitor, the capacitance of which is measured in order to derive the distance between these two electrodes.



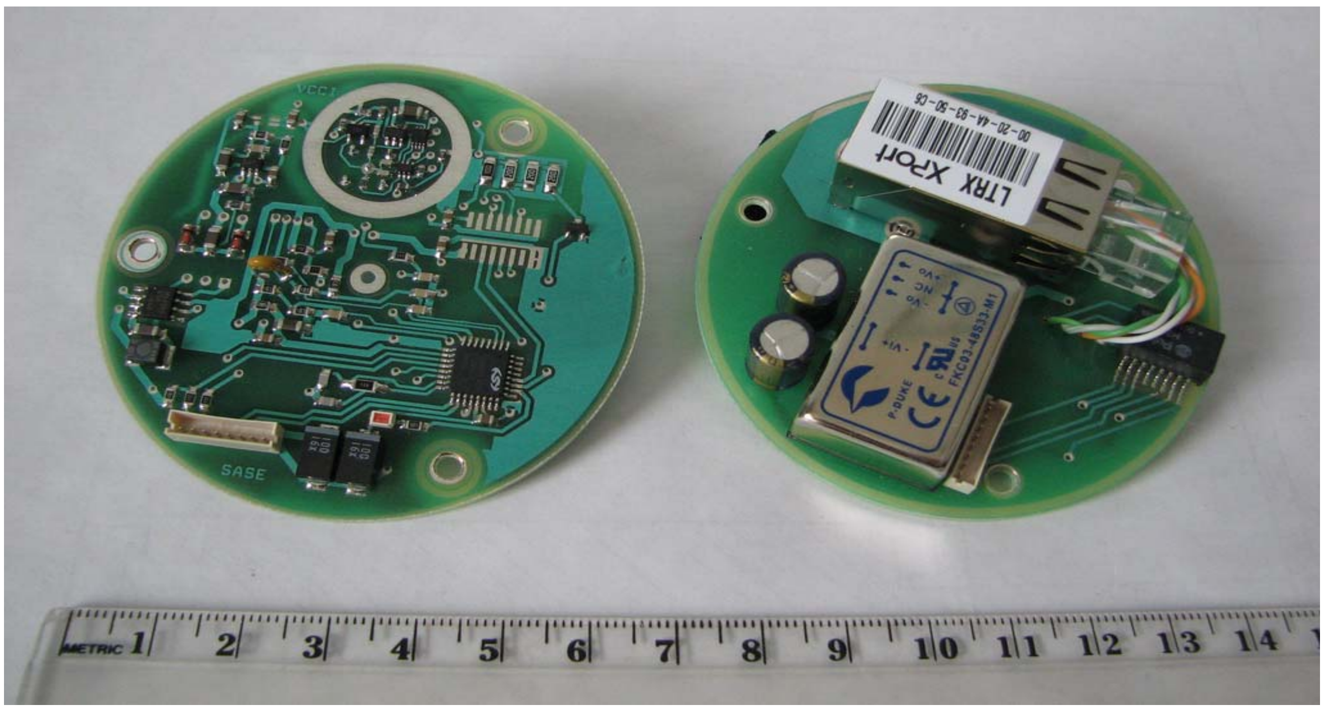
T0=4xRxCg
T1=4xRxCg+4xRxCr
T2=4xRxCg+4xRxCz

$$\frac{T_1 - T_0}{T_2 - T_0} = \frac{C_r}{C_z}$$

A method used for measurement is to convert variable capacitance into frequency, after that to convert the frequency to digital form. The developed circuit uses the idea presented at the work of N.Toth and Gerard C.M. Meijer [1]. General idea of the converter is an RC-generator with oscillating frequency determined by it's internal parameters. To connect by turns Cr and Cz one can measure 3 periods T0,T1, T2 and calculate Cz removing parasitic capacitance C.

SASE consists of two independent parts: upper one with electronics inside (usually named as head) and lower one (usually named as vessel) filled with water. The general view of the sensor is shown at the picture on the left. All the body parts are done with stainless steel. On the top there is a special nest for a 1.5 inch ball to provide alignment survey. Inside the vessel there is a hole for placement of temperature probe.

The electronics of SASE is mounted on two printed circuit boards. The board 1 includes Lantronix XPort [3], Power supply controller, DC-DC converter and transformer. The board 2 includes **C=>F** converter and flash microcontroller. On the picture below a view of the SASE electronics is presented. The board 1 is at the right side, the board 2 is at the left one.



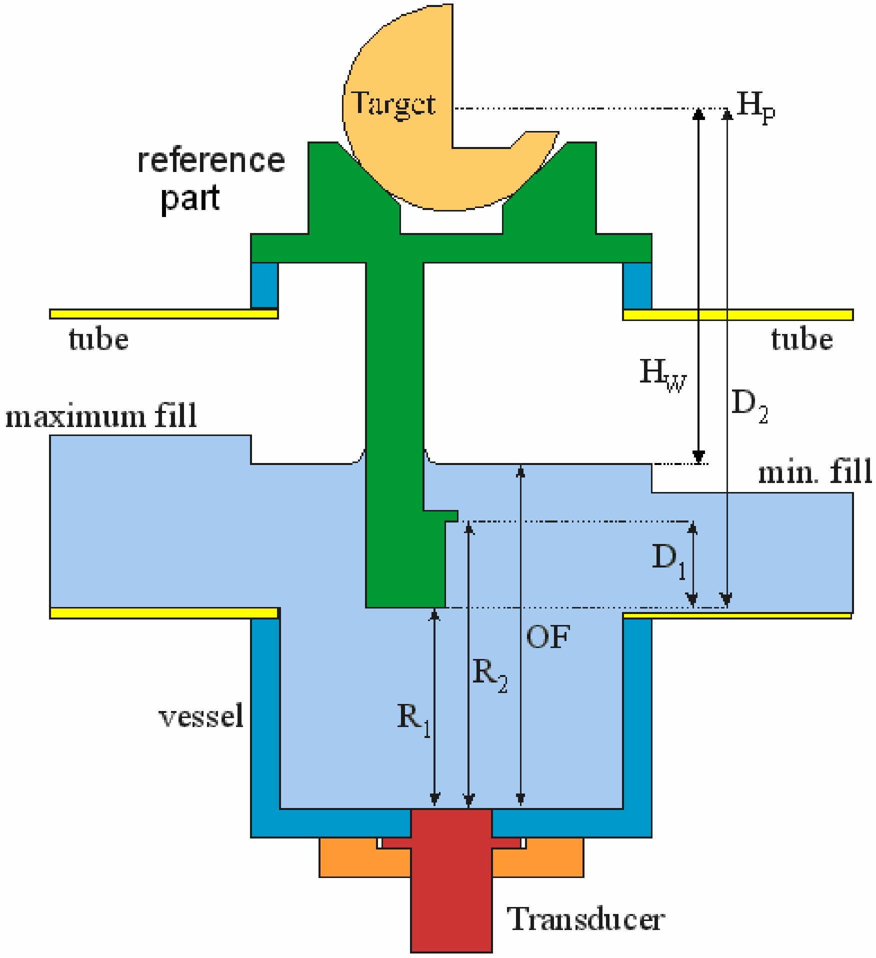
3. ULTRASONIC LEVEL SENSOR ULSE

The presented ultrasonic level sensor ULSE is also intended for monitoring of LCLS Undulator vertical position:

- Displacement range - 5 mm ;
- Resolution – not worse 0.2 μm;
- Accuracy - not worse 5.0 μm;
- Sampling rate – 100 Hz.

A pulse-echo method is used in ULSE for water level measurements. The ultrasonic hydro-location is well known and widely distributed method of distance measurements for many applications.

One of precise methods was described by Markus Schlösser and Andreas Herty at their report presented at the 7th International Workshop on Accelerator Alignment [4]. Their idea is to locate not only the water surface in a vessel, but also two addition surfaces with calibrated distance between them and at the calibrated distance to alignment reference target. This idea pushed us to develop the Ultrasonic Level Sensor for precise measurement of the absolute vertical displacements of accelerator structures.



Principle of organizing the reference surfaces at the ULSE

(Picture is from the
M. Schlösser & A. Herty ***report)***

$$H = D_2 - D_1 \cdot \frac{t_{of} - t_{R1}}{t_{R2} - t_{R1}}$$

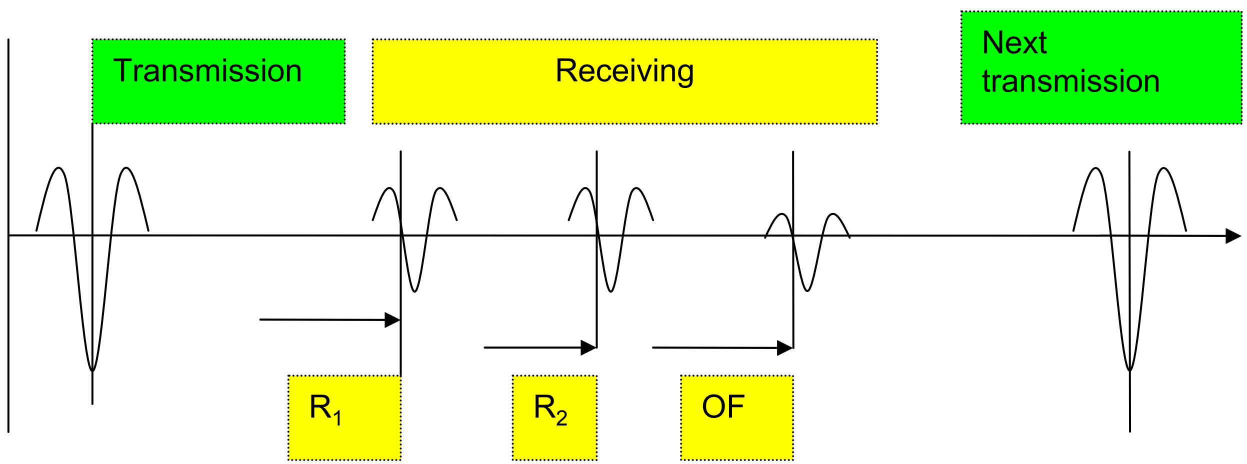
***H - distance from the water surface* Hw**
***to external reference surface (point)* Hp**

ULSE consists of ultrasonic transducer, vessel with tube outlet, reference part, temperature probe. The reference part has two reference surfaces to calibrate the measurements and special nest for a 1.5 inch ball to provide alignment survey. There are no any electronics inside the body of ULSE. The electronics is placed into separate box, which can be located on some distance (up to 2 meters) from the mechanical body of ULSE. Choice of transducer for ULSE and physics of hand-picked transducer were in detail described in our report on IWAA06 [5].

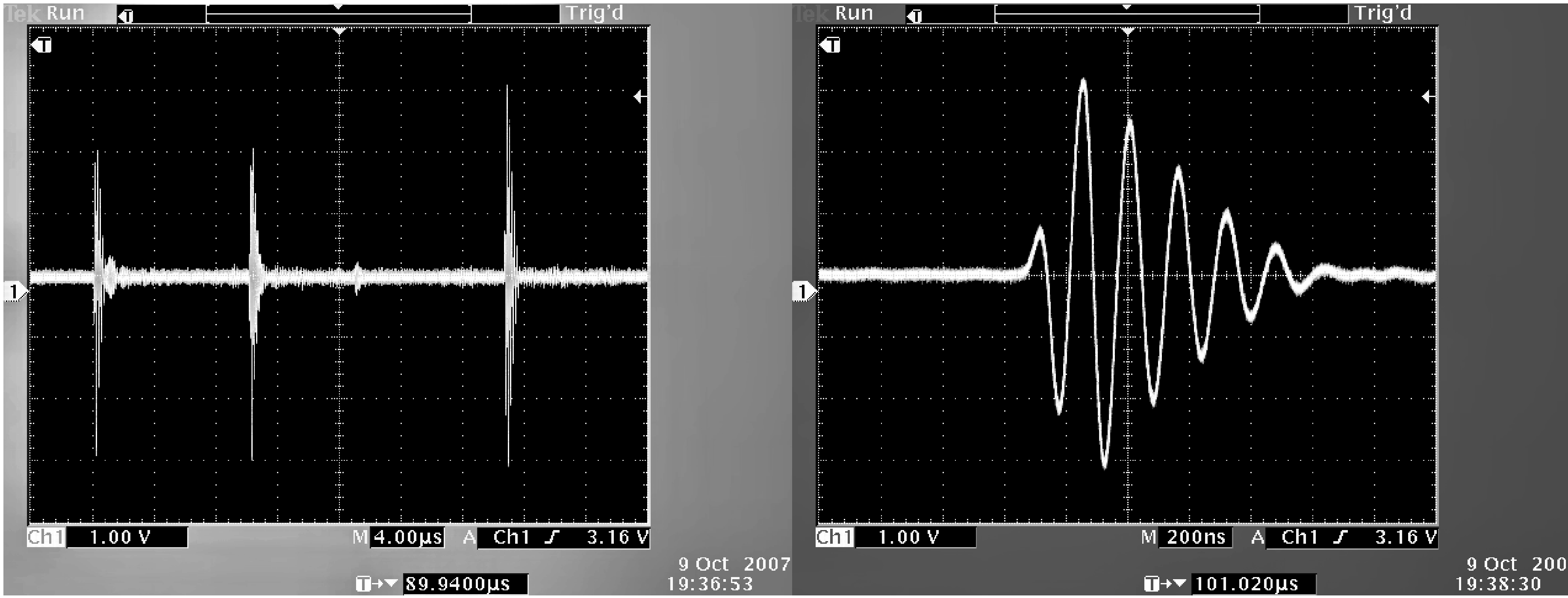
The box with electronics has four different connectors. Three of them are used for connection of the transducer, temperature probe, data acquisition system and power. The fourth connector is used for control of the reflected signals.

$$H = D_2 - D_1 \cdot \frac{t_{of} - t_1}{t_2 - t_1}$$

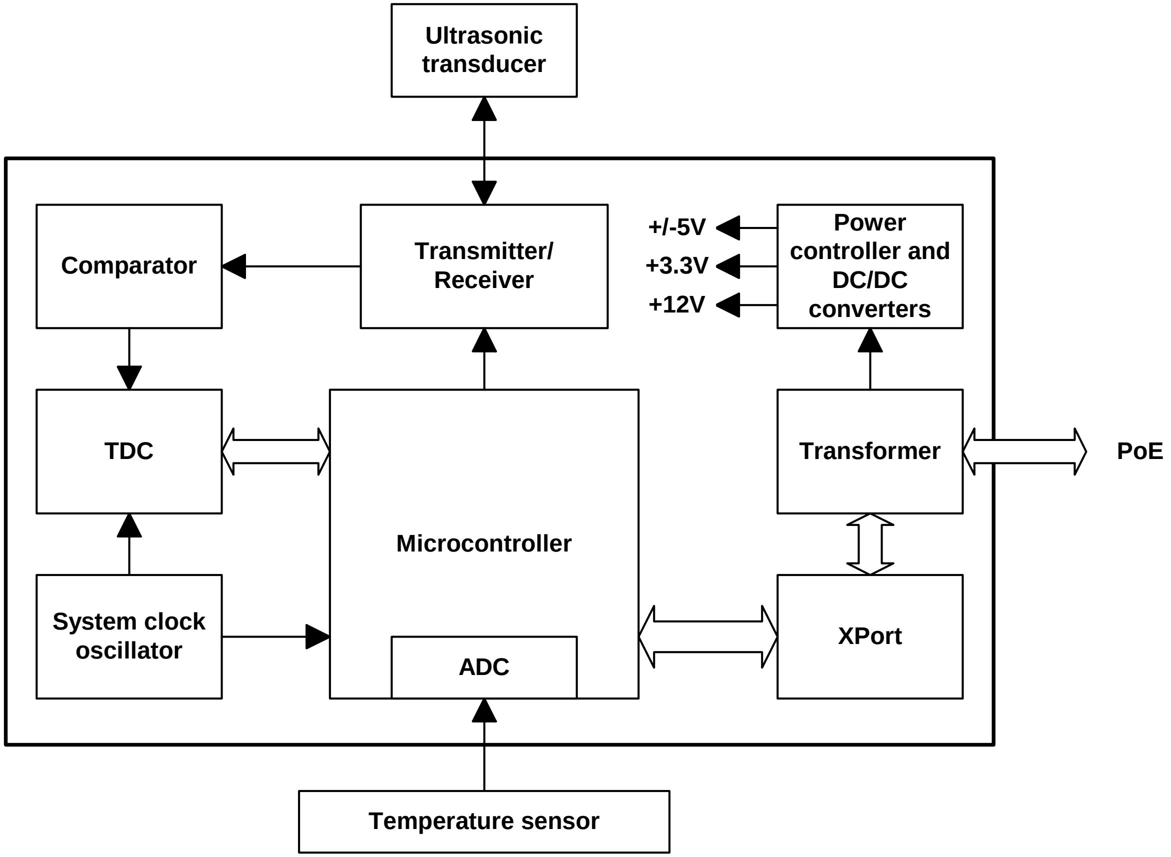
The goal of ULSE electronics is to measure time intervals with the accuracy as fine as possible and to calculate the resulting values



Time diagram of one measuring cycle



Real oscillograms of reflected signals.



Functional circuit diagram of the ULSE electronics

The sequence of operations of the electronics of the ULSE

- After power “*ON*” the Microcontroller begin fulfillment of program, placed in its internal memory. The microcontroller makes measurement cycle once on 10 ms.
- It forms start pulses for the Transmitter and TDC.
- The Transmitter generates electrical pulse for Transducer.
- The Receiver takes the reflected signals and sends them to the Comparator.
- The Comparator transforms analogous signals into digital pulses.
- TDC measures time intervals between the start pulse and the pulses coming from the Comparator.
- The Microcontroller gets digital codes from TDC and prepares them for the next transmission to PC computer.
- Number of cycles and clock frequency of PC is determined by system and size of the ULSE memory.
- The Microcontroller also can measure temperature of ULSE vessel and accordingly temperature of water inside the vessel with help of temperature probe and inboard ADC. Temperature measurement resolution is about 0.1 C.

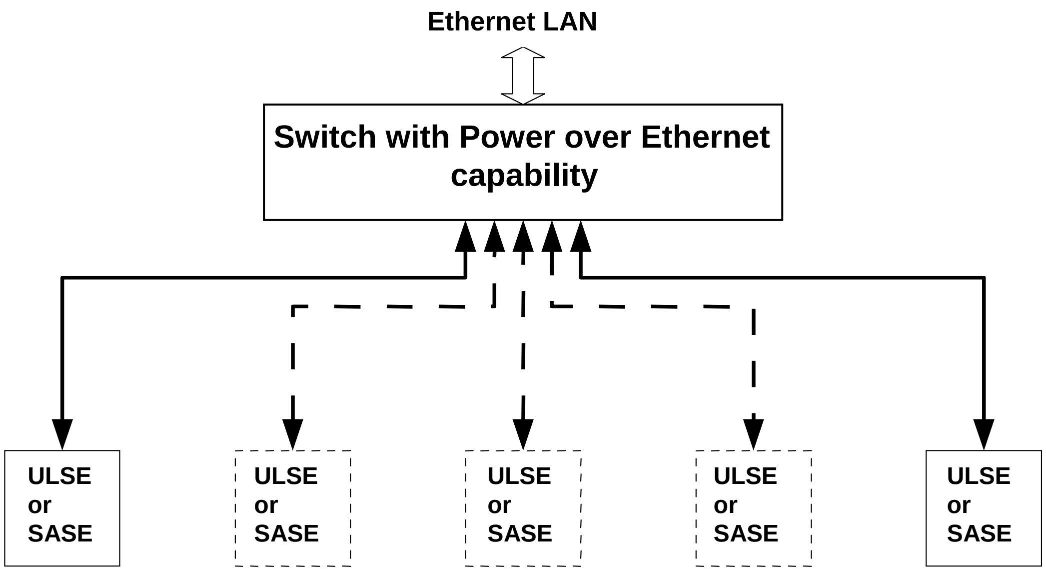
4. DATA ACQUISITION SYSTEM OF LEVEL MEASUREMENTS

Data acquisition is organized with help of Local Area Network based on Power over Ethernet (**PoE**) interface and standard system of commands ***Field Point F1001*****,** National Instruments Corp [6].

PoE interface is a system to transmit electrical power, along with data, to remote devices over standard twisted pair cable in an Ethernet network.

PoE interface operates under IEEE 802.3af specification. The specification provides 48 V DC over two out of four available pairs on a Cat3./Cat5. cable with a maximum current of 400 mA for a maximum load power of 15.4 W.

Functional diagram of HLS Data acquisition system.

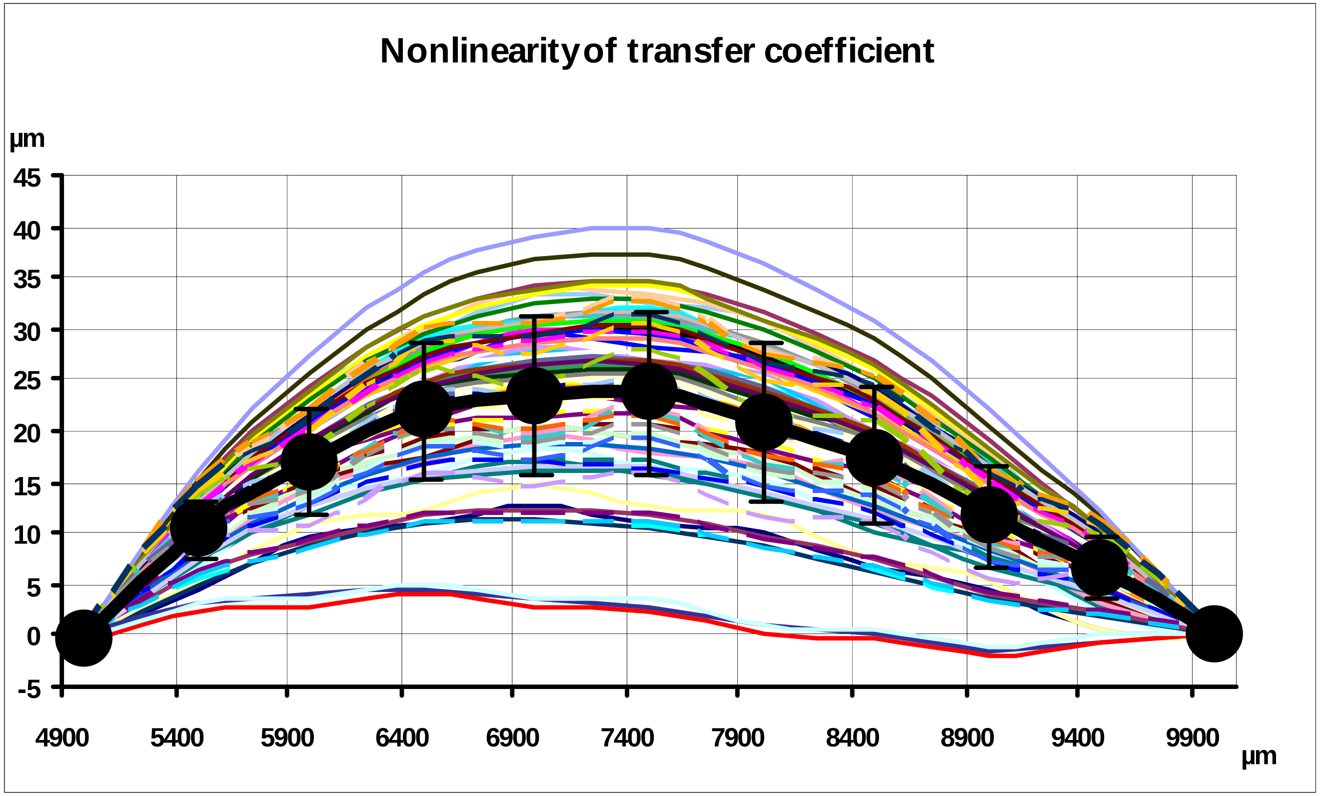


- All sensors (ULSE or SASE type) are connected up to standard switches with Power over Ethernet capability (one channel of the switch per one sensor).
- The switches are connected to local area network based on Ethernet.
- Number of the used sensors can easily vary by changing number of switches.
- Length of the connecting cables between the sensors and the switches can be as long as 100 meters.

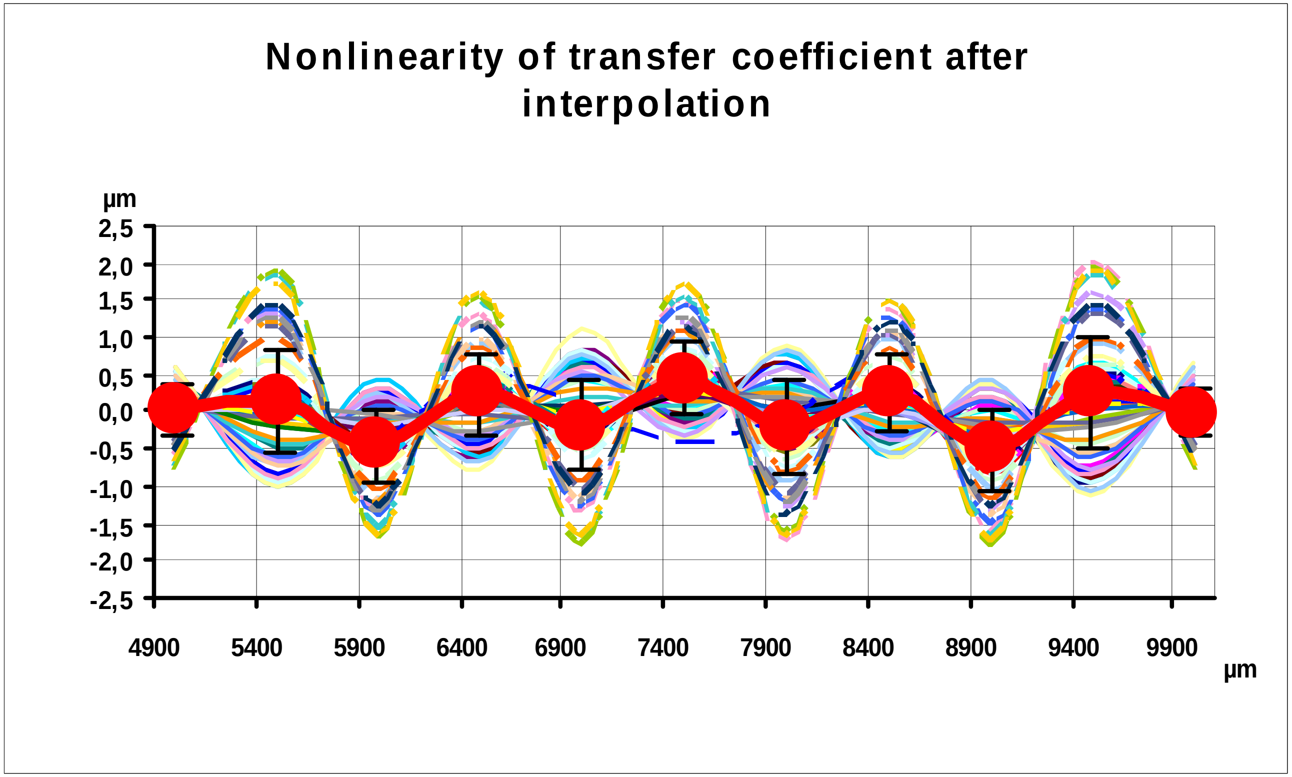
5. COMPARISION OF TWO KINDS OF THE SENSORS

Ultrasonic sensor has a lot of benefits in comparison with capacitive one:

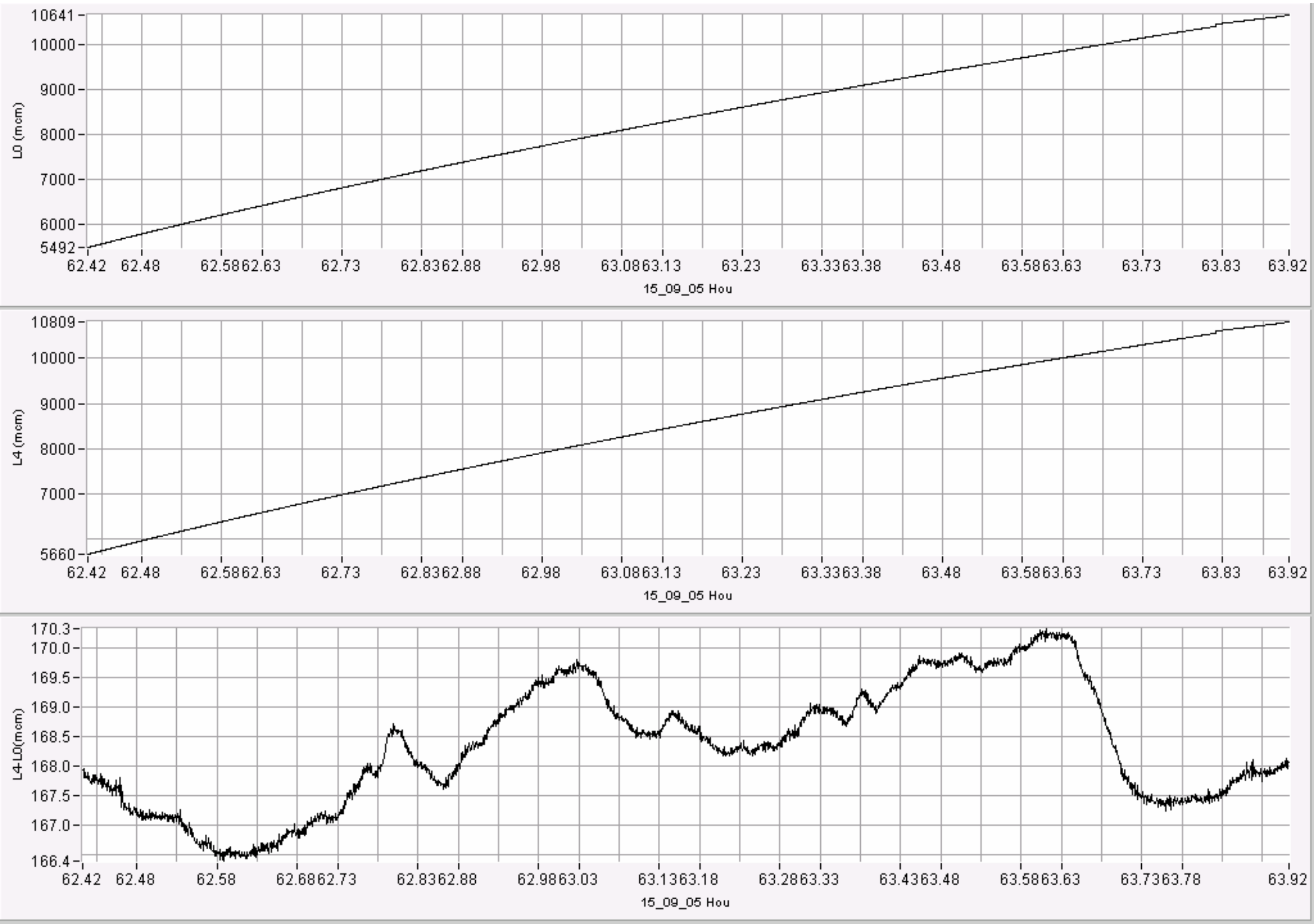
- more high absolute accuracy
- more sensitivity at more high sample rate
- measuring data don't depend on electronics drifts (temperature and time) because of calibration capability during each measuring cycle
- no dependence of relation "signal/noise" from measuring level
- high linearity of transfer coefficient (output signal => level)
- no need in precise calibration – only accurate measurement of two linear sizes for reference part



Nonlinearity curves of transfer coefficient for 80 SASE sensors.



Nonlinearity curves of transfer coefficient after interpolation by the 3rd order polynomial for the SASE sensors.



Absolute level increases

More then

5mm

Level difference

Less than

4µm

Checking of the accuracy (water flew in)

Capacitive level sensors have now only two benefits.

1. Capacitive sensors are more inexpensive. For ultrasonic sensor price of transducer forms considerable part of costs.
2. Capacitive sensors are working during many years. There is a big experience of work with them. Ultrasonic level sensors have not such experience.

So very important question! ***"What is reliability of the ultrasonic transducers? How long they can work without essential worsening of their characteristics?"***

The ahead installation of HLS system at LCLS Undulator magnet line promises getting of very interesting experience. It will be the first HLS system consists of two different kinds of level sensors.

6. REFERENCES

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[2] A. Chupyra, M. Kondaurov, A. Medvedko, S. Singatulin, E. Shubin “SAS family of hydrostatic level and tilt sensors for slow ground motion stadies and precise alignment” Proceeding of 8th IWAA04, Geneve, 2004.

[3] http://www.lantronix.com/device-networking/embedded-device-servers/xport.html

[4] M. Shlösser, A. Herty, “High precision accelerator alignment of large linear colliders – vertical alignment”. Proceedings of the 7th IWAA, Spring-8, 2002.

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[6] http://zone.ni.com/devzone/cda/tut/p/id/3346.

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