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First Measurements and Results With a Stretched Wire Test Setup[1)]

Franz Peters, Georg Gassner, Robert Ruland

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Abstract

A stretched wire test setup[2)] has been implemented to gain experience for the final design of a wire system, which will meet the position monitoring requirements in the LCLS undulator section[3)]. The report briefly introduces the system's architecture and describes first measurements and results.

Introduction

The LINAC Coherent Light Source [LCLS] is a free electron laser, designed to produce high brilliant X-ray beams using Self Amplified Spontaneous Emission [SASE]. Due to the physics of SASE, the electron beam has to be held very precisely on the same trajectory as the X-ray light beam generated by the undulator magnets. To optimize the SASE output, trajectory deviations between both beams have to be minimized to a few micrometers along the entire undulator section and held stable over the time period between beam-based-alignment processes.

Consequently, extremely high position stability of all magnets in the undulator section is required to operate the LCLS successfully. The knowledge of any magnet movement exceeding few micrometers during periods of several weeks is essential for efficient X-ray generation.

A well known principle of monitoring transverse component positions along beam lines is the application of stretched wires, associated with suitable wire position sensors and electronics. The particular challenge at LCLS is the required wire system performance in conjunction with the length of the undulator section and the large number of monitors. Verification of system stability and resolution under real conditions is the primary goal of this test setup.

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1) Work supported in part by the DOE Contract DE-AC02-76SF00515. This work was performed in support of the LCLS project at SLAC.
2) Originally developed as DESY contribution to the FFTB experiment at SLAC, F. Peters et al.
3) General Undulator System Requirements, LCLS PRD 1.4 - 001, Heinz-Dieter Nuhn

SLAC National Accelerator Laboratory, Menlo Park, CA 94025

1. The stretched wire test setup

The geometry of the wire test setup in the Sector 10 alignment laboratory is shown in *Figure 1*. The laboratory is located in a former access tunnel to the Linac. Most of the tunnel is more than five meters below ground except for a short section around the access region. Air conditioning and air distribution equipment is installed as shown on the sketch below. The air temperature is measured near both ends of the wire system. During most of the measurements air conditioning was switched to OFF, due to other activities inside the tunnel.

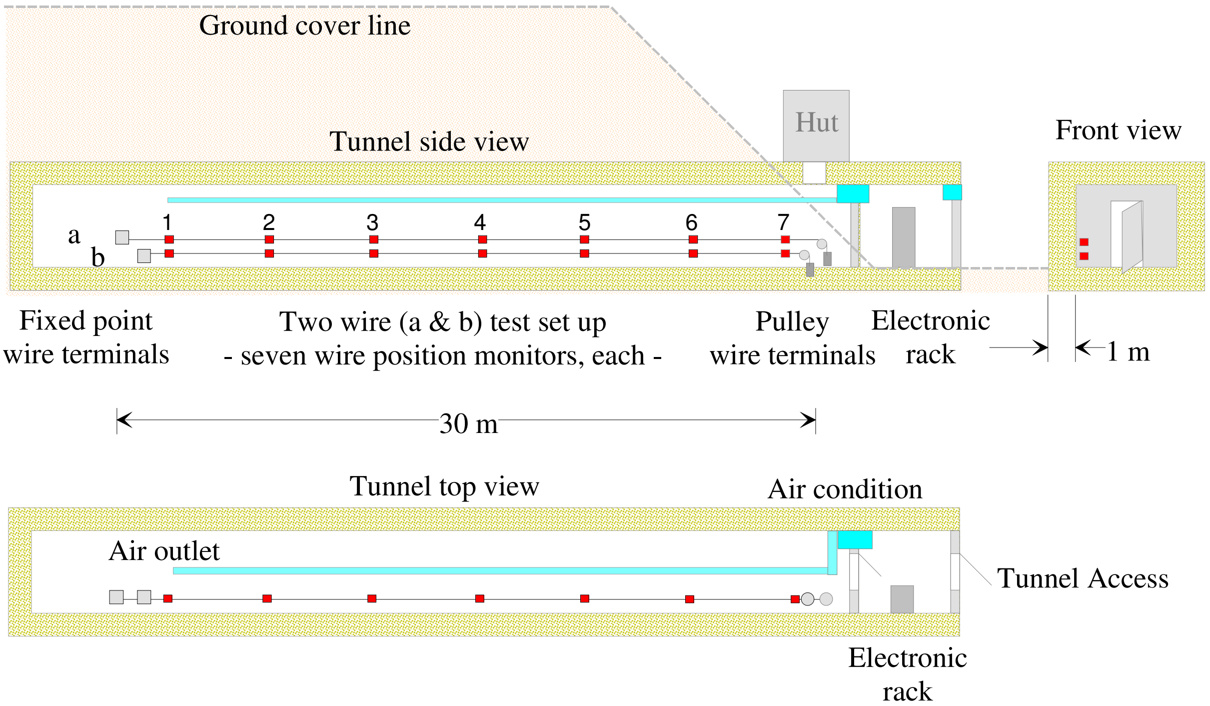


Figure 1 Wire system test set up - geometrical layout at the Sector10 alignment tunnel -

Two stretched wires with associated equipment are placed on the east wall, roughly one meter above the floor in an upper and lower position. Seven position monitors are distributed equidistantly on each wire between the end stations. The first and last monitors are close to the end stations. The distance between end stations is about thirty meters. The length of both wires is slightly different as shown in *Figure 1*.

Each wire is fixed at one end station and the other end station is equipped with a pulley. To stabilize and minimize the sag, the wire is stretched by a weight as illustrated in *Figure 2*.

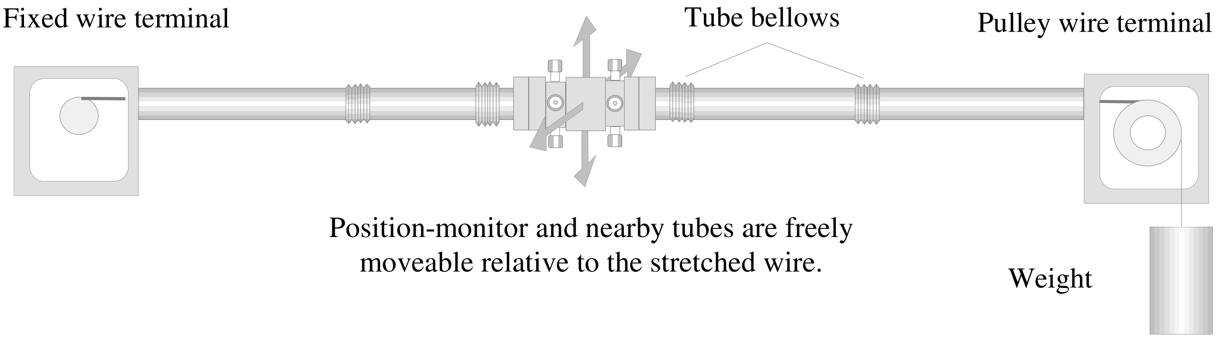
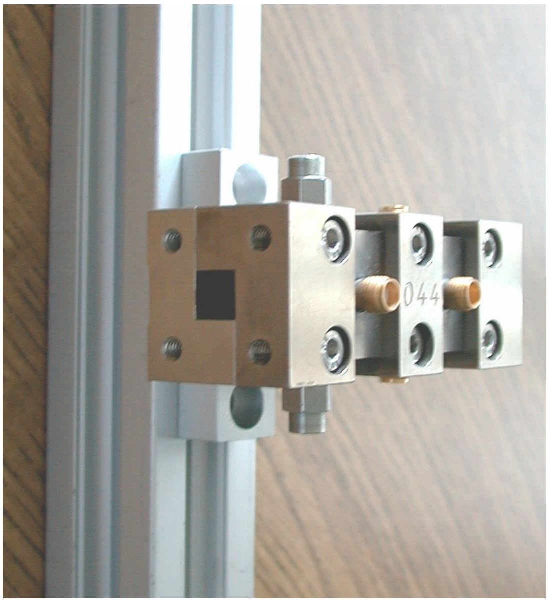


Figure 2 Principle scheme of the stretched wire position system.

The entire wire is enclosed in metallic tubes or boxes. Position monitors are mechanically decoupled from the rigid tube with bellows and are freely moveable with minimal force in all radial directions.

A wire position monitor is shown in Figure 3a. Four small RF loops, i.e. antennas are positioned inside the monitor gap in the horizontal and the vertical plain. The monitor gap is 8 by 8 millimeter square.



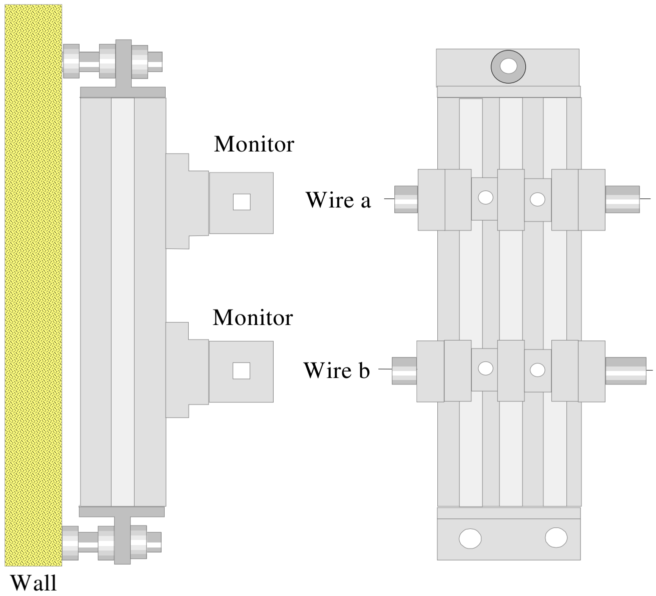


Figure 3a Wire Position Monitor front *Figure 3b Position Monitor support*

Pairs of monitors are installed on one common support attached to the upper and lower wire as shown in *Figure 3b.*

Both wire systems are controlled by a PC based data acquisition system as shown in *Figure 4.*

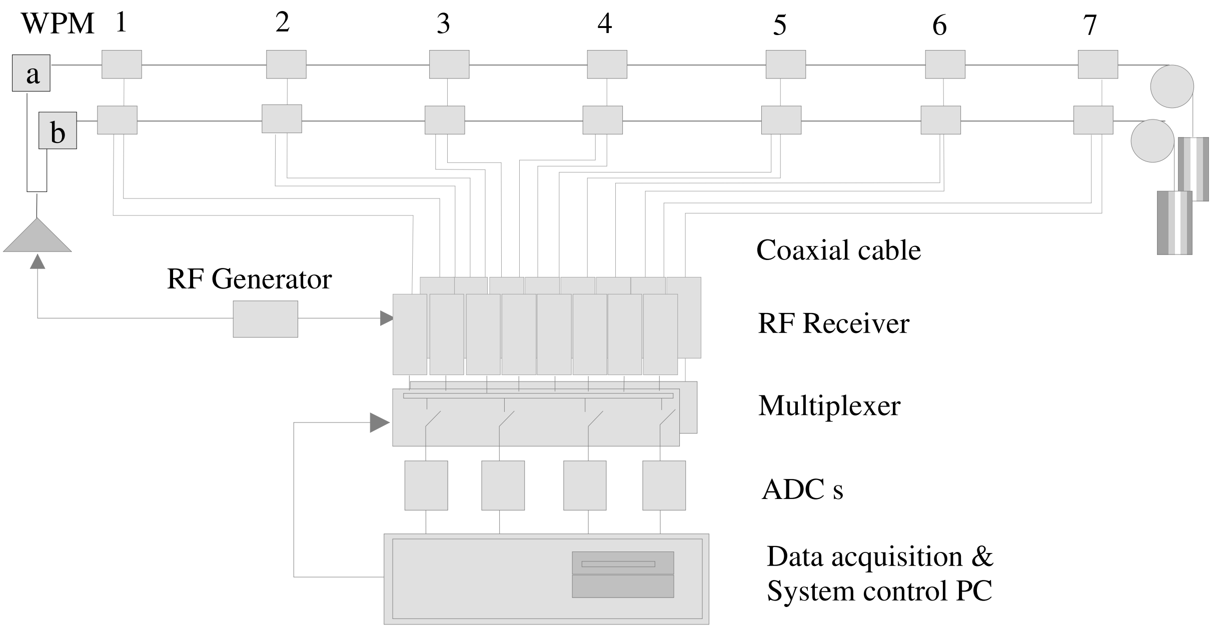


Figure 4 Wire system test set up - electrical layout and control -

All monitor loop signals are transmitted via coaxial cables to a central electronic station. The loop signals of each monitor are multiplexed and digitized by four ADCs in parallel. The set up is controlled by one standard PC in a fully automated way. Measurement values are stored in a database with time stamps and other parameters like air temperature etc.

Function

The stretched wire system works like a coaxial RF transmission line, where the electromagnetic field strength is inversely proportional to the radial distance from the wire. The monitor loop signals Ui are proportional to the field intensity inside the loops. With pairs of loops in opposite positions around the wire in the horizontal and vertical plane, the wire position is given as:

$$\text{Horizontal} = C * (U_{\text{left}} - U_{\text{right}}) / (U_{\text{left}} + U_{\text{right}}); \quad \text{Vertical} = C * (U_{\text{upper}} - U_{\text{lower}}) / (U_{\text{upper}} + U_{\text{lower}})$$

The constant C is defined by the geometry of each individual monitor.

Function Test

One of the convenient advantages of a stretched wire systems is the ability of quick and conclusive overall system checks, which can be executed in situ simply by moving the wire end stations in horizontal or vertical directions.

The result of such a cross check is shown in *Figure 5* as the response of wire position monitors 1 to 7 on large and small horizontal movements of one wire end station. All readouts should be simply on a straight line, if the shape of the moved wire remains stable.

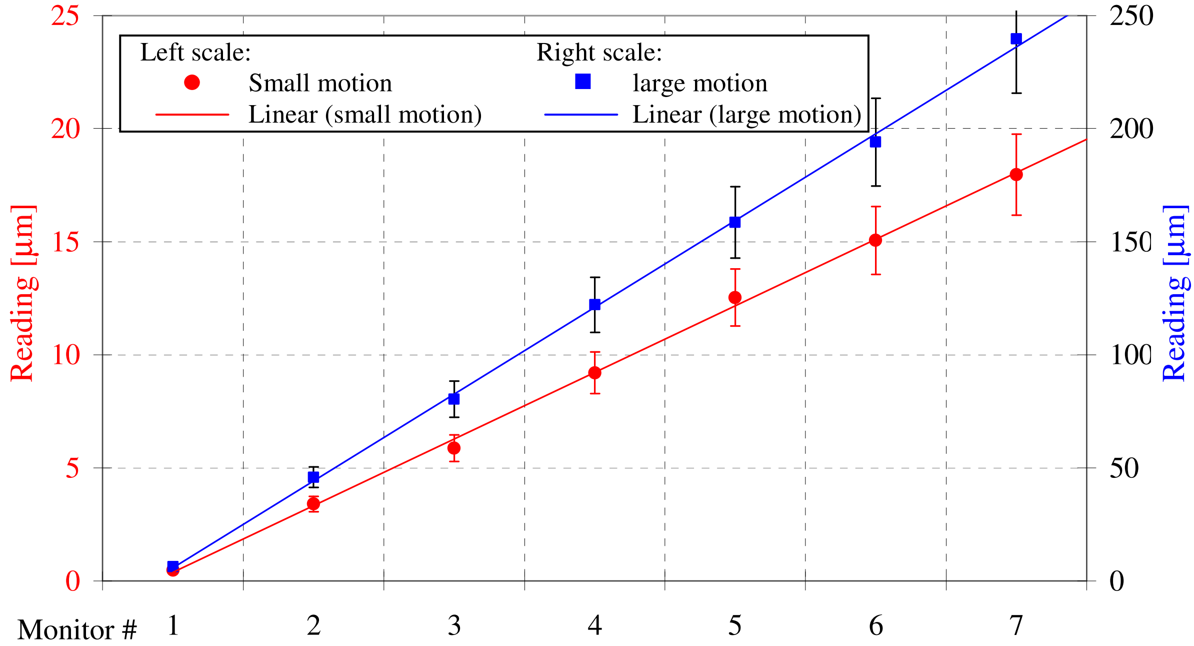


Figure 5 Wire system test set up - overall system test by dedicated movements of end station e2 -

The error bars indicate a ten percent expected uncertainty due to the non calibrated individual readout channels. Since the results shown above were satisfactory for the planned relative measurements, no readout calibrations were done for the upcoming measurements.

On the final system, automated calibration of individual monitors with associated coaxial cable and electronic can be executed in situ any time to increase the accuracy of individual wire position readouts over a wider range and to homogenize the scale of all monitors.

2. First Measurements and Results

First wire position measurements with the setup were done during May 04 with seven monitors on the upper wire. The outcome was surprising at a first glance, because of unexpected large wire motion versus time of day at all seven monitors as shown in *Figure 6*.

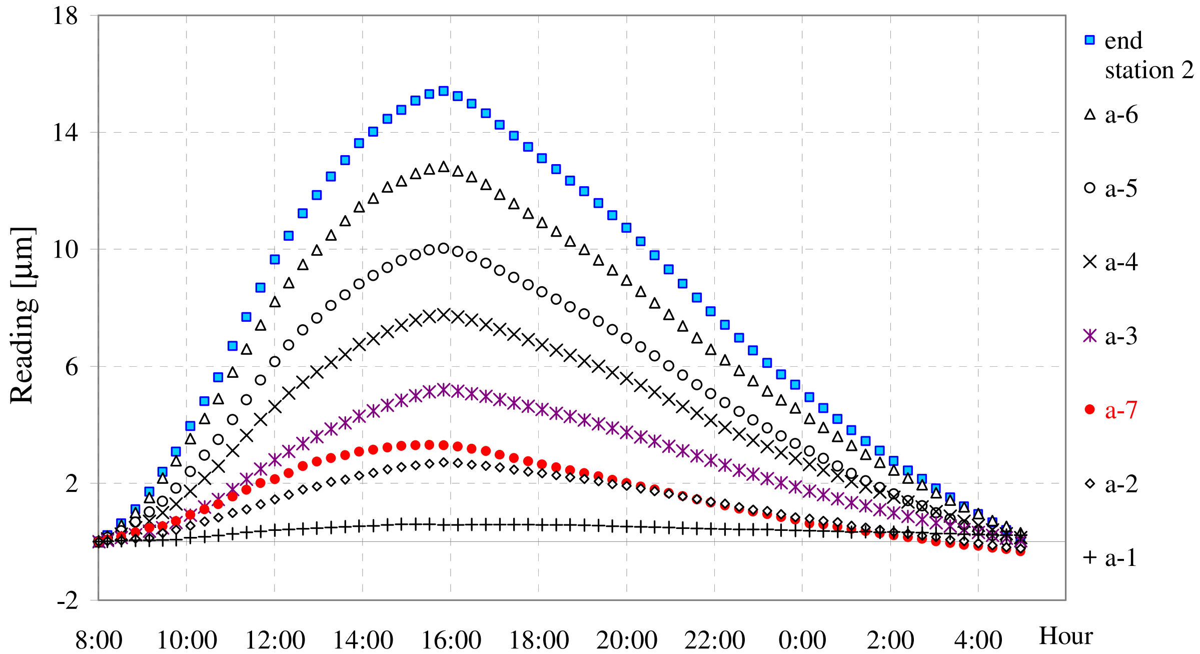


Figure 6 Horizontal wire positions at seven monitors of wire a and position of end station 2.

As the picture clearly illustrates, all curves correlate except for monitor a-7. Its general behavior looks similar except for the maximum position. This correlation indicates that monitors a-1 to a-6 in fact did not move, but that instead the position changes were caused by a moving end station (see also self test *Figure 5*).

With the data from monitor a-1 to a-6 the movement of the endstation-2 position was derived with a linear fit, illustrated as the blue curve shown in *Figure 6.* This calculated end station movement explains all position changes of monitors a-1 to a-6 down to fractions of microns. Long term observations still show movements of the other stations on a small scale. The deviating behavior of monitor a-7 can be explained if we assume that this monitor moves along with the end station but on a smaller scale.

This seems quite reasonable considering the small distance (0.7 meters) between monitor a-7 and the endstation-2 particularly with regard to the environmental conditions. Both units are located close to the uncovered part of the tunnel which is exposed to direct sun light. The horizontal movements shown in *Figure 6* are strongly correlated with time of day. In addition, similar movements and correlations were observed in the vertical direction.

Additionally, a four day record confirmed the first observations. *Figure 7* shows the wire position data as a strip chart record. Correlation with time of day looks impressively distinctive. The minima around 8:30 am two hours after sunrise and the maxima around 3:30 pm correlate with the time when the sun hits the uncovered part of the Sector 10 tunnel. From the weather record, the 22nd of May was a cloudy day followed by a sunny one, which explains the various daily shapes.

It needs to be realized that even the inside of a tunnel with a cross section as shown in Figure 1 and concrete wall thicknesses of one meter reacts promptly to heating its outside surface by the sun with up to 20 µm movements.

Not only the end-station is affected by movements but also on a smaller scale all the other sensors. To mitigate this effect, the uncovered part of the tunnel was thermally isolated with foam. Daily coupling to the outside temperature is now reduced and more than a factor of five smaller than before as shown in *Figure 7*.

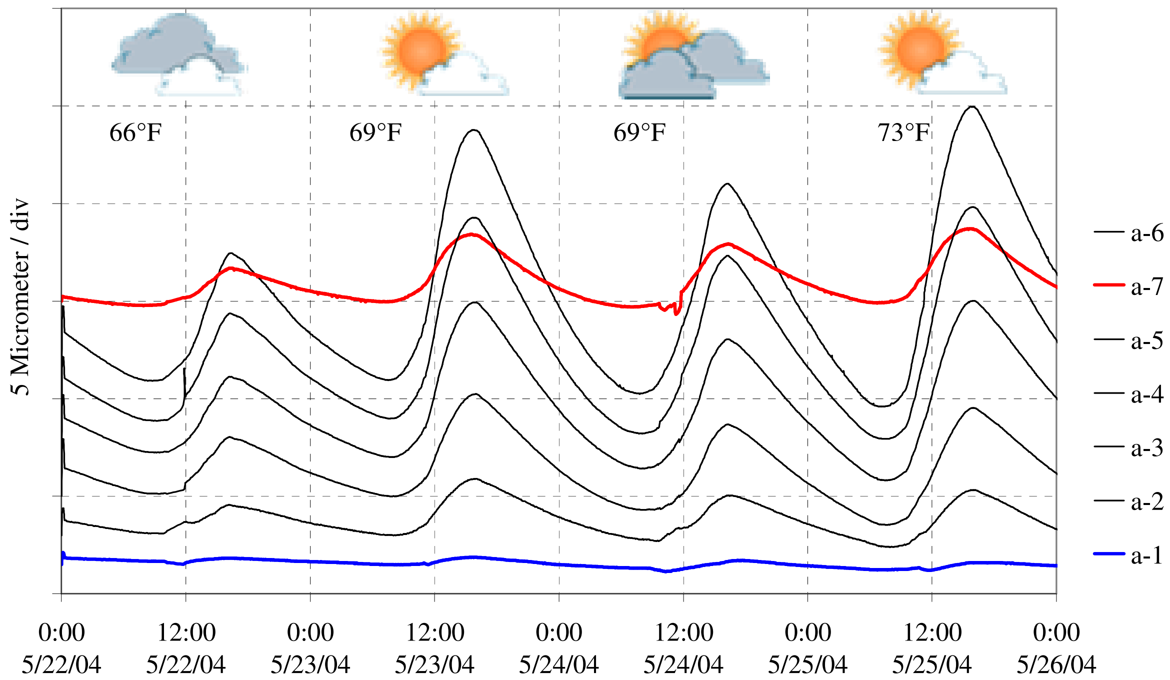


Figure 7 Four day strip chart record of horizontal wire positions at monitors a1 to a7.

After commissioning the second wire, data was continuously recorded during October. The horizontal wire position tracks at all monitors on both wires are shown as a strip chart in *Figure 8.*

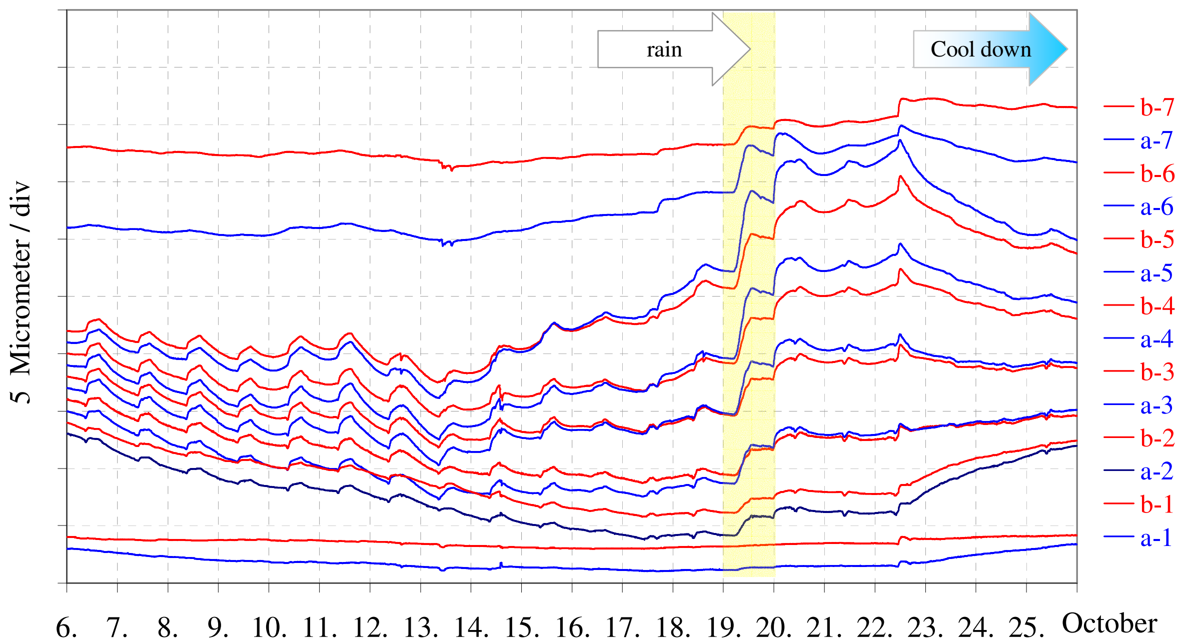


Figure 8 Strip chart record of horizontal positions of both wires and seven monitors at each

Due to the foam isolation of the uncovered tunnel, the daily cycles are smaller compared to data shown in *Figure 7* but nevertheless distinctive.

By assuming that mainly the end-station moves, the wire positions shown in *Figure 8* were transformed into actual wall movements, see *Figure 9*.

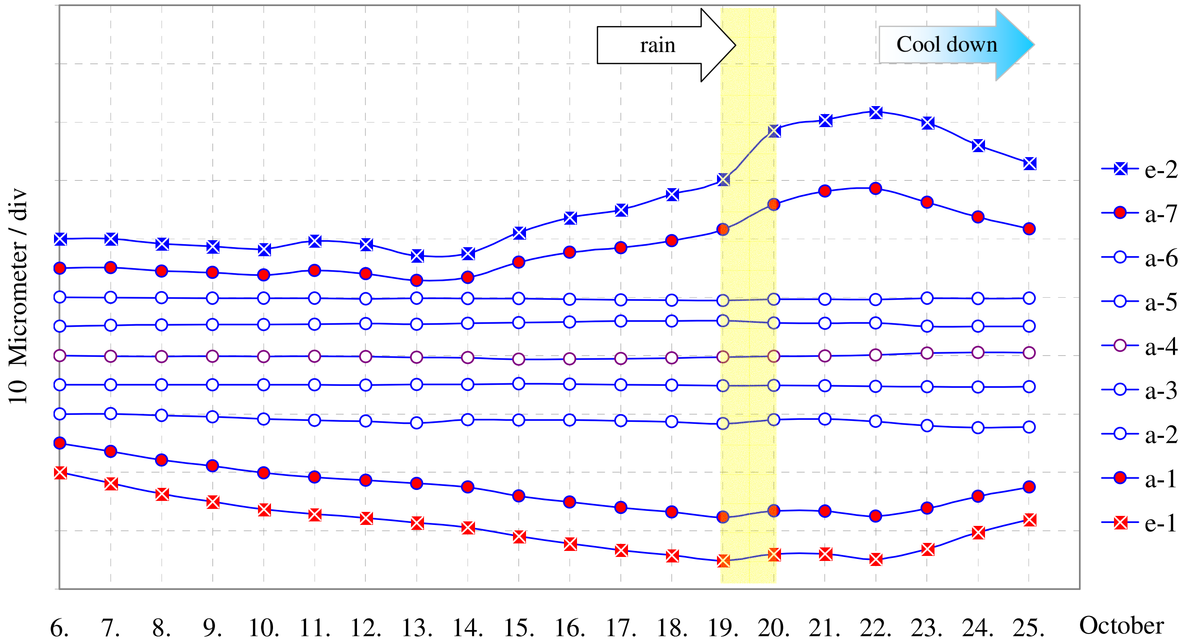


Figure 9 Horizontal wall positions at seven monitors and two end stations. - Daily snap shots -

The wall section from monitor a-3 to a-6 seems to be stable within a micrometer over the entire run. But both tunnel end sections move with different speed and direction. On October 19th endstation-2 moved roughly 10 µm. Note: *Figure 9* shows just daily snap shots, higher order frequency motion as shown in *Figure 8* are filtered. The motion trends at both ends of the tunnel change direction on October 22nd. On that day air conditioning was switched from OFF to continuous cool down.

A more suggestive artist view of wire and wall positions during the October run is illustrated in *Figure 10*.

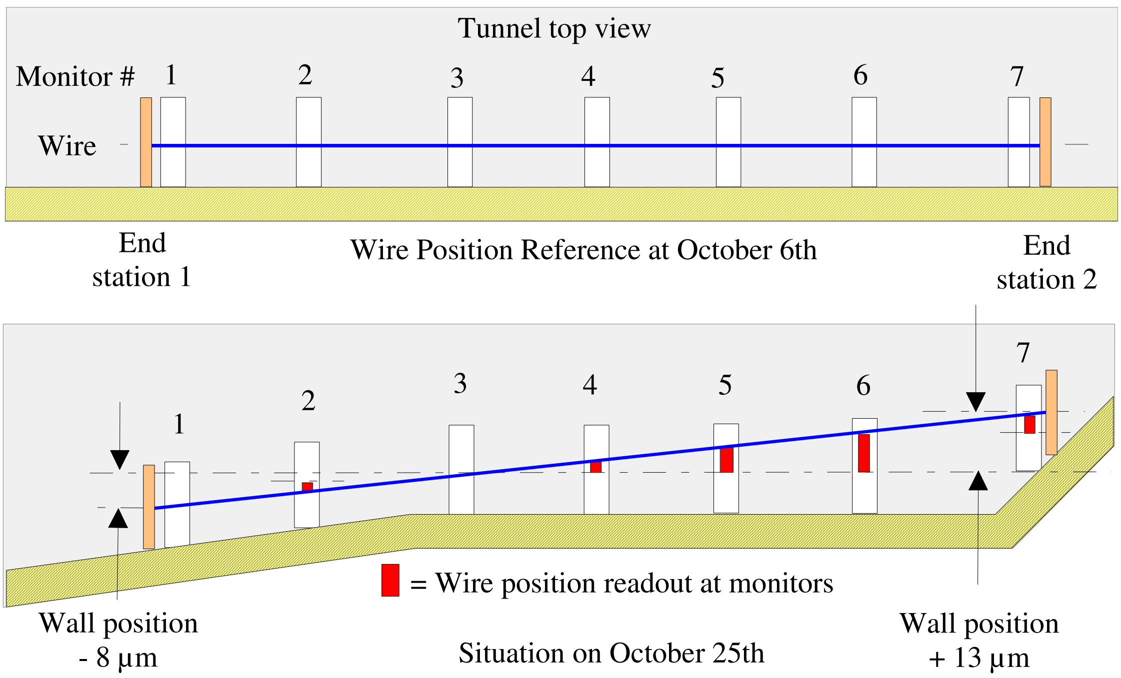


Figure 10 Tunnel wall deforming during the October run.

At run end, after a few days of continuous cool down, the air temperature dropped below the lower threshold starting the familiar automated air conditioning cycle. Now tunnel air temperature measured at one specific place oscillates about 0.7 °K as shown in the upper part of *Figure 11*.

Monitor supports and wire end stations are slightly different from a thermodynamic point of view. Therefore a small wire motion is expected at all monitors to be dependent on and correlated with the tunnel air temperature. Due to relatively short support distances to the wall, the expected effect is small but nevertheless measurable as plotted in the lower part of *Figure 11*.

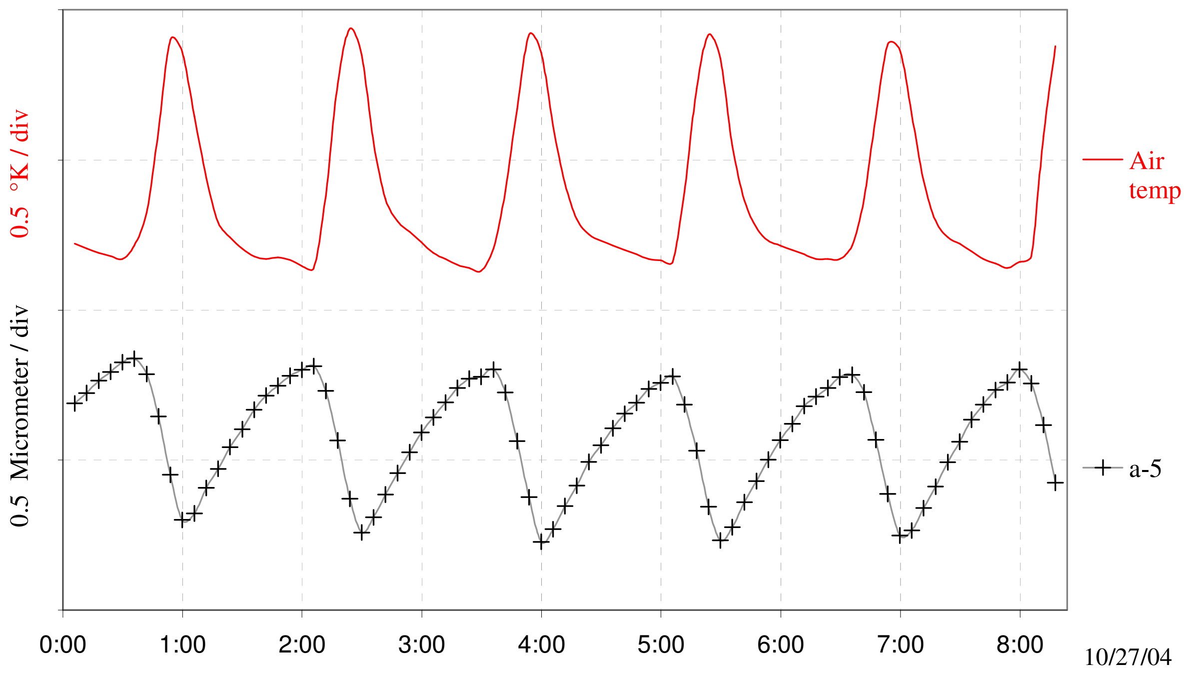


Figure11 Correlation of wire position with air temperature swings, generated by air condition duty cycles.

The smooth track and small scattering of position readouts shown in *Figure 11* reflect the readout resolution and stability of the wire system test setup.

Conclusion

The wire system test setup has continuously delivered plausible data during several months without any failure. Readout stability and resolution of the system appear to be capable of measuring transverse component movements at longer beam lines down to a few micrometers over several weeks.

The measured performance meets position control requirements of the LCLS undulator system. Further R&D will be necessary to investigate the wire dynamics of a 135 meter long wire and a large number of wire position monitors in the undulator section in comparison to the Sector-10 test setup.