A PROOF-OF-PRINCIPLE STUDY OF A SYNCHRONOUS MOVEMENT OF AN UNDULATOR ARRAY USING AN EtherCAT FIELDBUS AT European XFEL

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The European XFEL project is a 4th generation X-ray light source. The first beam will be delivered at the end of 2015 and will produce spatially coherent ≤ 80fs short photon pulses with a peak brilliance of 10^{32}-10^{34} photons/s/mm^2/mrad^2/0.1% BW in the energy range from 0.26 to 29.2 keV at electron beam energies of 10.5 GeV, 14 GeV, or 17.5 GeV. On the project start-up stage three undulator systems SASE1, SASE2 and SASE3 will be used to produce photon beams. Each undulator system consists of an array of undulator cells installed in a row along the electron beam.

Objectives

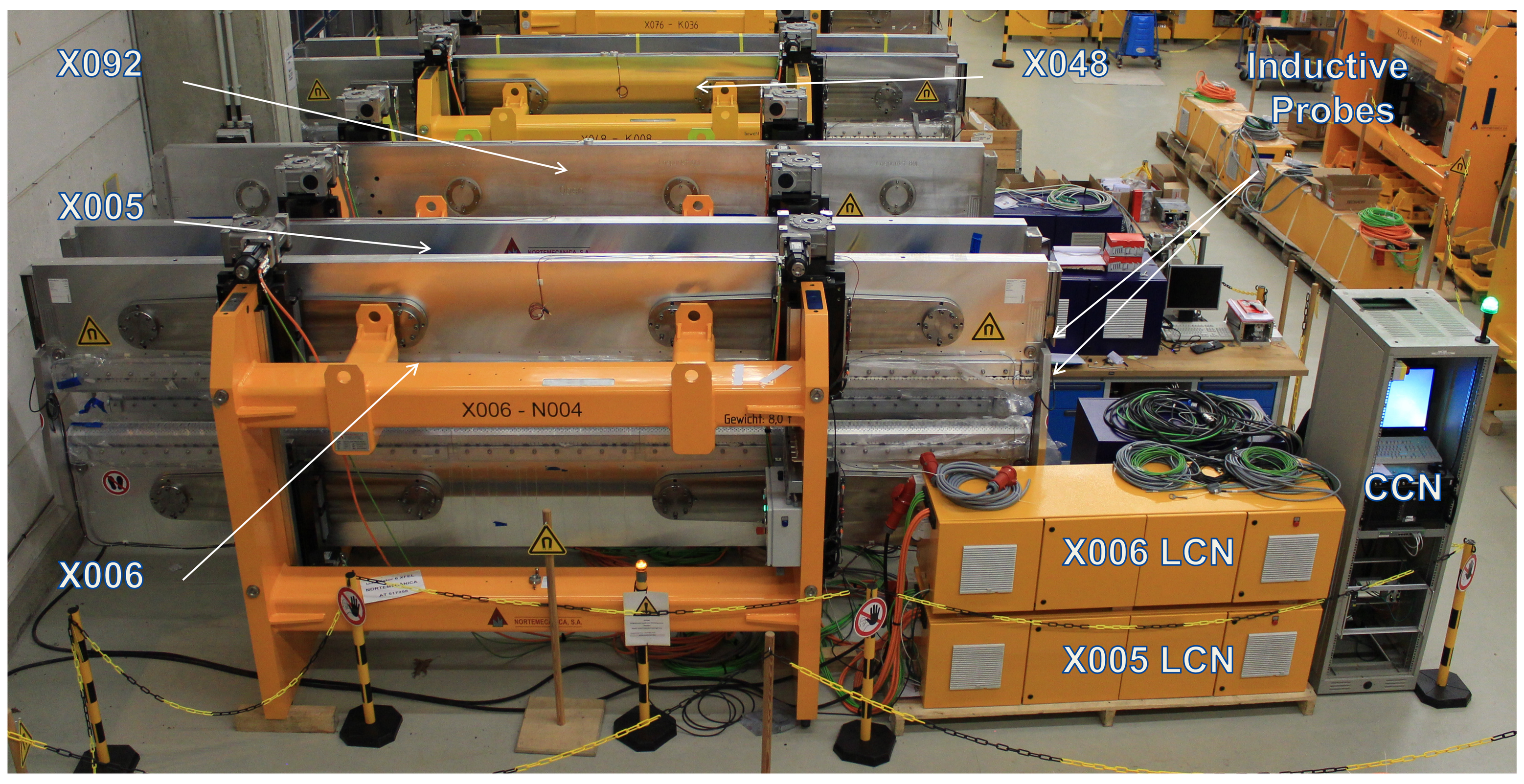
Fast tuning of the radiation wavelength is highly desirable for many spectroscopic techniques requiring fast variation or scanning of the radiation wavelength, which is set by the gap of the undulator system. Dynamic control of the undulator gap is therefore of great importance for user operation. Thence one of the important tasks for the control of the undulator system is a synchronized gap change of the undulator cells.

The simplest way to achieve this is to issue a common start command for all undulator cells. The assumption is that if the start commands on all undulators will be synchronized, if there is no big difference in mechanical and magnetic properties of the undulators and all dynamic control parameters of undulators are the same, although the undulators are running freely, the gap change delay could stay in a reasonable small range of several milliseconds.

A more advanced technique uses a virtual master axis. This is already implemented in the Local Control Node (LCN) of undulator cell, where the axis that controls the phase shifter gap is coupled to the virtual undulator gap axis. Two components of one undulator cell, undulator and phase shifter must run synchronously.

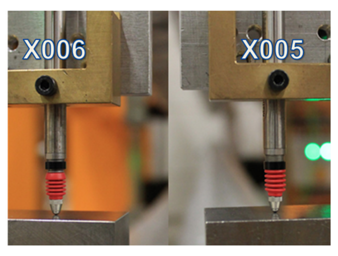
The purpose of this investigation is to prove the satisfactory synchronization level for an array of undulator cells as well as find the reachable level of synchronization between undulator and phase shifter. These results will help to plan the further software development strategy, namely the need to implement a virtual axis in the global control system and couple it with local virtual axes.

Study of the Movement Synchronization Between four Undulators



The undulators X005, X006, X048 and X092 have been daisy chained over the EtherCAT network and connected to the Central Control Node (CCN). The CCN is used to generate the start command and distribute it via EtherCAT Fieldbus to all undulators at the same time, so that they change their gap simultaneously. After the start command has been received by the LCN the local control program start to move the axes to the new position.

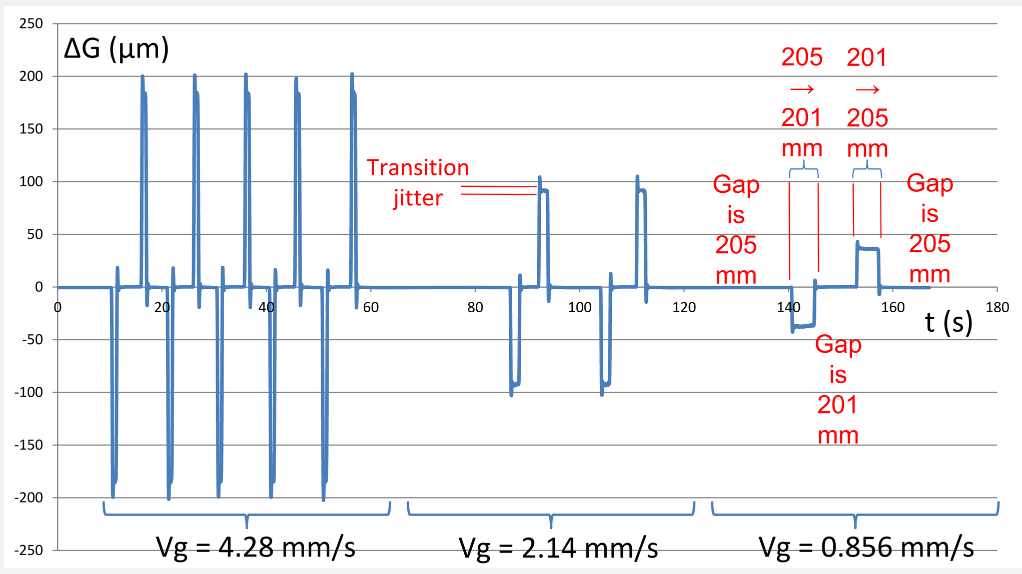
In order to measure the delay of the gap changes between undulators the movements of undulators have been traced using **two independent methods**. The **first** was using the Beckhoff **TwinCAT Scope View** software. The Scope View was running on the CCN and collects the linear encoder position values from the TwinCAT System Manager of each LCN. These linear encoders are physically located on both sides of undulator and are measuring directly the gap size. The **second** method was used as a cross check.



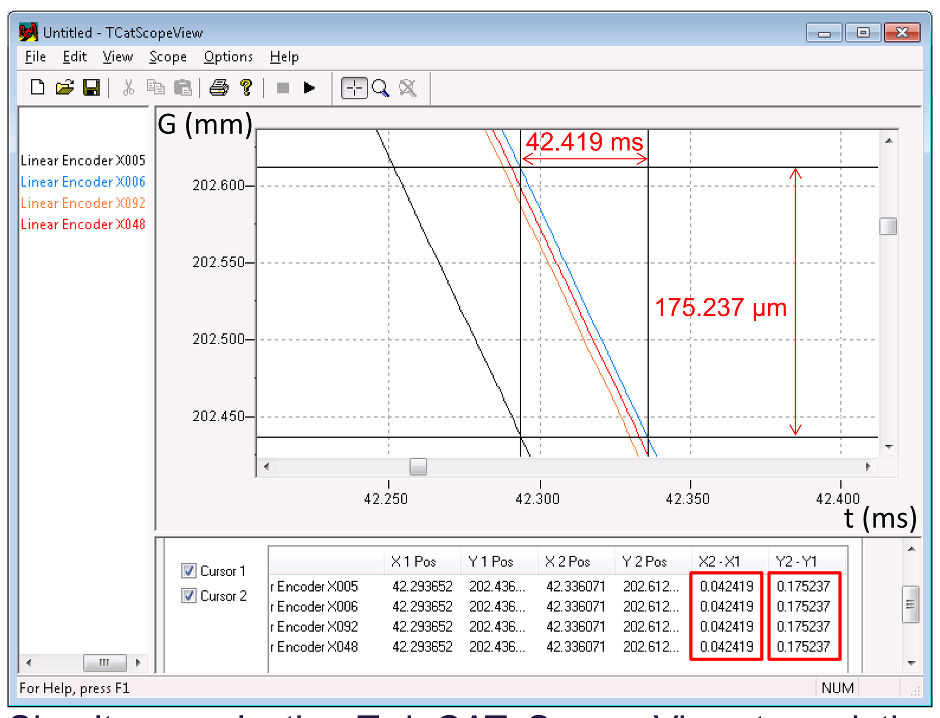
Two Millimar inductive probes P2004 have been fixed near the linear encoders of two undulators X005 and X006 and measured directly the gap size.The probes were connected to the Millimar C1216 compact amplifier **in the differential mode**, so the output of the amplifier ΔG is equal to the difference between first gap G_1 and second gap G_2. The resolution of the measurement system is 0.01 µm.

The accuracy of this measurement is limited by typical noise level. In our setup the accuracy was better than ±0.02 µm. That means, that, with a 8.56 mm/s gap change speed, the minimal time delay that could be detected is $4 \cdot 10^{-5}$ mm ÷ 8.56 mm/s = $4.7 \cdot 10^{-6}$ s.

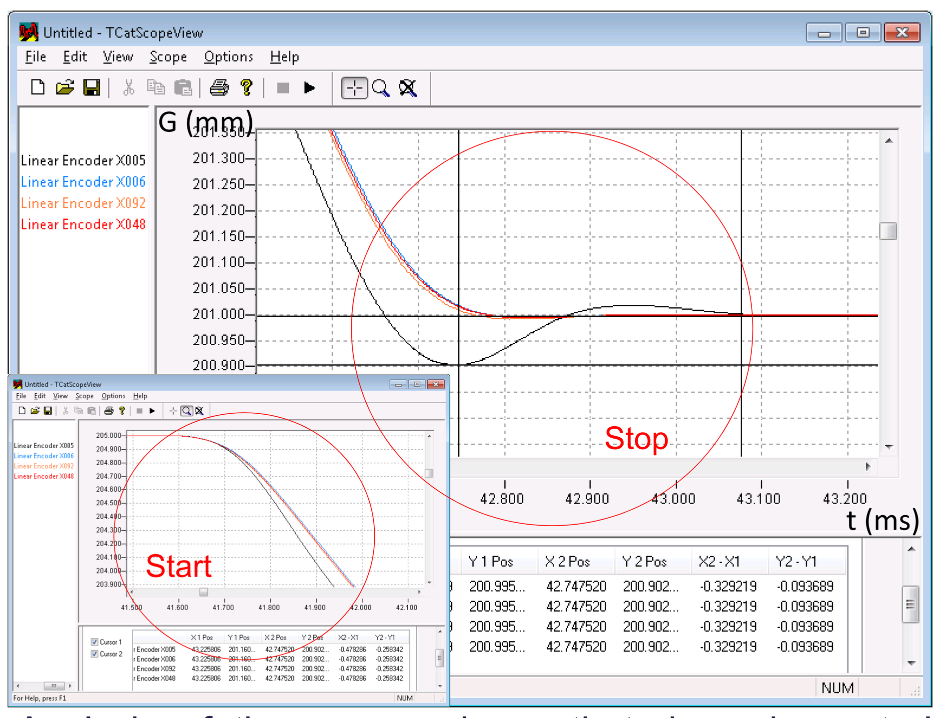
The system gap has been changed between 205 mm and 201 mm using 4.28 mm/s, 2.14 mm/s and 0.856 mm/s gap change velocities. The results show that after issuing the start command, the value from inductive probe installed on X005 starts to change faster than value from inductive probe installed on X006. During the motion, the difference between both probes stays almost constant. As soon as the set value for both undulators is achieved, the difference gets back to zero.



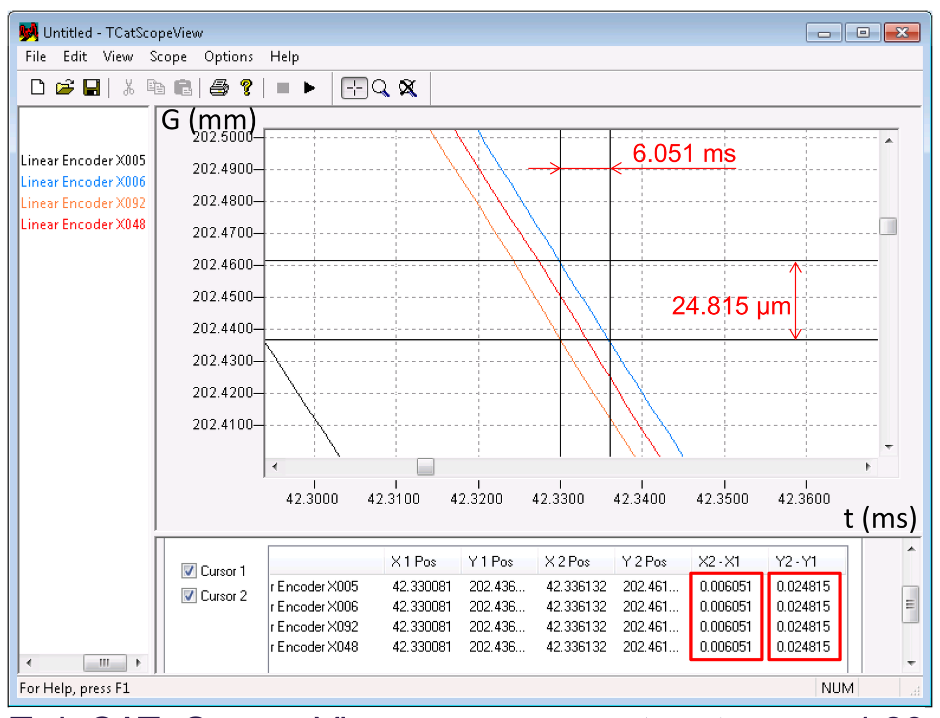
The measurement results for all three speeds show that the average time delay between X005 and X006 is 42.78±1.49 ms. To calculate this value the following formula is used: $\Delta t = (\Delta x/2 - \sigma/2) / v_g$, where Δx is the difference between maximal and minimal lag distance by closing and opening the gap, σ is the average value of jitter during the transition period and v_g is the gap change velocity.



Simultaneously the TwinCAT Scope View traced the value of linear encoders at v_g = 4.28 mm/s for all four undulators. Comparison of two measurement methods shows very good agreement

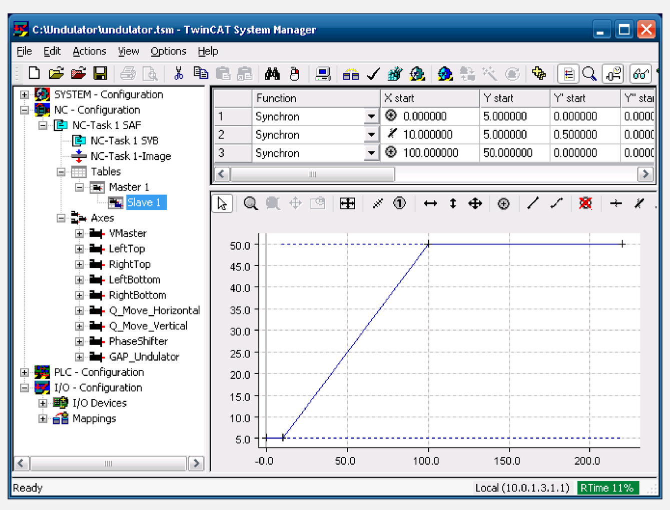


Analysis of the curves shows that dynamic control parameters of undulator X005 are not optimized. This is clearly observed at the start and at the end of the movement.



TwinCAT Scope View measurements at v_g = 4.28 mm/s show that the synchronization of the gap change between X006 X048 and X092 undulators is better than 10 ms.

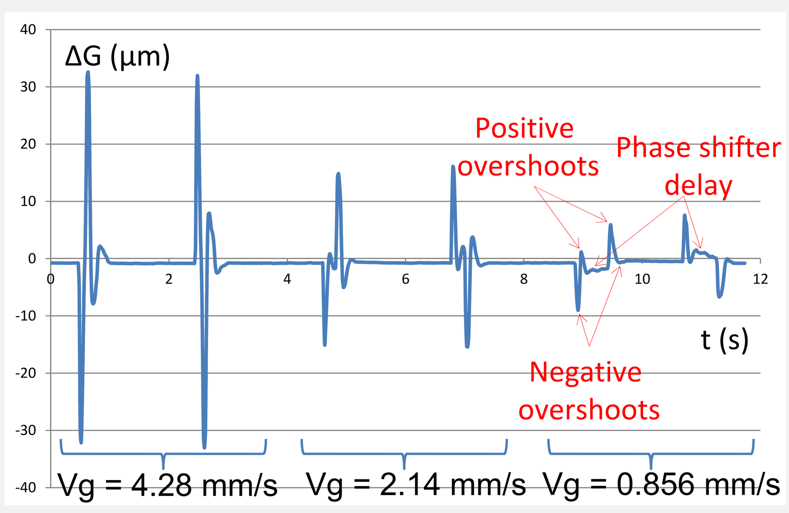
Study of the Movement Synchronization Between Undulator and Phase Shifter



Camming table for the phase shifter

The movement of undulator and phase shifter has been traced using the same differential measurement method. One inductive probe has been used to measure the undulator gap and the other one was used to measure the phase shifter gap. The undulator gap was changed from 75 to 75.5 mm and back with 4.28 mm/s, 2.14 mm/s and 0.856 mm/s gap change velocities. For these measurements the 1:1 camming table in the region from 10 mm to 100 mm was used

The measurements show that the phase shifter starts to move with some delay. Negative overshoot is ~ 7µm at 0.856 mm/s speed; later the control system tries to compensate this following error and the phase shifter overshoots the undulator gap by ~1µm. Afterwards, there is a small following error, which corresponds to ~ 1ms delay between undulator and phase shifter gaps. When the undulator stopped, the phase shifter again has ~7µm overshoot. The overall deviation between undulator and phase shifter gaps is in the range of ~±7ms. Anyhow it is important to mention that the requirement of the phase shifter gap control accuracy is ± 10 µm. Therefore these overshoots at 0.856 mm/s gap change velocity are acceptable.



Difference between undulator and phase shifter gaps measured by Millimar C1216

Conclusions

- The results obtained by TwinCAT Scope View are in a very good agreement with independent measurements obtained by inductive probes.
- The movement synchronization better than 10ms for undulators running freely can be achieved. Two prerequisites for this are individual adjustment of dynamic parameters of the undulator, which can neutralize dissimilarities of mechanical or magnetic properties, and synchronization of the start command to better than the local PLC cycle time. Better synchronization may be achieved by the implementation of one virtual axis in global control system and coupling it with all undulator cells in one system.
- Coupling of phase shifter axis to undulator virtual axis results in a synchronization better than 15ms. Taking into account that both devices have completely different mechanical construction and control elements, this is an encouraging result which allows the assumption for further improvement.

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