THE LOCAL CONTROL SYSTEM OF AN UNDULATOR CELL FOR THE EUROPEAN XFEL

European XFEL

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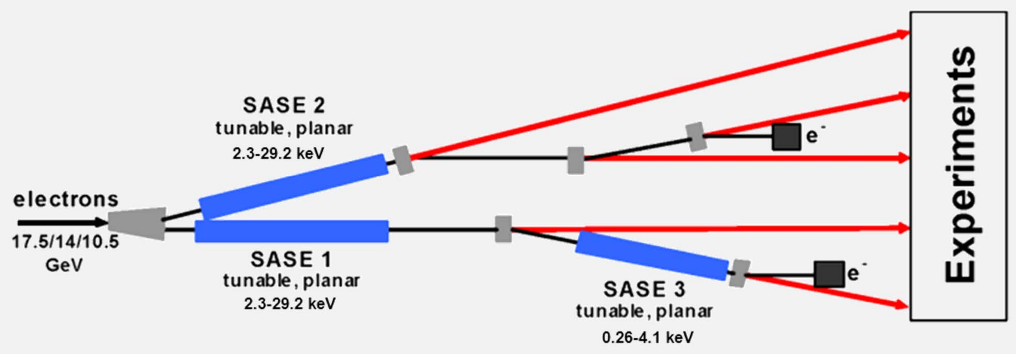
The European XFEL project is a 4th generation light source. The first beam will be delivered in the beginning of 2015 and will produce spatially coherent ≤80fs short photon pulses with a peak brilliance of 10^{32}-10^{34} photons/s/mm^2/mrad^2/0.1% BW in the energy range from 0.26 to 29 keV at electron beam energies 10.5 GeV, 14 GeV or 17.5 GeV [1, 2]. Three undulator systems SASE 1, SASE 2 and SASE 3 are used to produce photon beams. Each undulator system consists of an array of undulator cells installed in a row along the electron beam.

At the project start-up stage three undulator systems SASE1, SASE2 and SASE3 will be used to produce photon beams. The electron bunch train is distributed into two branches by a flattop kicker magnet into SASE1 and SASE2 beam lines, where hard X-ray beams are generated.



Photon Beamline	Electron energy GeV	Photon energy keV	Wavelength Å	Gap mm	Magnetic period mm	Quantity of Undulators
SASE 1	10.5	2.3 – 14.9	5.4 – 0.83	10 – 24		
&	14	4.1 – 18.7	3.0 – 0.66	10 – 20	40	35
SASE 2	17.5	6.4 – 29.2	1.9 – 0.43	10 – 20		
	10.5	0.26 – 2.2	47.7 – 5.6	10 – 28		
SASE 3	14	0.47 – 2.6	26.6 – 4.8	10 – 24	68	21
	17.5	0.73 – 4.1	16.9 – 3.0	10 – 24		
						Total: 91

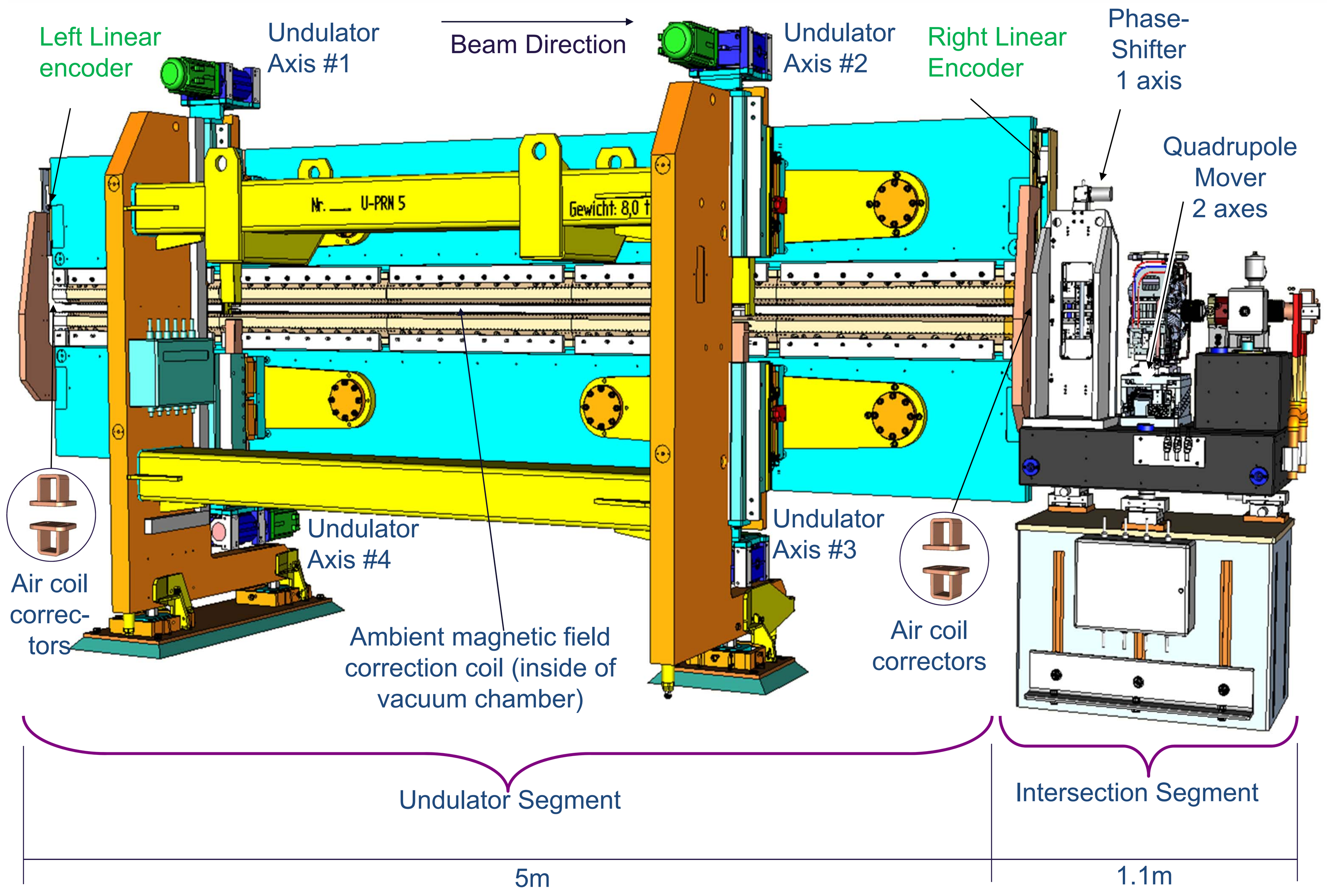
After passing through SASE1 the electron bunches are used a second time by passing through the SASE3 undulator system to create additional soft X-ray beam.

Requirements

- Undulator gap control accuracy ±1 µm.
- Quadrupole mover positioning repeatability ±1 µm.
- Phase shifter gap control accuracy ± 10 µm.
- Max. Steering Power for Air Coil Correctors ±0.6 Tmm
- Accuracy of the temperature measurement of magnet structures ± 0.03 K.
- Gap control with low following error (<±10µm).
- Local temperature measurement and appropriate undulator gap correction.
- Undulator gap dependent air coil correction.
- Undulator gap dependent phase shifter control.
- Motion control for quadrupole movers.
- 3 way mixing valve control for the beam pipe temperature stability.
- Safe operation, damage prevention, proper and precise movement limitation, failure detection.

Undulator Cell Control

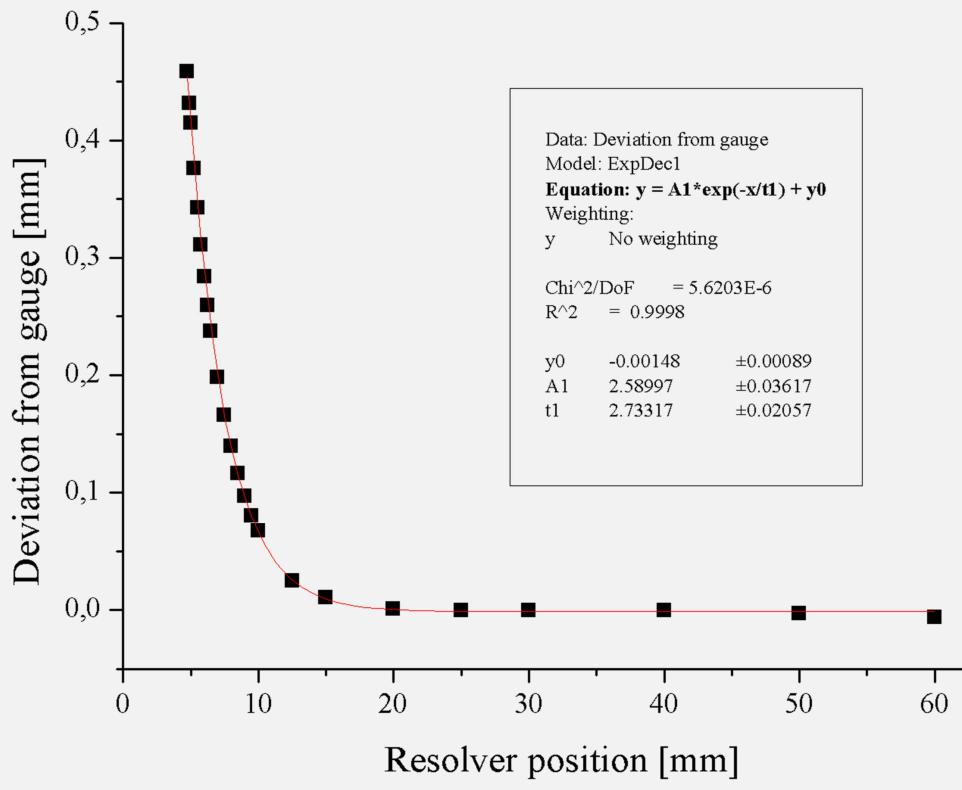
A single undulator cell consists of a planar undulator, a phase shifter, magnetic field correction coils and a quadrupole mover. The local control system of the undulator cell is based on industrial components produced by Beckhoff Automation GmbH and a PLC implemented in the TwinCAT system. Four servo motors control the gap between the girders on each undulator with micrometer accuracy. One stepper motor is used for phase shifter control, and two other stepper motors control the position of the quadrupole magnet. The current of magnetic field correction coils as well as the gap of the phase shifter are adjustable as a function of the undulator gap. The high level of synchronization (<<1µs) for the complete undulator system (for instance SASE 2 with 35 undulator cells in total) can be achieved due to implementation of a fast EtherCAT fieldbus system in the local control.



Control components of an undulator cell

Control of the Undulator Gap

The undulator can be operated either using rotary encoders or linear encoders as a feedback for the servo drivers. At small gaps the strong magnetic forces cause a deformation of the undulator support frame and thus cause deviations between the linear and the rotary encoder readings. To compensate the influence of these deformations the gap is measured with high precision external gauges. The results of these measurements are used as feed forward corrections in the PLC.



Temperature Drift Compensation

To compensate for magnetic field changes due to temperature variations the gap correction method is used. The required gap correction is calculated in the PLC program. The correction is done according to equation:

$$\Delta g_{Loc} = \frac{\lambda_U \eta}{b + 2cg / \lambda_U} \Delta T_{Loc}$$

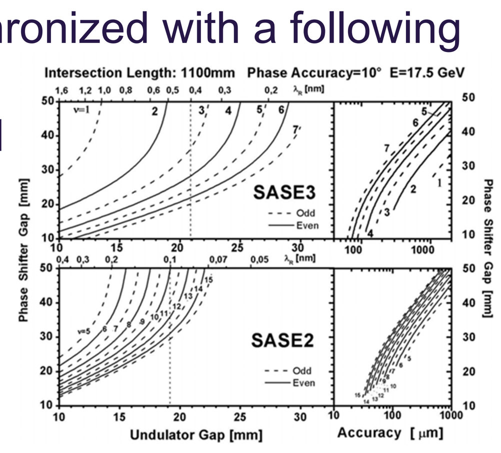
where $\Delta T_{Loc} = T_{Nom} - T_{Loc}$, T_{Loc}, is the local temperature, T_{Nom} is the nominal operating temperature of the undulator system, is the undulator period length, g the undulator gap, η is the reversible temperature coefficient of NdFeB ($-1.1 \cdot 10^{-3}$ K^{-1}), b and c are empirical constants describing the gap dependence of the peak field.

Quadrupole Mover Control

The quadrupole mover control consists of two actuators for horizontal and vertical movement, driven by five-phase stepper motors and two LVDT sensors as feedback for each motor.

Phase ShifterControl

The phase shifter is controlled by means of a look up table, which is evaluated from the magnetic tuning curves. Both motion controls, undulator and phase shifter, are synchronized with a following error of ≤10µm. The basic control requirement is that the phase shifter gap has to follow the undulator gap.



Magnetic Field Corrections by means of Air Coils

On each undulator segment two horizontal and vertical air coil correctors are used

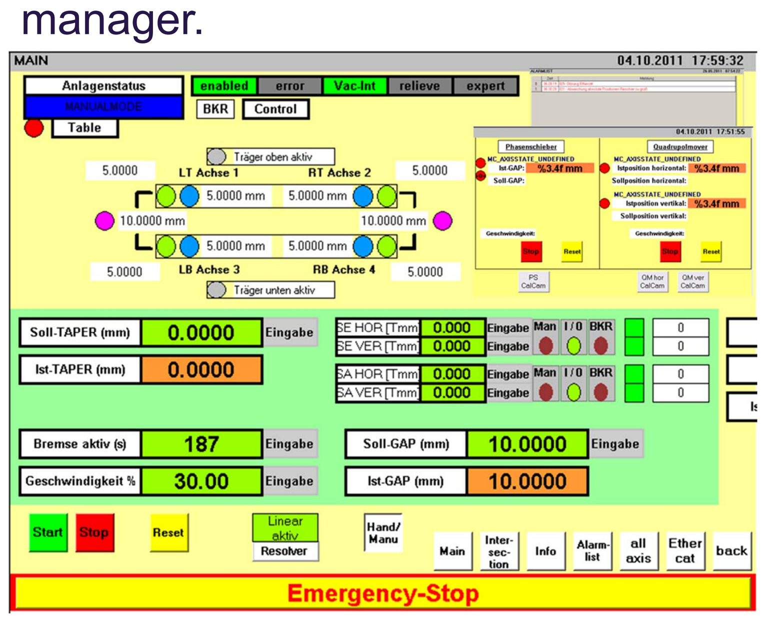
- to compensate residual gap dependent steering errors of the undulator (~ ± 0.1 Tmm),
- to compensate residual gap dependent steering errors of the phase shifter (~ ± 0.05 Tmm),
- for beam ballistic steering of ± 0.45 Tmm.

The air coil correctors are controlled using look up tables. These look-up tables contain the steering strengths as a function of the undulator gap, which are required to compensate 1st and 2nd field integral errors.

An ambient magnetic field correction coil consisting of two parallel wires is fitted inside two bores of the vacuum chamber. It can be used for compensation of an ambient magnetic field of up to 150µT.

Implementation

The local control system of undulator cell is completely implemented in Beckhoff's PLC and TwinCAT system manager.



The graphical user interface consists of main control window, intersection control, alarm display, axes status and system information.

The local control system provides all possibilities for control, monitor and error tracing of each undulator cell. It also provides the interfaces to integrate the local control system into the global undulator control system.