THE SUNDAE2 MEASUREMENT SYSTEM AT EUROPEAN XFEL

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Abstract

European XFEL is preparing a combined Hall probe, moving and pulsed wire measuring system SUNDAE2 (Superconducting UNDulAtor Experiment) , which conceptual design has been presented already before. Now the hardware realization with functional tests can be reported. The challenge is to operate these systems under vacuum to magnetically characterize S-PRESSO (Superconducting undulator PRE-SerieS mOdule), in construction at Bilfinger and planned to be installed at European XFEL.

THE SUNDAE2 MEASUREMENT SYSTEM

With the aim of providing users with photon energies 40 keV, European XFEL is planning to install up to six superconducting undulator (SCU) modules at the end of the hard X-ray permanent magnet undulator (PMU) line SASE2 [1]. For magnetic characterization of the SCU modules two measurement systems have been developed: SUNDAE1 [1, 2] and SUNDAE2. The SUNDAE2 measurement system is designed for the characterization of the entire SCU module which will contain 2× 2 m long coils with 18 mm period plus phasematcher in a 5 m long cryostat. It is currently tested with a spare PMU with 40 mm period length U40 from the European XFEL hard X-ray beamlines. The challenge for the characterization is the tiny, 5 mm × 10 mm racetrack-shaped electron beam chamber which is part of the cryostat and will have a temperature of about 20 K. For the characterization we will use three characterization techniques: Hall probes, pulsed wire and moving wire. In this article the set-up of the system is given in detail. Measurement results for the pulsed wire are given in [3], which can be found also in this proceedings.

The photo in Fig. 1 shows the current set-up with the U40 undulator, which allows testing the systems under vacuum, but of course at room temperature and with the larger period length of the U40. In order to not pollute the electron beam chamber the measurement environment follows the rules for handling Ultra High Vacuum systems. Two larger dedicated vacuum chambers produced by CECOM with 2.7 m and 1.2 m length and DN350 CF axial flanges and smaller chambers are used to host all the infrastructure for the three measurement systems. A couple of windows allow visual control and doors allow faster access to the motion parts. Two pump carts with scroll and turbo pumps provide pressure in the 10^{-7}mbar range. For vibration-free vacuum preparation three ion getter pumps are used beneath the large vacuum chambers.

HALL PROBE SYSTEM

The Hall probe part of SUNDAE2 is facing the problems of the tiny vacuum chamber a temperature range which extends from about 20 K in the cryostat to room temperature in the in air correction coil chambers at both sides of the cryostat. In total four Hall probes and a temperature sensor are soldered to a printed circuit board which is screwed on a Ti sledge. The sledge is guided inside the chamber with flexors made from PEEK and is pulled through the chamber via the signal cable, an eight channel flexible print board. The electrical signals are transmitted to a fixed cable connected to the vacuum feedthroughs by a slipring. For the data acquisition of the Hall probe data Keysight 3458A voltmeters are foreseen. A rather constant pretension is provided from the other side by a constant force pulling mechanism. The position is measured with an Attocube IDS310 interferometer to a 4 mm diameter retroreflector at the sledge (see Fig. 2) which demonstrated a stable position signal along the entire length of the electron vacuum chamber. This technique will be used for checking the straightness of the electron beam vacuum chamber inside the cryostat at the factory acceptance test at Bilfinger. The printboard has been tested in a LN_2 bath. The sledge is guided by the electron beam chamber and hence it cannot be adjusted in height. To compensate for this, there are three vertical Hall probes at different heights, spaced 0.1 mm apart to allow to determine the on-axis field. The fourth Hall probe is used for the horizontal field components. The Hall probes from Asensor Technology AB have active areas of $0.1\times 0.1\,\mathrm{mm}^2$ with 1 μm thickness. They will be calibrated in our 2 T cryogenic calibration setup. A detailed description of this device and first measurements can be found in [4]. For parallel operation of the Hall probe sledge and pulsed and moving wire techniques a parking position for the sledge is provided. This allows the wire to be placed on-axis in the center of the electron vacuum chamber. During the Hall probe measurements the parking of the wire is in the top outer position of the chamber where the sledge has a small recess.

PULSED WIRE SYSTEM

The xy adjusting units for the wire are placed in the outer ends of the large vacuum chambers. The stages are UHV compatible SmarAct solutions with travel ranges of 60 mm in horizontal and 25 mm in vertical. One stage is placed on a motorized longitudinal stage which allows smooth tension changes under vacuum. The tension is controlled with a high vacuum compatible tension sensor (type 8431 from Burster). This allows measurement series with different

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Figure 1: SUNDAE2 measurement setup with a 5 m long U40 permanent magnet undulator. The entire setup spans 11.2 m. From left to right: DN350 vacuum chamber hosting a xyz adjustment for the thin wire and the drive system and parking area for the Hall probe sledge. On the red concrete stone follow the laser based detections systems for the pulsed wire. The large chamber on the right of the undulator hosts the tension system for the Hall probe sledge and xy stages for the wire. On the red stone on the right the interferometer for distance control of the Hall probes is placed. Large windows allow visual control and large DN250 doors allow quick access for installing the wire. Due to the limited conductance of the electron beam chamber, two pump carts equipped with scroll and turbo pumps provide the vacuum. Optionally ion getter pumps below the large chambers enable vibration-free vacuum.

tensions without breaking vacuum which implies in view of the superconducting undulator without a time consuming thermal cycle to room temperature. Vacuum operation of pulsed wire requires a good damping system. As baseline the wire is clamped in a sandwich of Sorbothane© upstream horizontally and downstream vertically. The repetition rate can be kept rather short with just an increase from 1 Hz in air to 0.3 Hz in vacuum. As the combined system of Hall probe and pulsed wire requires a wire length of 11 m, the resistance is rather large. It ranges from 160 Ω for a 75 μm diameter CuBe wire over 550 Ω for a 50 μm diameter CuBe to 2400 Ω for a 100 μm Ti wire. Therefore, the current pulses require adequate high voltages in short pulses. Thin wires and short pulses are needed to keep the dispersion effect low [5]. As current sources we use a bipolar pulse generator (burstpuls 1000 from GBS), which provides rectangular pulses up to 1 kV and two different power supplies which allow arbitrary waveforms. Using the approach of measured pulse forms instead of using the model of a rectangular pulse [6–8] in the correction algorithms allows the use of Gaussian, Lorentz or sinc pulses which do not suffer from spikes caused by the steep sides of the rigid rectangular shape. Recently we could add to the AETECHRON 7234 amplifier a combination of four-quadrant amplifier A1230-02 and transformer from Hubert. While the 7234 is limited in bandwith for usable voltages to 125 kHz the Hubert amplifier delivers 1 MHz also for the maximum voltage of 75 V per unit. In one amplifier are two units which can be combined and the transformer delivers another factor three (for short pulses only). The current into the wire is measured via shunt resistors typically with 1 Ω and 10 Ω, but switchable up to 330 Ω. As our pulsed wire setup with the long undulator suffers strongly from induced currents due to the wire oscillation in the

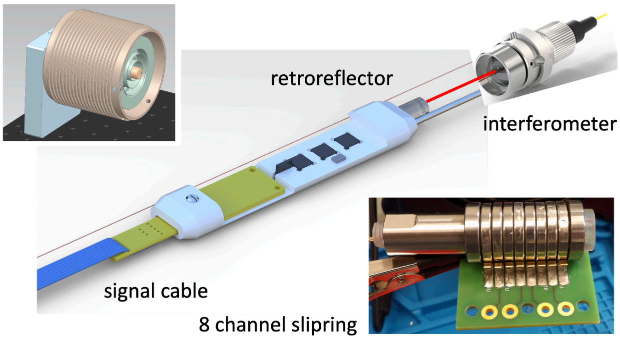

Figure 2: Sketch of the Hall probe sledge made of Ti with PEEK (Polyetheretherketon) flexor elements to be guided by the vacuum chamber while minimizing the thermal contact. Four Hall probes, three vertical ones, spaced vertically by 100 μm and one horizontal plus a temperature sensor are soldered on a printboard. Position control is via interferometer with a 4 mm diameter retroreflector. Also shown is the pretension main spring and the slipring to transfer the electrical signals.

magnetic field. Diodes are used to block these induced voltages in both directions. This reduces effectively a decay and overlapping with reflections [9].

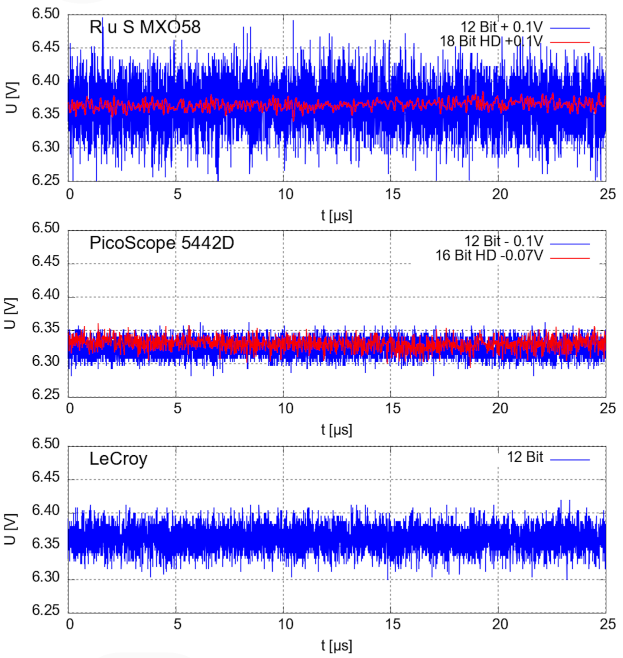

Figure 3: Noise reduction due to HD (high definition) modes of some digital oscilloscopes. All oscilloscopes have native 12 bit ADCs, the HD modes reduce significantly the noise level by sacrificing bandwidth. For this measurement the signal was split, so that the comparison is made on the identical signal.

The laser photodiode system to detect the wire oscillation is mounted on a DN64 CF cube with 4 windows of optical quality. A crossed arrangement - for horizontal and vertical wire oscillation - with fiber coupled class 2 lasers from Schäfter + Kirchhoff (51nano-S) have been selected. These lasers are optimized for stable output power by large bandwidth and low coherence and showed by far the best performance under among the tested lasers. With adjustable output voltage they can be adjusted to the input range of the data acquisition. Low noise photodiodes with large active area and switchable gain were chosen from Thorlabs (PDA100A2). The laser can be remotely adjusted transversely to the wire and normal to vary the focus and hence the sensitivity. The cube with the laser detection can be manual adjusted in longitudinal direction to find minimum impact of longitudinal waves with their much faster propagation speed [6]. For data acquisition an 8 channel oscilloscope with only 100 MHz but an 18bit HD mode is used. Physically it has also a 12 bit ADC like our former used LeCroy oscilloscope with 1 GHz bandwith, but the signal to noise ratio in the HD mode is improved significantly as shown in Fig. 3. Seven channels are used, two for current readings, the main pulse and, amplified, the remaining induced currents. The oscillating signals are detected in DC and AC for both directions. The DC signal is needed for the calibration of the oscillating amplitude and the AC signal allows higher resolution. And finally the tension is monitored. Although the signal of a single pulse is impressively good, averaging is always needed. The sensitivity of the method is shown in Fig. 4. The step into the vacuum stabilizes the signal due to absence of air motion. In addition a slight decay of the signal due to the damping in air vanishes in vacuum. What remains is a beating the signal which might be caused by longitudinal travelling waves. More detailed measurement results, discussion of calibration and a comparison with Hall probe data from the U40 can be found in a separate article in these proceedings [3].

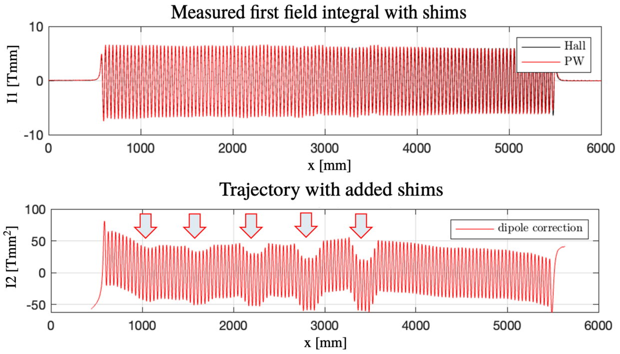

Figure 4: First field integral measurement (75 μm CuBe wire, 2.3 N Tension, 25 μs, rectangular pulse, 125 averages in air) with added shims to demonstrate the sensitivity of the pulsed wire technique. The marker show the local offset bumps were generated with increasing thickness of the shims: 50 μm, 100 μm, 200 μm, 300 μm and 400 μm. The trajectory has been integrated from the measured first field integral where the bumps can only be surmised.

SUMMARY AND OUTLOOK

The SUNDAE2 setup for measuring 5 m long SCUs has been optimized and started operation in vacuum. Signal quality could be increased by identifying areas of optimization in hardware, namely low noise laser source, high bandwith amplifiers, HD oscilloscopes, but also in operation like proper calibration of the individual measurements before averaging. With the current quality of the raw data of the pulsed wire, we can now to start optimizing the correction algorithms to integrate the remaining systematic effects. The Hall probe components will soon be assembled. Both systems will be tested together before summer. SUNDAE2 has to be fully operational by end of the year to allow measurements with the sc undulator right after delivery.

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