HALL-PROBE BENCH FOR CRYOGENIC IN-VACUUM-UNDULATORS

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Abstract

The Helmholtz-Zentrum Berlin (HZB) builds a 2m long in-vacuum Hall-probe measuring bench for the characterization of several in-vacuum cryogenic undulators currently under development. Accurate local magnetic measurements need a positioning control of about 5 µm. Fabrication tolerances and potentially strong temperature gradients require an active correction of the Hall probe movement along a straight line. The HZB-bench employs a system of laser interferometers and position sensitive detectors, which are used in a feed-back loop for the Hall probe position and orientation.

INTRODUCTION

Short period undulators (SPUs) permit the production of high energy photons with low electron energies. The electron energy is the main cost driver for 3rd synchrotron light source and next generation light sources such as FELs, ERLs and USRs. SPUs can be realized either in permanent magnet or superconducting technology. Following the Japanese development many in-vacuum undulators have been built all around the world. Even better performance is gained with cooled permanent magnet structures[1]. Currently, four cryogenically cooled permanent magnet undulators (CPMUs) are operated at 3rd generation facilities and there are plans for more CPMUs in the near future. The potential of short period CPMUs is summarized in [2]. The limits of CPMUs are clearly defined by the magnetic material. This is different for superconducting undulators (SCUs) where the material properties are steadily improving. One superconducting undulator (SCU) is successfully operated at ANKA since 2005 and a short prototype has recently been installed at the APS [3] [4]. A comparison of both technologies is given in [2]. It is expected that CPMUs will be the workhorses for the next 5-10 years.

With shorter period lengths the mechanical tolerances of undulator structures become tighter. Similarly, the demands for the magnetic field measurement equipment increase. The measurements have to be performed under vacuum conditions in the presence of thermal gradients and old concepts from in-air undulator characterization cannot be used. New concepts of Hall-probe benches have been developed in several laboratories [4] [5] [3].

These concepts are based on a careful alignment of the bench and only minor mechanical corrections during field scans. Mechanical imperfections are compensated numerically afterwards utilizing the geometric information about the Hall-probe position during the Hall-probe scans. This concept relaxes the tolerances on mechanical alignment and minimizes the data post-processing effort. This bench fits into the vacuum tank next to an undulator and is designed for the use at undulator temperatures down to 10 K.

REQUIREMENTS FOR THE BENCH

The following requirements refer to different undulators and do not have to be fulfilled simultaneously: The magnetic structure of the undulator extends up to 2 m along the beam axis. The minimal magnetic gap is 1.5 mm and the undulator periods range from 5-20mm. The maximum transverse width of magnetic structure is 40 mm while the field is to be determined over ±10mm horizontally. At a maximum measuring speed of 20 mm/sec up to 50 samples per undulator period are taken. Usually, the temperature of magnetic structure is 77K employing integrated cooling with liquid nitrogen. Utilizing cryocoolers for thermally isolated fixed gap devices the temperature can be as low as 10K.The Hall-probe-bench together with the undulator structure has to fit into a 300mm diameter vacuum vessel. The vacuum tank with the cryogenic undulator and the Hall probe measuring bench is integrated into the undulator support and drive mechanism.

The accuracy of the Hall probe position / orientation is aimed at 5 µ / 20µrad.

DESIGN

General Considerations

The Hall probe moves along the long axis by a slide on a rail side to side to the cryogenic undulator in the same vacuum tank.

The longitudinal position is determined by a laser interferometer while the slide moves along the rail [6].

An active control of the transverse position is provided because the support structure cannot be fabricated as stiff and precise as needed for a passive scheme. Also bending due to thermal stress is anticipated. The transverse position is derived from position two sensitive diodes (PSDs) [7] detecting the light from two laser beams intercepted by two pinholes. The Hall probe is positioned by a digitally controlled feedback loop relative to the slide using piezo-driven stages [8].

Two orientation angles of the Hall probe are measured with the 3-axis laser interferometer system and the data

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are used in two more feedback loops to keep the Hall probe orientation fixed.

Detailed Design Considerations

The Hall probes are GaAs based Hall sensors (GH-701) with 0.3 mm diameter active area in a SMD housing 1.5 mm x 1.5 mm x 0.6 mm [9]. Two Hall probes are mounted orthogonal to each other and measure the transverse magnetic field components.

The holder is made of ordinary electronic board FR4 and is gold plated to reduce the thermal swing while moving through the cold gap of the undulator.

The digitization of the analogue Hall-probe signal is the most critical part. Existing measurement systems feed the analogue signal into an in-air digitizer. Various schemes have been developed to reduce the noise introduced by cable bending during the scan. In the 1st stage the analogue-digital transformation will be done outside of the tank as well. For the future it is planned to do the digitization on the slide in vacuum. This electronics will be built around the amplifier TI PGA280, the ADC AD7767-2, and the constant current source LT3092 [10] [11].

The measuring slide glides along a rail almost 3 m long mounted next to the undulator inside the vacuum tank. It carries six piezo actuators, two pinholes attached to the Hall-probe holder, a mirror for the laser interferometer and the electronic circuit for two Hall probes. The Hall-probe holder is positioned by piezo- actuators providing five degrees of motional freedom. The total horizontal and vertical travel of the piezo actuators is 20 mm and 5 mm [8] with an positioning accuracy < 1µm. Measurements on the prototype bench demonstrated an angle stability during reversal of scanning direction of about 10 to 15 µrad.

The transverse position of the Hall probe is derived from an expanded laser beam parallel to the nominal axis. Pinholes attached to the Hall probe holder on the slide cut out a portion of that laser beam depending on the transverse position. Two stationary PSDs at the other end of the travel convert the light position into an electric signal that is used in a digital feedback loop. This feedback loop drives piezo-actuators such that the Hall probe maintains a fixed position with respect to the laser beam axis [7].

The motion along the long axis is realized by pulling stainless steel strings. The motion is introduced into the vacuum chamber (VC) via magnetically coupled rotary feedthroughs. The slide glides on blocks made of epoxy with WS_2 immersed. The longitudinal position is measured by a laser interferometer [6] with up to 100 samples/sec.

The moving slide connects to the stationary equipment by a vacuum compatible energy chain. This energy chain, which is under development, is moved in parallel to the slide by a separated actuator system. Within this energy chain there are only digital signals except for the read-back position of the piezo actuators, and, in the first stage the analogue Hall-probe signal.

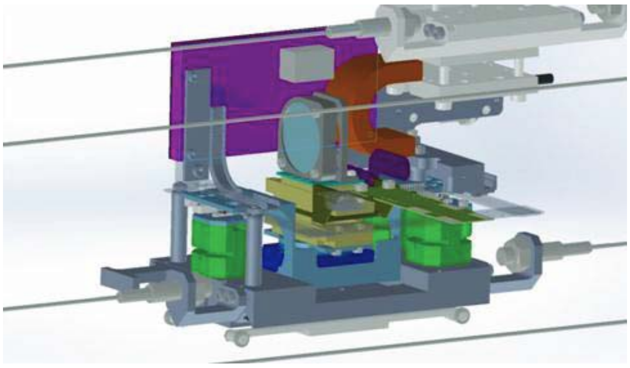

Figure 1: Engineering view of the Hall-probe slide.

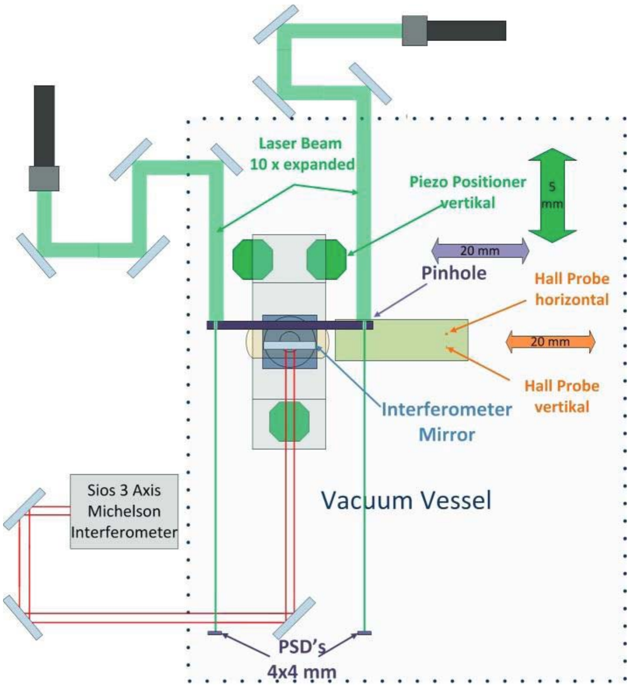

Figure 2: Schematic illustration of the Measurement-System.

The commissioning of the new measurement bench will be done in a 300 mm diameter cylinder of 2.9 m length integrated into a prototype support and drive system. Numerous flanges are provided. The connection between the two undulator girders and the support and drive mechanism is vacuum sealed by flexible bellows.

The set-up is controlled by LabView program. An FPGA provides the signals for the on slide electronics and the readings of the PSDs.

3-Axis Interferometer

A 3-axis interferometer of the type Sios Modell SP 2000-TR permits measurement of the longitudinal position, pitch and yaw. It provides submicrometer resolution over a range up to 2m. The three beams with a separation between the beams of 12 mm provide an angle measurement range of ± 1.5 arcmin.

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PSDs

Position sensitive detectors are used to measure the roll as well as the horizontal and vertical offset perpendicular to the magnetic axis. Two HeNe Lasers which are attached on optical breadboards outside of the (VC) expanded (10x) and aligned with three high resolution kinematic mirror-mounts and introduced through viewports, irradiate two pinholes on the slide nearby the Hall probes. The resulting optical spots are projected on two PSD's.

The active area of the PSDs is 4x4 mm making two dimensional measurements possible. They provide a typical position resolution below 0.5µ and a typical detection error of ca. ± 70 µm which varies depending on operation environment.

Calibration Procedure

The calibration of the Hall probes is done off line by comparing the Hall signals with the output of an NMR Probe in a calibration magnet (Fig. 3). An old BESSY I dipole magnet is powered by a new Danfysik power supply exhibiting a polarity switch. In future the overall accuracy is aimed to be 10^{-5} at a maximum field amplitude of up to 2T. To push magnetic induction to 2T the used iron yoke of the dipole must be supplemented with pole shoes consisting of CoFe. In future setups the calibration should be done with the same digitization electronic which is subsequently used for digitization on the measurement slide. A temperature dependent calibration and a temperature monitoring during the magnetic field scans are essential.

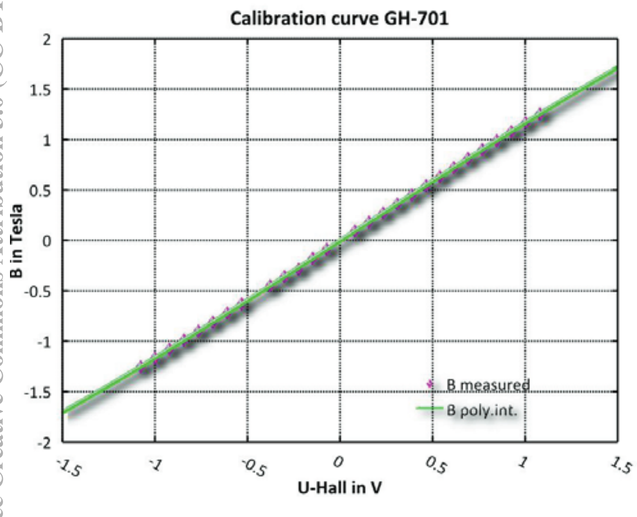

Figure 3: Calibration curve GH-701.

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