Application Note MS33

Piezo-based Positioning for Magnetic Field Detection

Cryogenic Undulator Validation

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Introduction

X-rays, also referred as synchrotron radiation, serve as an important tool to observe the structure and dynamics of matter. Modern light sources like free-electron lasers or third and fourth generation storage rings provide X-rays for a vast range of scientific areas, such as nanotechnology, health and medicine, engineering, forensics, archaeology, and agriculture. The synchrotron radiation is generated by bending magnets, wigglers or undulators. While bending magnet and wiggler radiation have a broader spectrum of photon energies, undulator generates narrow peaks, i.e. bright and coherent radiation at specific harmonics. This specific peak spectrum and defined photon energy is the main advantage of undulator radiation. In general, undulators generates radiation with the highest brilliance (the brilliance parameter describes the quality of the emitted radiation). Therefore, they are the workhorses for generating synchrotron radiation in currently used as well as upcoming light sources.

Undulator as the source for synchrotron radiation

An undulator is an insertion device, it consists of two or more arrays of permanent magnets and CoFe-Poles, periodic arranged, generating an alternating magnetic field. The electron is hence forced to follow the undulating trajectory.

At the storage ring BESSY II in Berlin-Adlershof, all undulators use permanent magnets based on the rare earth alloys NdFeB or PrFeB. Over the last few years, Cryogenic Permanent Magnet undulators (CPMUs) were intensively developed. Compared to the conventional technology of ordinary undulators or in-vacuum undulators, the CPMUs features an increase of the undulator peak field resulting in higher photon energies for the given electron energies. This feature qualifies this type of undulators in particular for free-electron laser sources.

Magnetic Field Determination

The CPMUs' magnetic properties are determined using a vacuum Hall-probe bench. The Hall-probe bench measures with two orthogonally orientated Hall-probes the magnetic field to control the performance of the undulator at different temperature levels. Later, the undulators will be cooled to about 77 K. By characterizing the undulators at different temperatures, thermal influences can be specified precisely.

The CPMUs move on a 2 m rail, parallel to the longitudinal dimension of the undulators' magnetic structure. The slide on the rail is driven by a slope drive. The longitudinal errors scale with the period length. With shorter period lengths, the geometric errors become more problematic, especially the longitudinal position errors. These are noticeable as phase errors of the emitted radiation.

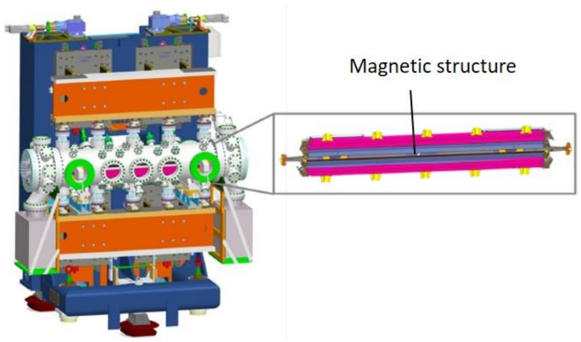

Figure 1: CAD model of a CPMU-17; developed by HZB (Kuhn, 2018)

The accuracy of the Hall-probe orientation relative to the magnetic axis of the undulator is aimed to 5 µm and 20 µrad. Three linear positioners of the model ANPz101 are responsible for the pitch and roll angle as well as the vertical position of the probes. An ANR240 rotator changes the yaw angle while two more linear horizontal positioners ECSx3030 are capable of moving the horizontal direction perpendicular to the horizontal direction of the bench. Together with the slope drive, these six positioners realized in total six degrees of freedom (see figure 2 and 3).

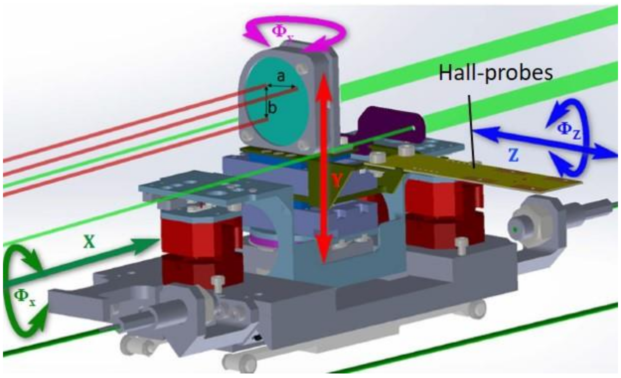

Figure 2: CAD model of measurement slide

The position of the Hall-probes is measured in five degrees of freedom by two optical systems. A three beam laser interferometer for the angles (pitch and yaw) as well as the longitudinal position, and in addition two position sensitive detectors for the transversal positions. A typical measurement

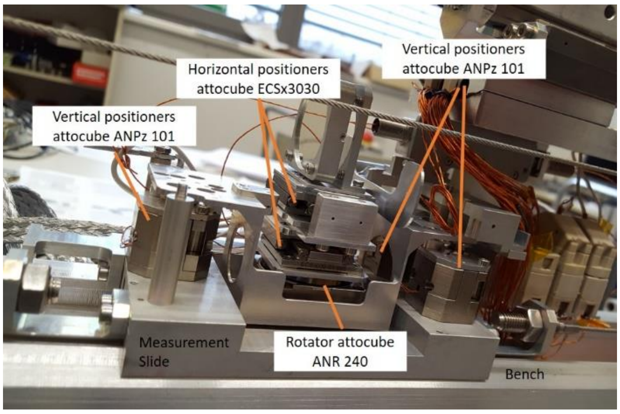

Figure 3: Measurement slide with integrated attocube positioners

tool for this purpose is the IDS3010 (not used in this particular setup) as it features the flexibility to be used in any kind of environment and the required precision of +/- 1ppm (in ambient conditions).

Combining the interferometer and attocube piezo motors guarantee a position accuracy of the Hall-probes of at least 5 µm and 20 µrad.

Positioning Accuracy and Magnetic Field Measurements

The position setup for the Hall-probe as described above allows for longitudinal measurements of the magnetic flux density in dependency of the longitudinal and transversal position.

In order to specify and to investigate the thermal influences on the magnetic field, the Hall-probe bench is used to determine the magnetic flux density at different temperature levels. Figure 4 shows an increase of the magnetic flux density by about 15 % for lower temperatures for a CPMU prototype with 11 periods of 9 mm length and a magnetic gap of 2.5 mm. In other words, the higher magnetic flux density results in the possibility of using shorter period lengths and thus achieving higher photon energies for given electron energies. In addition, the resistance of the magnets to radiation damage caused by the electron beam increases.

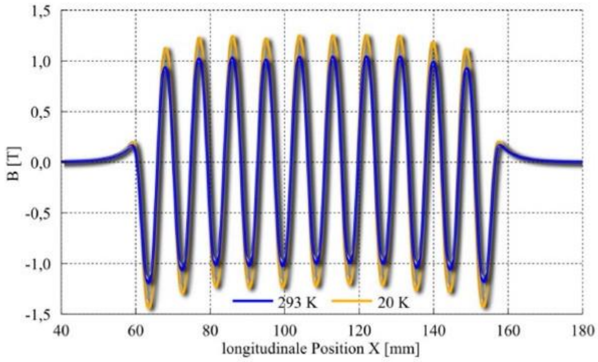

Figure 4: Longitudinal determination of magnetic flux density

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