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CHARACTERIZATION AND IMPLEMENTATION OF THE CRYOGENIC PERMANENT MAGNET UNDULATOR CPMU17 AT BESSY II

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Abstract

In fall 2018, the cryogenic undulator CPMU17 was installed in BESSY II. Before installation, the undulator was characterized with an in-vacuum Hall probe bench and an in-vacuum moving wire. Both measurement systems were developed at Helmholtz-Zentrum Berlin (HZB). The commissioning of the undulator included the orbit and tune corrections, optimization of the injection efficiency, characterization of the heat dissipation, tuning the Landau cavities for a reduction of the heat dissipation in the taper sections (temperatures below 60°C) and testing of the machine protection system. The undulator is ready to deliver light for beamline commissioning. In-situ spectral tuning on a high undulator harmonic will be done as soon as the double crystal monochromator (DCM) is operational.

INTRODUCTION

CPMU17 [1] will deliver hard photons for the Energy Materials In-situ Laboratory EMIL [2]. The soft branch is equipped with the APPLE II UE48, which has already been installed for more than two years. For BESSY II, CPMU17 is the first in-vacuum undulator (IVU) ever installed in the ring. The undulator was designed and built at HZB with strong support from FMB Feinwerk- und Messtechnik GmbH (www.fmb-berlin.de). The demands of the user community for greater access to the tender X-ray regime will lead to further IVUs being built at BESSY II (including an in-vacuum APPLE II [3]). Two new magnetic measurement system were developed and built at HZB for the characterization of this and future devices.

MAGNET PERFORMANCE

The CPMU17 magnet girders were assembled after a sophisticated magnet sorting [4]. The field integrals of the complete structure were characterized with the new in-vacuum moving wire system developed at HZB [5]. Excellent wire damping under vacuum was achieved with a Soborthan covered wire clamp and a 1.5 s-delay before each measurement. The field integrals were minimized at room temperature in air utilizing magic fingers at both undulator ends. These could easily be removed for rearrangement, even with the vacuum tank in place. The device is installed in a low-beta section, such that a good field region of only a few mm is necessary.

During cool down the vertical field integrals see a gap dependent offset. These can be reproduced in simulations, and this is due to the temperature dependent partial saturation of the endpoles. Additionally, a quadrupole term shows up at low temperatures. This is not yet understood, but can be corrected with the tune feed forward system (Fig. 1).

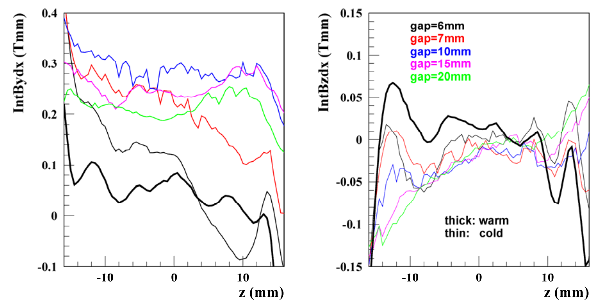

Figure 1: Vertical (left) and horizontal field integrals of CPMU17.

The local field distribution was characterized at low temperature utilizing the in-vacuum Hallprobe bench [5]. An excellent reproducibility was achieved with a yaw-correction after measurement (Fig. 2). Yaw, pitch and position are derived from the 3-axis interferometer, which is part of the bench.

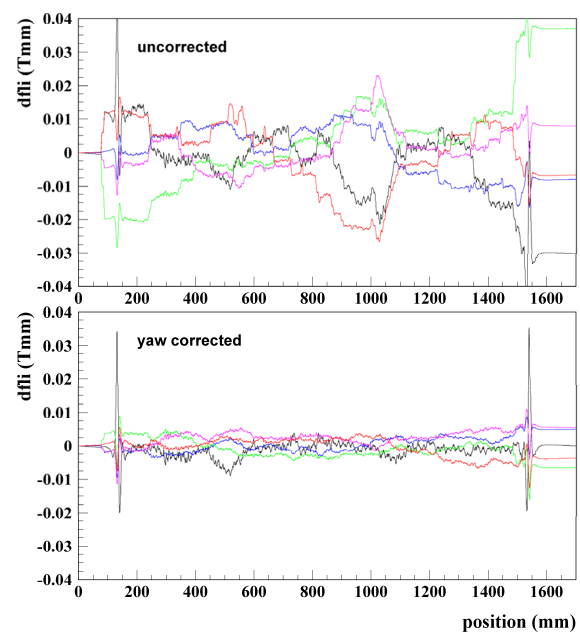

Figure 2: Individual differences to an average of five period-filtered 1st-field integrals without (top) and with yaw-correction.

Since the new SAFALI-system [6] for this bench was not yet operational, several field scans at different heights were performed. The fields of each scan were fitted in five consecutive sections, where each of them amounts to 1/5th of the undulator length (Fig. 3 left, thin lines). Then, the

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five fields corresponding to the five vertical positions were fitted at each position and the minimum was derived. These minima are plotted in Fig. 3 as a black thick line. The variation of the field level over the undulator lengths demonstrates a gap variation of only ±10µm. This low value was achieved without any geometric tuning, and it is a consequence of precise machining of many parts, which contributes the gap error. This result is consistent with a laser tracker measurement of the assembled structure without vacuum tank. The thick black line in Fig. 3 deviates from the blue line, which was derived from the nominal on-axis scan. The discrepancy indicates a bending of the Hall probe bench. The field data were analysed with respect to the phase error. The original data deliver a phase error of 6.8° (Fig. 3 right). The 5 field values of the blue line were splined, and the analysis yields a phase error of 7.8°. The values validate the approximation. The phase error is dominated by systematic gap errors. These values still include the bending error of the bench. Therefore, the 5 fitted minima were splined as well, and the phase error was derived. As expected the phase error goes down to 4.6°. This value will further be minimized with in-situ spectral tuning, which will be described later.

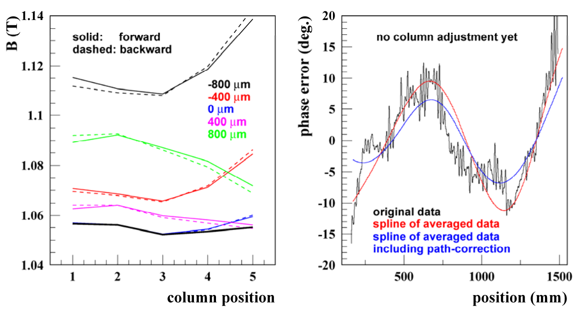

Figure 3: Left: Fitted effective fields at several vertical and longitudinal positions and for different scan directions. The longitudinal positions coincide with the locations of the columns, which support the in-vacuum girders. Right: phase errors from original and from simplified splined data (for details see text).

UNDULATOR COMMISIONING

The air coils for the compensation of residual dipole kicks are located in the taper section close to the electron beam (distance to beam 23mm). Special inserts were installed in the taper chambers upstream / downstream for the housing of the water-cooled coils (Fig. 4). They operate in air and provide field integrals of 0.26 Tmm and 0.24 Tmm horizontally and vertically.

The horizontal and vertical tune shifts are compensated globally, such as for the other permanent magnet based BESSY II undulators. The non-linear terms are not compensated, since they are small.

The gap measurement system is based on two optical micrometers, which operate in air and measure directly the gap upstream and downstream [4]. The data are used in servomotor feedback loops. CPMU17 is the only IVU, which uses this measurement principle on a daily basis. The system works reliably in all operation modes, including top-up. This design is particularly helpful in CPMUs, where the gap opens by more than one mm during cool down and where thermally induced drifts may occur.

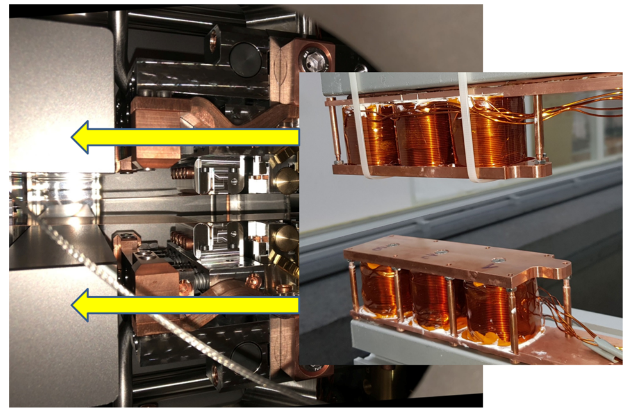

Figure 4: Two inserts (arrows) in the taper section housing the water-cooled air coil arrangement.

Without gap feedback, periodic gap drifts of several 10µm are observed over time periods varying between 8h and 12h. These drifts are cancelled in normal operation with gap feedback switched on. A much smaller gap modulation between the two measurement systems may remain. Fortunately, this effect shrinks with smaller gaps (stronger forces), where the phase error is most sensitive to gap errors (Tab. 1). Therefore, we do not expect a thermally induced degradation of the spectral performance. Further studies will be conducted in the future with the DCM.

Table 1: Thermally induced periodic drifts of upstream and downstream gap with feedback switched off. The data are the window of the total drift. The sign indicates the relative drift direction upstream and downstream. With feedback on, the gap variations are 1-2µm.

Gap	upstream	downstream
22	-55 µm	8 µm
15	-45 µm	6 µm
11	25 µm	-5 µm
8	9 µm	9 µm

The periodic structure warms up at high currents by about 2 K independent upon the gap (Fig. 5 left). This indicates, that the taper angle has no significant impact on the magnet structure temperature. The taper sections heat up significantly with current, where the two ends behave differently due to a different geometric environment of the accelerator vacuum system close by. Currently, the machine protection system limits the temperature of the taper sections to 90°C. The downstream taper temperature stays below this limit only with a specific setting of the Landau cavities and the main cavities, which elongates the pulse length and reduces the wakefield losses (Fig. 5 right).

A new dedicated machine protection system monitors the electron beam offset and angle, and switches off the RF before the beam can damage the CuNi-foil, which covers the magnets. The protection system can be switched off only if the undulator is at a safe position (gap=22 mm), which is hardware interlocked.

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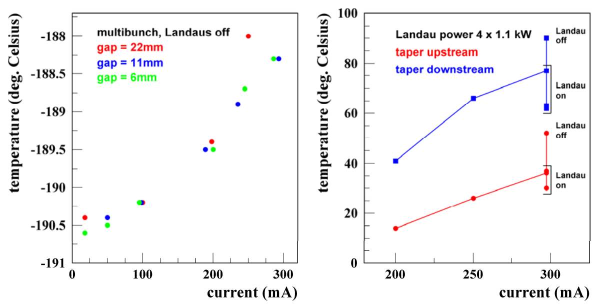

Figure 5: Left: Temperature of the magnet girder versus current for several gaps. Right: Temperatures of the flexible tapers versus current. “Landau on” includes also optimization of main cavities. Landau power means the power, which is deposited into the cooling water.

THE NEXT STEPS

CPMU17

In the 2019 summer shutdown, CPMU17 will be removed from the ring for an upgrade. The work will be done in the ring tunnel in a temporary laminar flow box, before it will be reinstalled. Two issues will be addressed: i) the lateral displacement of several bellows must be cured in order to enhance the bellow lifetime. For this purpose the liquid nitrogen interface boxes must be modified. Currently, the bellow misalignment limits the minimum gap to 10 mm, though 6 mm have been tested already with beam. With the bellows aligned, the optimization of the top-up efficiency at smallest gap will be continued; ii) a dedicated taper cooling system will be installed to alleviate the impact of wakefield losses. Currently, the taper temperature depends upon the gap history. This indicates a transportation of the dissipated energy mainly via the RF-fingers. They are optimized for good electrical contact rather than for good thermal transmission. Water cooled copper inserts will be soldered into the CF300-flanges at both ends of the vacuum chamber. Copper strips will connect the inserts and the copper frames, which support the flexible taper foils (Fig. 6).

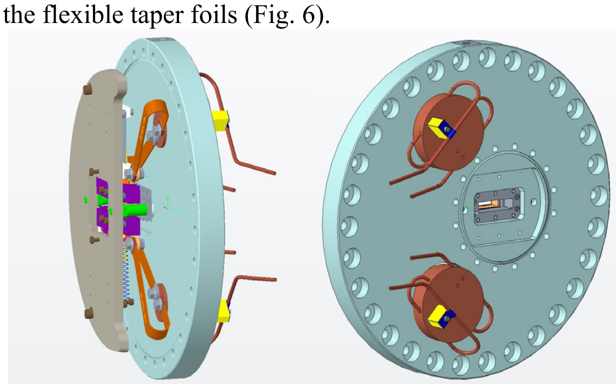

Figure 6: Water cooling of the flexible taper sections.

Hall Probe Bench

The HZB-SAFALI-system will be implemented soon. As usual, two parallel laser beams represent a virtual guide for the Hall probe slide. Different from other systems, the laser beams of the HZB-system are nearly parallel by design, where the deviation from parallelism is always constant and can be characterized beforehand. A single laser beam is coupled into the vacuum via a high quality optical window. Only in the vacuum the two parallel beams are generated via a specific optic (Fig. 7).

A beam splitter generates two beams with a separation of 20mm. Two retro reflectors enlarge the separation to 65mm.

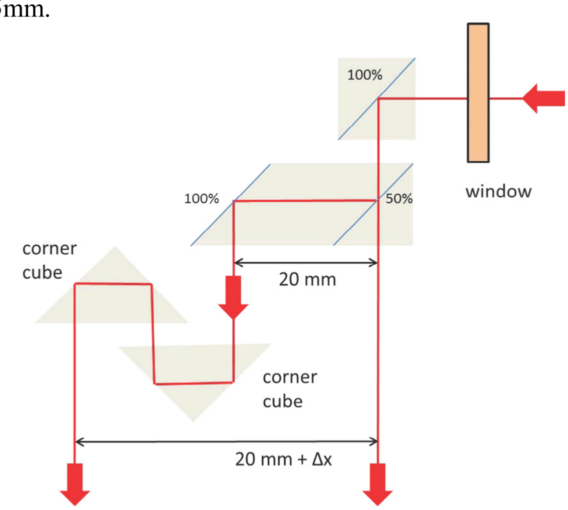

Figure 7: Generation of two parallel laser beams for HZB-SAFALI. The additional separation is: $\Delta x = 45mm$.

Higher Order Spectral Tuning

Only recently, Chubar reported about a new spectral performance optimization of small period undulators (SPUs) [7]. Usually, undulators are tuned in air, and in the past, a control measurement under vacuum happened only rarely. This may change in the future, but even a measurement of a cryogenic undulator at low temperatures does not guarantee best spectral performance in the storage ring over years of operation. A safe measure is an in-situ characterization of high harmonics as described by Chubar. Based on measurements and simulations he established a linear correction scheme. He applied a longitudinal taper and offset corrections to several NSLS II SPUs with a great spectral improvement. Obviously, a systematic gap variation is the main contribution to the phase error. Hence, a higher order correction should be considered to cope with performance changes over time. Each magnet girder of CPMU17 is supported by five columns. An adjustment of only three of them (the three center columns of one girder) provides full flexibility, because the gap and taper change is realized by other means. At HZB a new column length tuning will be tested which is based on an outside heating of the columns. First estimates show, that gap variations of about 10 µm / column / 10 K are possible. For example, the phase error (Fig. 3 right) can be reduced easily by 1°-2° via a tuning of one central column. A heater and a temperature control will be setup for CPMU17. This enables a higher order spectral tuning as soon as the DCM will be installed and commissioned.

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