FIRST RESULTS FROM TWO NOVEL IN-VACUUM MAGNETIC FIELD MEASUREMENT DEVICES AS BUILT AT HZB

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Abstract

The characterization of cryogenic in vacuum permanent magnet undulators with periods less than 20 mm and correspondingly narrow gaps requires new in-vacuum measurement systems. The positioning accuracy of the HZB in-vacuum Hallprobe bench has substantially been improved (a few µm) with appropriate feedback systems. A new in-vacuum cable tray has been developed. Another system for field integral measurements, an in-vacuum moving wire, is under commissioning. Both devices are presented.

IN-VACUUM HALLPROBE BENCH

Positioning Accuracy

The general layout of the bench has been presented a few years ago [1]. The accuracy of the device is based on five piezo actuators and five optical measurement devices for feedback: three laser interferometer channels and two 2D-position sensitive detectors. The positioning accuracy of the in-vacuum Hallprobe bench has been successfully tested over a length of 0.5 m with the laser interferometer feedback switched on [2]. The range was limited because the cable tray was not operational, yet. Meanwhile extensive tests of the new in-vacuum cable tray have been performed. The tests will be described in the next section.

Cable Tray

The IV-cable tray has to carry the electric support for five piezo actuators, three Hallprobes, three digitizers, two limit switches and an incremental encoder for the synchronization of the drives for the Hallprobe carriage and the cable tray. In total, 76 wires are required. Three 26 strand multifilament wires and one encoder cable must be supported by the cable tray. Additionally, the cable tray serves for the cooling of the digitizers. The digitizers as developed at HZB are optimized for minimum power consumption nevertheless, a conduction cooling is needed. The UHV-compatible cable tray must fit into the compact IV-Hallprobe bench.

There is no commercial cable tray available which meets all requirements and a new device had to be developed. A CuBe-sheet of 200 µm thickness was chosen for the support of the cables. The metal sheet is bent by 180° where the location of the bow moves during the Hallprobe scans.

The metal sheet was formed like a shallow rain pipe in order to stiffen the free-standing structure during movement and to prevent the cables from sliding away.

Interestingly, the radius r of the pipe defines the radius of the cable tray bow R (Figure 1) as derived from a simple energy consideration. The stored energy of the metal sheet bow consists of two parts, which are assumed to add linearly, the energy W_R needed to bend a flat sheet to the radius R and the energy W_r required to bend the same sheet in orthogonal direction to the radius r.

$$W = W_R + W_r \tag{1}$$

$$W_R = \frac{1}{24 \cdot R} E \cdot \Phi \cdot \mathrm{B} \cdot H^3 \tag{2}$$

$$W_r = \frac{1}{24 \cdot r^2} E \cdot R \cdot \Phi \cdot \mathrm{B} \cdot H^3 \tag{3}$$

Here, E is the module of elasticity, Φ is the bending angle, B is the width and H is the thickness of the metal sheet. With a given radius r the radius of the bow R is derived from a minimization of the total energy W with the result $R = r$. The metal sheet must not follow a perfect circle in transverse direction. Instead, it can be approximated with a polygon.

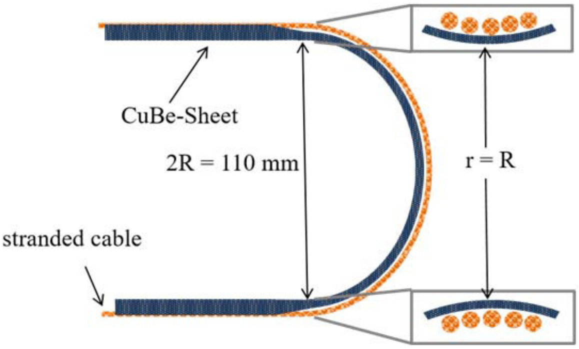

Figure 1: Shape of the cable tray.

The dimensions of the cable tray are chosen to be: length = 2000 mm, width = 50 mm, thickness = 0.2 mm. The bow is realized with $R = 55mm$. The metal sheet has been tested in a dedicated test stand. Via a pneumatic drive system 100.000 full cycles have been applied. Apart from a few scratches no severe damage of the CuBe-sheet has been observed. The polygon-like bending in transverse direction slightly affects the smoothness of the motion, however, no impact on the functionality has been observed. Cables consisting of 26 Capton isolated stranded wires, each wire having 7 filaments, were chosen. The bundle of stranded wires has a woven structure for high flexibility and robustness against material fatigue. During the initial test three multifilament cables were put on the tray and the functionality of totally 10 wire pairs has been checked after each cycle. The wires itself survived the test, the copper woven shielding of the three bundles

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showed wear in form of a black powder. A chemical analysis of the powder indicated CuO and Ag. This is consistent with a visual inspection which showed partial damage of the shielding (Figure 2).

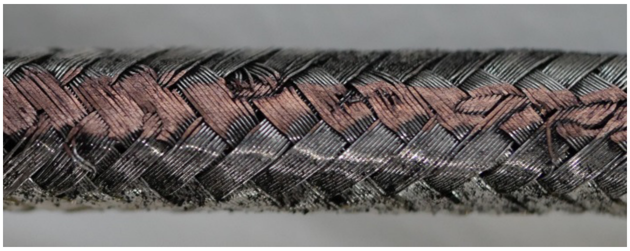

Figure 2: Insolation damage after 100.000 strokes.

The resistance noise of three wire pairs during motion over 100.000 strokes is plotted in Figure 3. With 4 s / stroke the run took about 111 h.

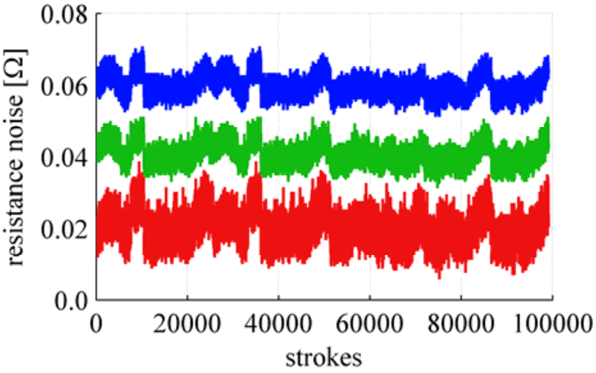

Figure 3: Resistance noise of three wire pairs (out of 33 pairs) over 100.000 strokes. The averaged resistance of each individual pair (about 1.3 Ω) is subtracted, and the graphs are vertically shifted for better visibility.

The noise of the red curve is twice as large as the noise of the blue and the green one. The history of the stranded cables is different, and most certainly, a few filaments of the 3rd wire pair (red data) are already damaged. Interestingly, this does not affect the functionality of the cable until the wire is completely broken. Minor drifts of the resistance are due to temperature variations over the day (the tests were switched off at night).

In a 2nd test the Cu shielding of the three old wire bundles was stripped (Figure 4) and the wire bundles were tested again over 50.000 cycles. The electrical tests were refined in this test. The resistance of 33 wire pairs was monitored five times for each cycle. Only one wire broke in the 2nd test. In a next step this test will be repeated in combination with the IV-bench under UHV-conditions.

Different wires and cable designs were compared with respect to their noise behaviour (Figure 5). The cables were connected to a 50 mA constant current power supply, and the voltage drop was measured. The resistance was evaluated from the voltage drop. The noise of a 22 Ω resistor served as reference.

The resistance noise of a stranded cable increases by 20-50% during motion (Figure 6). Nevertheless, the noise of a moved stranded cable is much lower as compared to un-moved ribbon cable. This underlines the benefit of a twisted pair wire as realized in the stranded cable.

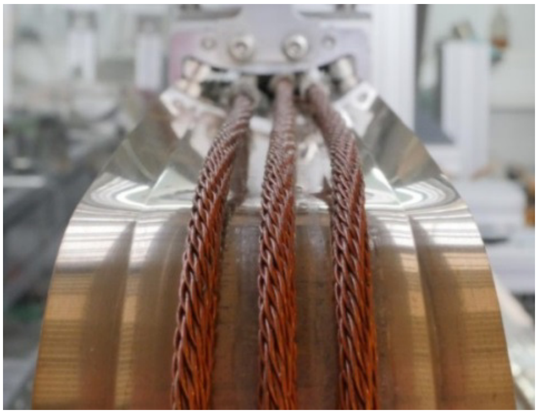

Figure 4: Three stranded cables in the cable tray with insolation removed.

The stranded cables have been qualified for the cable tray. The in-air noise level below 0.1 % is comfortable for the transport of digital signals and also, to some extent, analogue signals. For Hallprobe signals with a required accuracy of about 0.001% this cable is not suited. Therefore, an in-vacuum analogue-digital converter has been developed at HZB which digitizes the signal already within 100 mm distance to the Hallprobe nearly in place. The digitized signals are transported via the stranded cable as well.

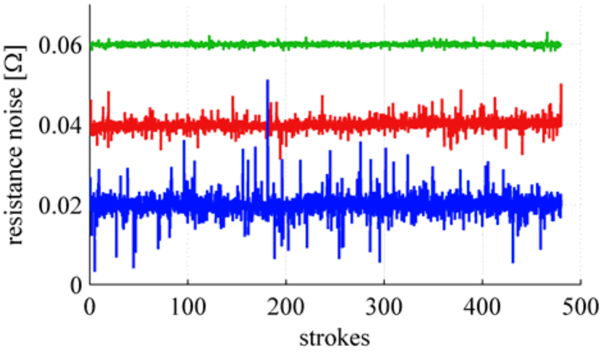

Figure 5: Resistance noise of 22 Ω resistor (green), 1.3 Ω moving wire pair of the stranded cable (red), and 1.1 Ω non-moving wire pair of ribbon cable.

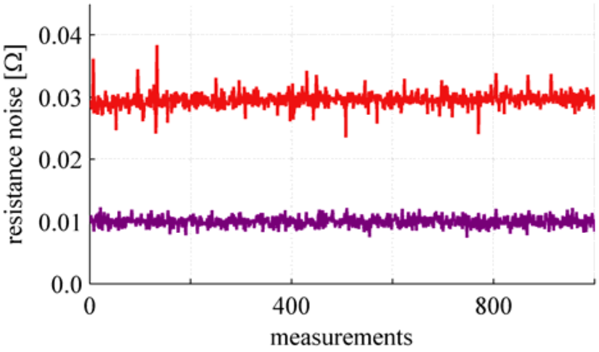

Figure 6: Resistance noise of a moving (red) and a resting wire pair (magenta) of the stranded cable. Other wires (older wires) show higher noise during motion.

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ISBN 978-3-95450-147-2

IN-VACUUM MOVING WIRE

General Layout

The design of the system was driven by the demand for robustness and reliability. All motion control components are located in air, and commercially available components are used. Two slides for the horizontal motion and four slides for the vertical motion are driven with servomotors. Absolute encoders are utilized in the feedback loops for a fast and precise positioning. Between the vertical slides a horizontal column is mounted which carries the wire fixtures. The wire tension is measured under HV-conditions via a HV-force sensor. The tension can be adjusted with a UHV-feedthrough. The system is depicted in Figure 7. The wire will be operated under vacuum conditions. The UHV-chambers are fabricated already but not installed, yet. The moving column is connected to the vacuum part via two edge welded metal bellows, dedicated for a high duty cycle.

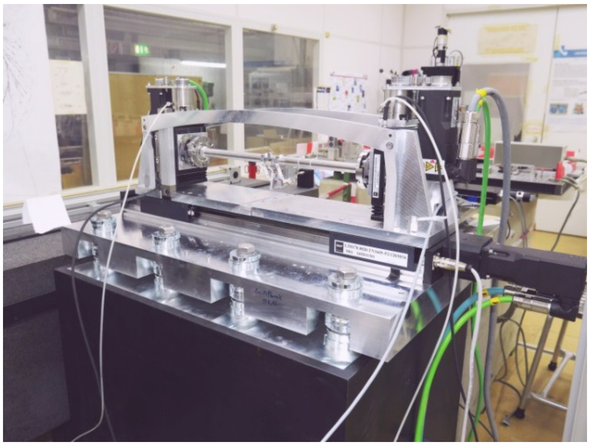

Figure 7: Half of the moving wire system.

The control software runs under LabView. It is implemented in a pxi-real time system which runs the hardware including the fast motion control via ethercat-protocol. The data acquisition can run in stepping or continuous mode to optimize the accuracy and reproducibility of the magnetic field measurements. Alternatively, a NI 7 1/2 digit voltmeter or an Agilent 3458A voltmeter is used for data acquisition.

Preliminary tests demonstrate the high dynamic of the system which is required for a sufficient signal to noise ratio. Typical measurement steps of 2.5 mm are performed within 100 ms and 50 ms seems to be possible. Similar to the old HZB-system the measurements are done with a single wire rather than a coil or a multifilament wire. The old system has a single scan rms-reproducibility of 3 Gcm, only.

First Measurements

The first measurements with the new system have been done only recently. One magnet girder of the old BESSY W/U (length = 2400 mm) has been used for testing purposes. The endpoles have not been compensated. Measurements of the vertical field integrals in a distance of 2.5 mm and over a transverse range of ±22.5 mm have been done (Figure 8).

The current reproducibility of the system as derived from the preliminary measurements is 0.039 Tmm (Figure 9). The error distribution is non-Gaussian which indicates the presence of systematic errors. The errors are independent upon the z-position. Certainly, an error contribution is due to the wire vibration, since the signal is pretty high. It is expected that the reproducibility of the new moving wire will be similar to the old system, once the commissioning phase will be finished.

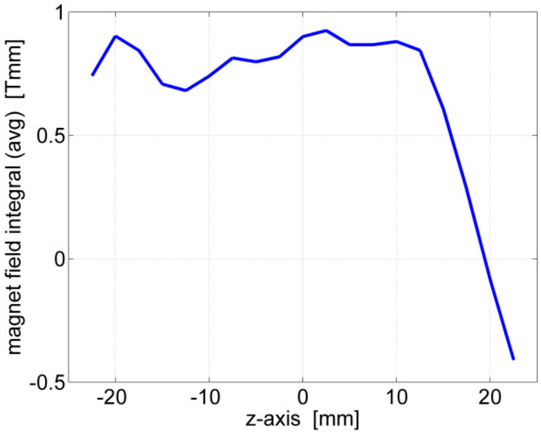

Figure 8: Field integrals of one I-beam of the BESSY W/U in a distance of 2.5 mm (averaged over 55 scans).

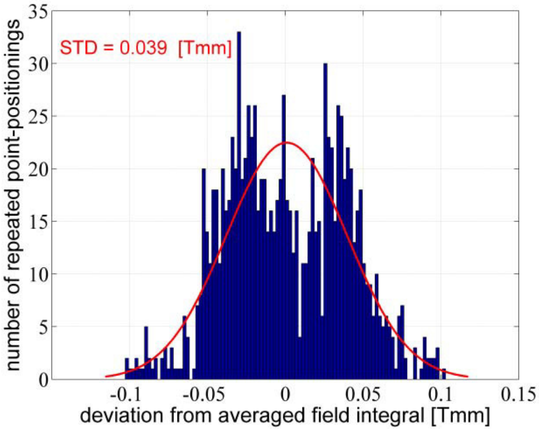

Figure 9: RMS-reproducibility of the moving wire measurements over 55 scans and all z-positions. Reduced histograms for 55 scans at a fixed z-position look similar.

In the future the system will be upgraded with a third unit for in-vacuum pulsed wire measurements. It is expected that the wire must be damped when operated in vacuum. Active damping will be tested in the near future.

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