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MAGNETIC MEASUREMENT SYSTEM FOR THE NSLS SUPERCONDUCTING UNDULATOR VERTICAL TEST FACILITY

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Abstract

One of the challenges of small-gap superconducting undulators is measurement of magnetic fields within the cold bore to characterize the device performance and to determine magnetic field errors for correction or shimming, as is done for room-temperature undulators. Both detailed field maps and integrated field measurements are required. This paper describes a 6-element, cryogenic Hall probe field mapper for the NSLS superconducting undulator Vertical Test Facility (VTF) [1]. The probe is designed to work in an aperture only 3 mm high. A pulsed-wire insert is also being developed, for visualization of the trajectory, for locating steering errors and for determining integrated multi-pole errors. The pulsed-wire insert is interchangeable with the Hall probe mapper. The VTF and the magnetic measurement systems can accommodate undulators up to 0.4 m in length.

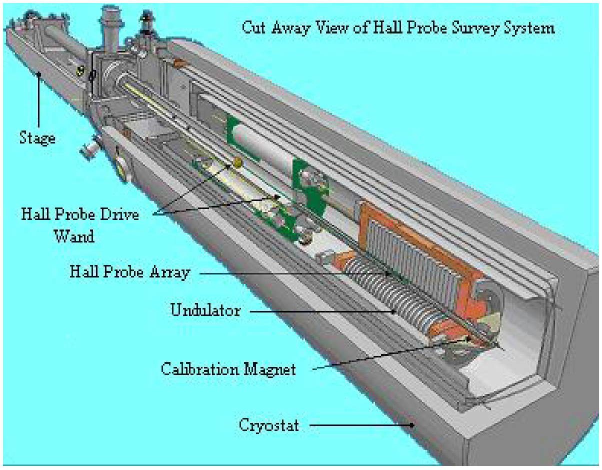

Figure 1: VTF main assembly cut away view

INTRODUCTION

The VTF consists of a vertical helium cryostat with associated vacuum and cryogenic hardware, a support structure which is inserted into the cryostat and an equipment rack which houses the instrumentation. The superconducting undulator to be tested, a superconducting calibration magnet and a zero-Gauss chamber are attached to the support structure. A hollow aluminum guide tube with an internal elliptical cross-section of 3mm by 12 mm passes through the undulator gap, the calibration magnet and the zero-Gauss chamber. The Hall probe slides through the guide tube. With the Hall probe removed, the pulsed-wire probe can be inserted down the same guide to provide complimentary field data for detection of trajectory errors.

HALL PROBE

The Hall probe consists of an array of 6 tiny Hall elements surface mounted to a thin printed circuit board. The board is sandwiched between layers of fiberglass to add stiffness, and to help index the probe in the aluminum guide tube. The sandwiched Hall array is soldered to a copper support tube, which is soldered to a larger diameter flanged holder tube, which is connected to a long-stroke linear stage. The stage has a bellows, which allows for probe translation under vacuum.

The individual Hall elements have an active area approximately 125 microns by 125 microns. They are arranged in two rows of three elements. On-axis and off-axis field data are taken, so that the peak field can be measured and field flatness and symmetry can be detected in a single scan. The second row is for redundancy in case of cold-cycling failure of a Hall element. The twisted wire pairs which deliver the sensor excitation current and transport the detected Hall voltages run along the inside of the copper support tube. The Hall excitation current is delivered by a pair of precision constant current sources.

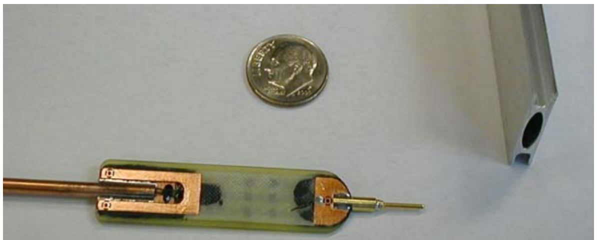

Figure 2: Assembled Hall probe and aluminum guide

The Hall voltages from the sensors are sequentially sampled by a Digital Multi-Meter (DMM) which is externally triggered. The long-stroke linear stage is driven by a motor, which is software-controlled to move at constant velocity. The motor microstepping signal is divided down to derive the external sampling trigger for the DMM. Thus the Hall probe scan is done ‘on-the-fly’, starting from a precise home position, acquiring the desired number of samples per undulator period. The raw Hall voltage data are downloaded from the DMM buffer and post-processed into calibrated field readings, using the polynomial fitted sensor calibration data.

Array coordinate detection

The relative coordinates of the active areas of each of the Hall elements in the array was detected by translating a magnetized needle over the array as the Hall voltage was being displayed.

Calibration

The VTF has its own superconducting calibration magnet for in situ calibration of the Hall probe at cryogenic temperature, however, a preliminary warm and cold calibration were also done using an NMR setup.

Figure 3: Calibration magnet (disassembled)

The cold calibration was done by submerging the probe in liquid nitrogen, which was contained in a small, vacuum insulated, double-wall Dewar. The narrow part of the Dewar containing the Hall probe at liquid nitrogen temperature was designed to fit, along with the NMR probe at room temperature, in the 1 ½" gap between the poles of the NMR calibration magnet.

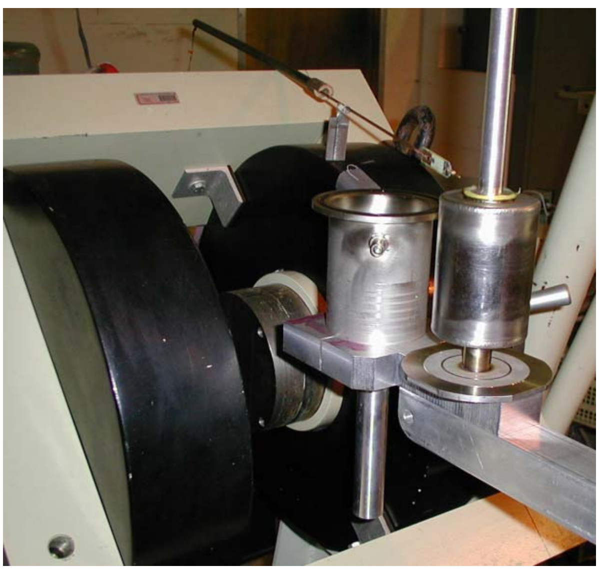

Figure 4: Cold calibration setup (Dewar disassembled)

Scanning

The scan starts with the Hall probe in the home position at the bottom of the aluminum guide tube between the poles of the calibration magnet, which will be in the superconducting state at cryogenic temperature. The current to the calibration magnet is varied and Hall voltage readings are taken for each of the Hall elements in the array. Then the system is software-configured for on-the-fly scanning, and the probe is commanded to move upward at constant velocity.

We plan to include two point magnets in close proximity to the aluminum guide tube which the probe will pass as it is pulled upward. The point magnets will be spaced by thermally stable rods affixed to the undulator. This will insure that the precise detection of the probe position with respect to the undulator is not effected by length uncertainties in the Hall probe drive assembly due to temperature gradients.

After passing the first point magnet, the probe is pulled through the undulator and past the second point magnet near the exit. The probe then passes into a zero-Gauss region where Hall voltage readings are taken for each of the Hall elements, which are then used for offset correction.

PULSED-WIRE PROBE

The pulsed-wire probe is still under development. It was designed to fit in the same aluminum guide as the Hall probe. The thin Be-Cu wire is housed inside a small diameter copper tube which is soldered to a larger diameter flanged holder tube, which is secured to a vacuum sealed X-Y stage. The stage provides fine lateral alignment of the copper tube.

The copper tube has guides attached to it at intervals to keep it straight in the aluminum guide tube. The wire is connected to a contact pin assembly at the far end of the copper tube, which forms a vacuum seal and electrically isolates the wire from the tube.

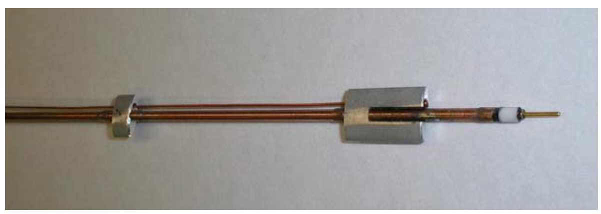

Figure 5: Pulsed-wire probe (end view)

When the pulsed-wire probe is inserted into the VTF assembly, the pin mates with a receptacle at the bottom of the aluminum guide tube. The wire feeds up through the copper tube and into the holder tube, where it passes through the gaps of a pair of optical interrupters which are oriented to detect the X and Y vibration of the wire. The interrupters have narrow slits over the emitters and detectors, which control the parallelism of the detection light, dramatically improving the X and Y signal isolation.

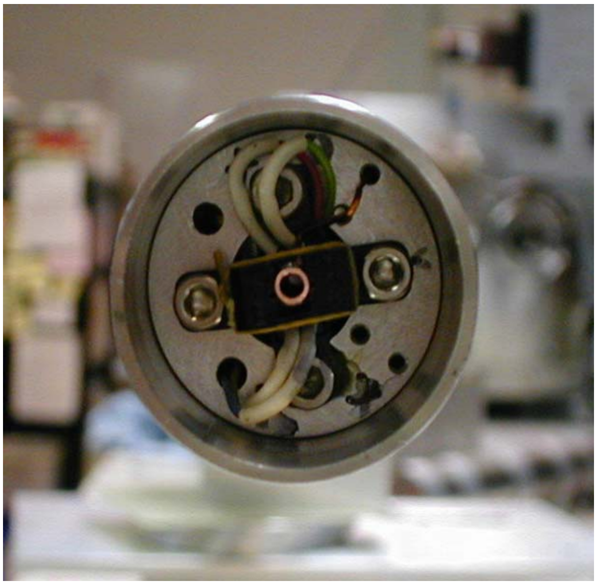

Figure 6: Wire vibration detector (interrupter assembly)

The wire feeds out through the top of the assembly and passes over a pulley, which is mounted to an X-Y stage. The stage permits fine lateral positioning of the wire in the interrupter gaps. The wire is tensioned with a hanging weight and electrical contact is made. The wire is excited in the usual manner [2] with a current pulse from a pulse generator. The amplified vibration signals are recorded using a sampling oscilloscope.

A 250 micron diameter wire was used for the first pulsed-wire test. The acoustic dispersion due to the wire stiffness corrupted the signal and could not be easily corrected [3]. When the 250 micron wire was replaced by 125 micron wire, the increased sensitivity to ambient vibration obscured the pulsed-wire signal.

It is a formidable engineering challenge to operate a pulsed-wire probe in a vertical cryostat environment which is inherently noisy. Hopefully, by increasing the pulse amplitude and by incorporating a wire vibration damper, a favorable signal to noise ratio can be achieved.

VTF TEST DATA

VTF Hall probe data of a 1.6 cm period Permanent magnet Small Gap Undulator (PSGU) were taken at room temperature and at dry ice temperature to verify the operation of the Hall probe survey system and to characterize the remnant field variation of the magnets with temperature. Figure 7 is a scan of the PSGU, which has 18 full periods.

A comparison of successive scans reveals that the repeatability error in probe positioning is typically less than 3 microns. A survey of the calibration magnet was conducted at room temperature and low current to examine the field homogeneity, which was in good agreement with the calculations.

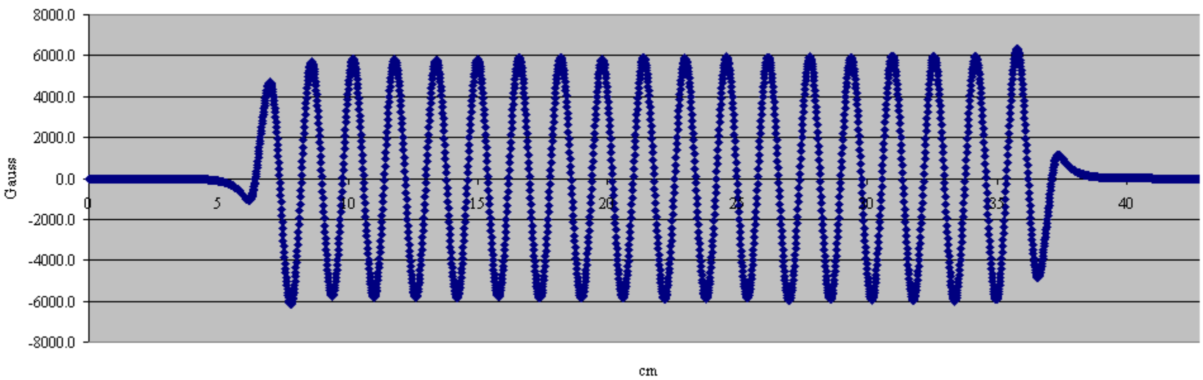

Figure 7: VTF Hall probe scan of the PSGU at room temperature

CONCLUSION

The process of assembling and testing the VTF magnetic survey system at room temperature has led to various hardware refinements which improve the precision and reliability of the system, and make it more user-friendly. The pulsed-wire probe will require further development, but the warm testing of the Hall probe survey system is completed, and it is now time to configure the system for cold testing.

ACKNOWLEDGMENT

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