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FIELD MEASUREMENTS FOR A SUPERCONDUCTING MAGNET AT ROOM TEMPERATURE

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Abstract

A superconducting multipole wiggler magnet was fabricated at the National Synchrotron Radiation Research Center (NSRRC) and was installed at the Synchrotron Light Research Institute (SLRI). A field strength of 3.5 T could be reached with NbTi superconducting coils while the magnetic arrays are immersed in a liquid helium bath. A removable mapping chamber, made from thin stainless-steel sheets, was designed to allow field mapping in the narrow aperture of the SMPW. The mapping chamber provides a room temperature environment for the magnetic field mapping and enables an easier field scan by Hall probes and stretched wire compared to the interior of the cryostat. The design for the mapping chamber includes a blockage of heat transfer from room temperature to the cryogenic beam chamber and strong enough features to resist deformations during evacuation. The mechanical design, strain simulation, thermal simulation and measurement results with the mapping chamber will be discussed in this paper.

INTRODUCTION

A superconducting multipole wiggler (SMPW) with a period length of 77 mm was designed, fabricated and measured at the NSRRC. The field strength of the SMPW, generated with NbTi superconducting coils immersed in a liquid helium (LHe) bath, is 3.5 T at a 22.5 mm pole gap. The layers of the cryostat from the inside out consist of a 4.2 K LHe vessel, a 80 K shielding and a 300 K vacuum vessel [1]. A semi-cool Aluminum (AL) beam chamber (~100 K) is inserted in the LHe vessel to supply an ultra-high vacuum environment for electron beam and to minimizing radiation heat transfer to the LHe vessel [1, 2]. In order to examine the field quality of the superconducting magnet, several measurement systems were developed for the superconducting magnet under vacuum and cryogenic environment [3-6]. A mapping method of the SMPW was developed to create a room temperature environment inside the AL-beam chamber that allows Hall probe mapping and stretched wire measurements in the cryostat. The challenge of room temperature environment created inside the beam chamber include a heat block and sufficient strength in the limited space available in the SMPW gap.

MAPPING CHAMBER DESIGN

Room temperature field mapping of a superconducting magnet was done in the cryostat of the SMPW, where space and thermal length are limited in the AL-beam chamber. Figure 1 (a) shows a sketch of the superconducting magnet arrays, the 4.2 K vessel duct, the AL-beam chamber, the mapping chamber and the Hall probe mapping system (HPS). Serval small G10 supports were inserted between the 100 K beam chamber and the 300 K mapping chamber to fix the position of the mapping chamber (hidden in the figure). The minimum distance between the 100 K AL-beam chamber and the 300 K mapping chamber is 1 mm while the space between the mapping chamber and the HPS is 2.4 mm. The clear space is 10 mm × 24 mm for the HPS, and 3 mm × 50 mm for the stretched wire measurement.

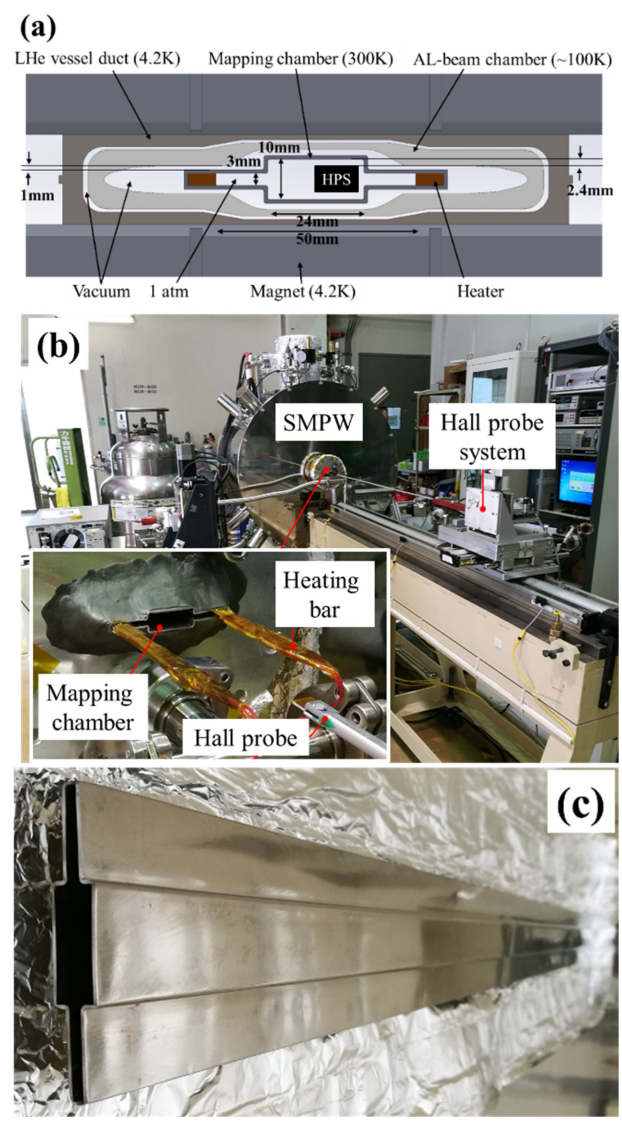

Figure 1: Field mapping at room temperature in a cryostat. (a) Sketch of the room temperature mapping chamber and cryostat. (b) Setup of the mapping system for the SMPW and (c) photo of the mapping chamber.

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The mapping chamber is at room temperature and heat conduction transfer is blocked by an insulation vacuum (better than 3.4×10^{-4} torr). Figure 1 (b) displays a photo of the setup of the Hall probe mapping system and the SMPW. Plastic clay was used to seal the vacuum between mapping chamber and end flange, as shown in Fig. 1 (b) insertion. A pair of copper heating bars were mounted on the side of the mapping chamber. A thin Ni-Cr resistance wire with a diameter of 0.1 mm was wound on the end of the copper bar that can generate a maximum of 38.2 W heating power on the mapping chamber wall. Figure 1 (c) shows a photo of the mapping chamber made of 1 mm thick stainless steel 316L (SS316L) and a length of 1170 mm to separate vacuum from atmospheric pressure. The mapping chamber forming process includes gas tungsten arc welding (GTAW), heat treatment for degaussing and surface polishing. A probe was assembled including a Hall sensor and an Aluminum tube with a maximum outer diameter of 5.2 mm and 8 mm in the vertical and horizontal directions, respectively. The probe sag was manually adjusted with a surveyor's level.

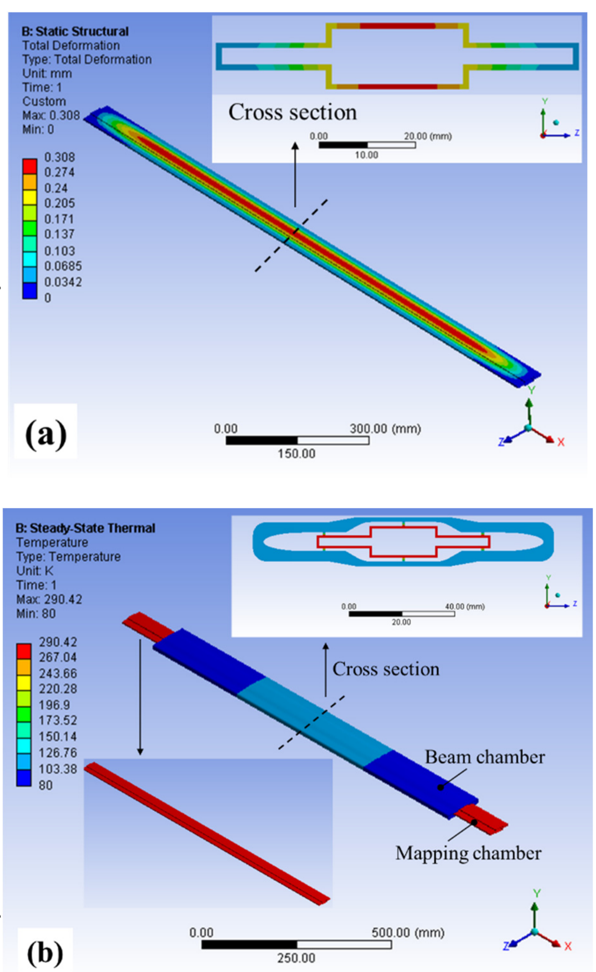

Figure 2: Mechanical strain and thermal simulation. (a) Deformation of mapping chamber under 1 atm pressure difference. (b) Temperature distribution of the SMPW after cool-down.

A one-dimensional Hall sensor was used to measure the field strength of the SMPW at room temperature within the cryostat. Dry nitrogen gas continually flowed through the mapping chamber to add to the heat convection and to avoid freezing inside the mapping chamber.

Mechanical strain and temperature distributions of the mapping chamber during measurements were simulated with the ANSYS software [7]. Figure 2 (a) shows the deformations of the mapping chamber with one atm pressure difference between inner and outer surface. The maximum deformation is 0.3 mm, thus confirming that the 300 K mapping chamber will not touch the 100 K beam chamber. Figure 2 (b) shows the temperature distribution of the mapping chamber after cool-down of the SMPW. The temperature of the mapping chamber is around 290 K allowing the HPS and stretched wire moving freely in the vacuum chamber of the cryostat. The conditions for the thermal simulations were: thermal interception on the beam chamber is 80 K, the air convection on the end flange and inner surface of the mapping chamber are 10 W/m^2 at 300 K, and thermal radiation has been included as well.

MEASUREMENT RESULTS

The Hall probe and stretched wire benches were setup at both ends of the SMPW to determine the field quality, shown in Fig. 1 (b). The local field distribution was mapped by the Hall probe while the integral fields were measured with the stretched wire method. Two separate Hall probe mappings were performed in the test Dewar and cryostat. The first field measurement of the superconducting magnet arrays were done with the LAKESHORE cryogenic Hall sensor of type MCT-3160-WN at 4.2 K ambient temperature within the test Dewar. The second measurement was done with the AREPOC Hall sensor, type HHP-MP, at 300 K ambient temperature within the cryostat. Figure 3 displays the on-axis fields along the longitudinal direction in the LHe cooled test Dewar (LAKESHORE sensor) and at 300 K (AREPOC sensor). In other words, both measurements were performed in the same magnet but at different ambient temperatures and with different Hall sensors. The maximum discrepancy is 0.3 % at the main peak of 3.5 T. This discrepancy may have been caused by different sensitivities to DC magnetic fields being not quite linear in the high field region and at low temperatures.

Figure 4 displays the comparison of the field mapping along transverse direction between the test Dewar and cryostat. The discrepancy of the fields between both measurements is 18.1 G or 0.051 % at x=0 mm. The cryostat data prove that the field homogeneity is better than 0.1 % in a region of ±5 mm. Both, cryostat and test Dewar data show that the field homogeneity of the SMPW is better than 0.3 % in a region of ±20 mm.

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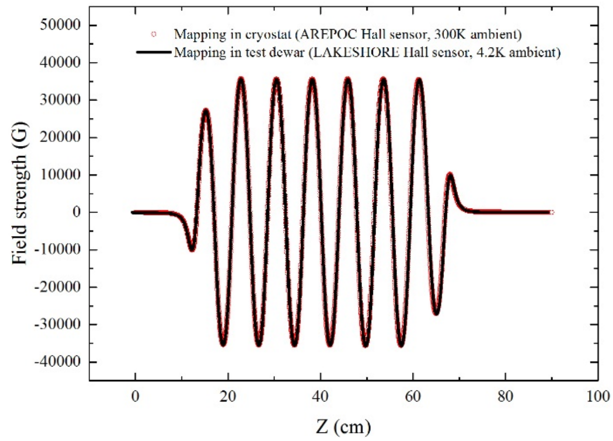

Figure 3: Field distribution measured with HPS along the magnet axis at room temperature and cryogenic temperatures.

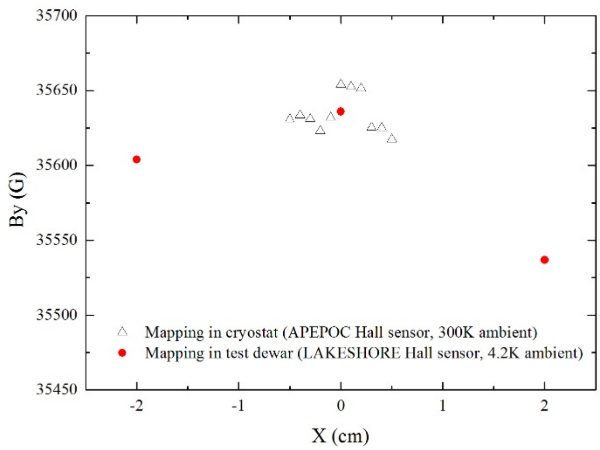

Figure 4: Field distribution along transverse direction mapping by the HPS in the cryogenic temperature and ambient room temperature.

Figures 5 (a) and (b) display the first vertical field integral (I_y) and horizontal field integral (I_x) in the horizontal plane as measured by the stretched wire method as a function of transverse offset. A polynomial fit is used to determine integral multipole errors and is shown in the table insert in Fig. 5. Only the integral dipole error is out of specification by a factor of two while other integral multipoles are quite small. The integral dipole error will be compensated with correction magnets. The on-axis second field integrals of the SMPW are also measured with the stretched wire and the results are 5730 G·cm^2 and -1080 G·cm^2 in the vertical (II_y) and horizontal (II_x) direction, respectively. These small multipoles of the SMPW were validated by the easy and smooth commissioning with an electron beam at the SLRI.

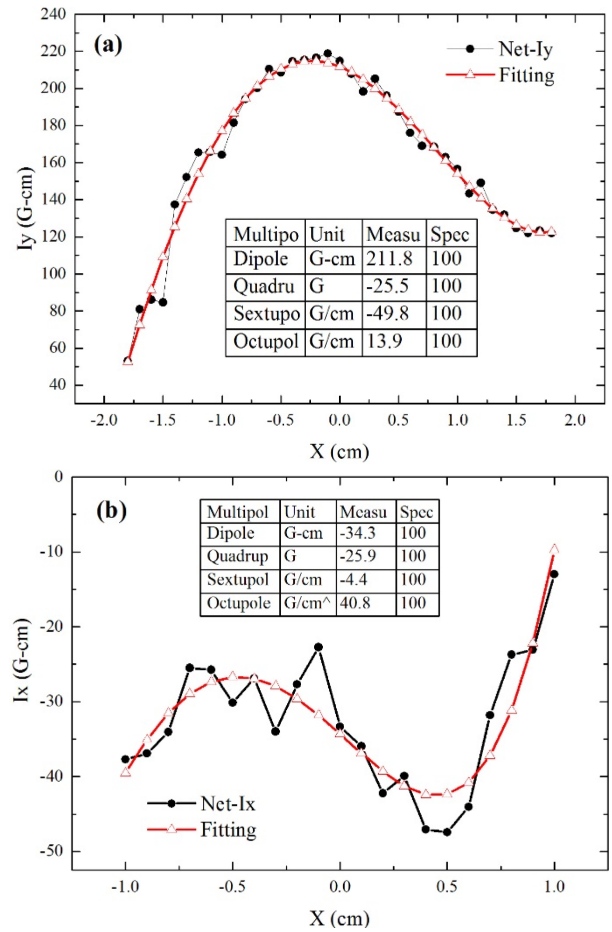

Figure 5: Field integrals measured with a stretched wire and fitted with a polynomial at room temperature in the cryostat. (a) Vertical field integral along the x-axis and (b) horizontal field integral along the x-axis.

SUMMARY

The field quality of the SMPW was successfully verified with HPSs and stretched wire measurements at ambient room temperature in the cryostat. The mapping chamber was designed and manufactured to isolate vacuum and temperature from the beam chamber of the SMPW. The Hall probe mapping results at room temperature are in agreement with 4.2 K mapping in the test Dewar. The stretched wire measurements were done in the same mapping chamber at room temperature. A broad good field region and small integral multipole errors of the SMPW support a proper design of the magnet.

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