MAGNETIC FIELD MEASUREMENT SYSTEM FOR SUPERCONDUCTING UNDULATORS*

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Abstract

The Reference Design Report of the proposed International Linear Collider includes helical superconducting (SC) undulators as a scheme to produce positrons. Planar SC undulators are also under development for the Advanced Photon Source at Argonne National Laboratory. This paper describes a conceptual design for a magnetic field measurement system that can measure, at liquid helium temperature, the field of an SC undulator with a horizontal undulator axis. The system consists of a cryostat and a linear-motion stage. The latter, which will have a travel length of approximately 3.5 m, is designed for helical as well as planar SC undulator magnetic measurements. The linear stage provides motion control for a set of Hall probes that are connected to a small-diameter carbon fiber tube inside the bellows-flange connections. The stainless steel bellows are kept at the same vacuum pressure as the cold mass in the cryostat. A linear encoder is used for the motion control of the stage, but a precise position measurement of the Hall probe relies on a laser interferometer system.

INTRODUCTION

The positron source of the proposed International Linear Collider (ILC) will have a section of helical superconducting (SC) undulators [1]. It is envisioned that the undulator section may consist of a number of identical undulators, each several meters in length. The planar SC undulator, also under development for the Advanced Photon Source (APS) at Argonne National Laboratory (ANL), currently has a magnetic period length of 16 mm and will ultimately have a magnetic length of about 2.4 m, while the vertical aperture of the beam chamber for the undulator section will be slightly larger than that for the ILC [2]. The magnetic fields and SC stability performances for the undulators must be measured with their axes in a horizontal direction to verify the field qualities and achievable fields after the SC coil "trainings."

Magnetic measurement systems for SC undulators that are relatively short in their magnetic lengths have been developed for use in vertical cryostats [3,4]. Designs of full-length helical undulator modules for the ILC have been reported. [5,6]. In this paper, a conceptual design is presented of a liquid helium (LHe)-temperature magnetic field measurement system for SC undulators with the undulator axis in a horizontal direction. Besides a cryostat, the system includes a linear stage, which is connected to a carbon fiber tube inside the bellows-flange connections for the motion control of the Hall probes.

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FIELD MEASUREMENT IN A VERTICAL CRYOSTAT

For short models of SC planar and helical undulators developed at ANL, the periodic on-axis fields were measured in a vertical cryostat in 4.2 K LHe [7,8]. A Hall probe was attached to the end of a 1.85-m-long stainless steel tube with a diameter slightly smaller than the aperture of the beam pipe. The other end of the tube was coupled to a motorized linear stage aligned with the undulator axis. On top of the cryostat flange around the stainless steel tube and linear stage, a bellows unit was installed to minimize changes in the temperature of the tube during measurements.

An on-axis field map at an excitation current of 500 A is plotted in Fig. 1. The Hall probe unit scanned the field at a velocity of 2 mm/s, and measurements were taken at an interval of 0.1 mm. The measurement of the Hall voltage was triggered by a linear encoder on the undulator axis that had a 1-μm resolution. The standard deviation of the field amplitudes, excluding the end field, was about 7×10^{-3}.

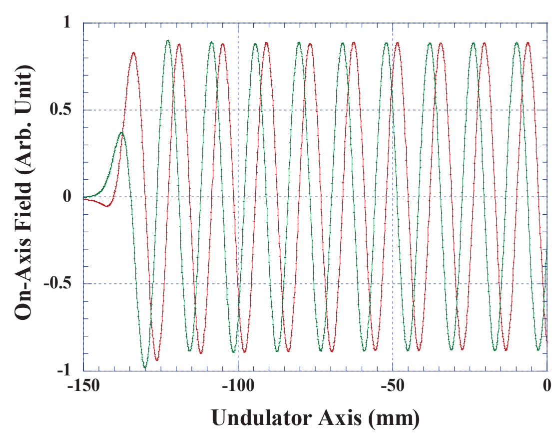

Figure 1: On-axis field map of a short R&D helical undulator at two angles 90º apart.

DESCRIPTION OF COMPONENTS

Cryostat

The design of a full-length undulator cryostat depends on several factors, such as the beam heat load to the beam chamber, the question of whether cryogens are to be used, and the undulator design itself. Figure 2 depicts a schematic drawing of a conventional undulator cryostat. It

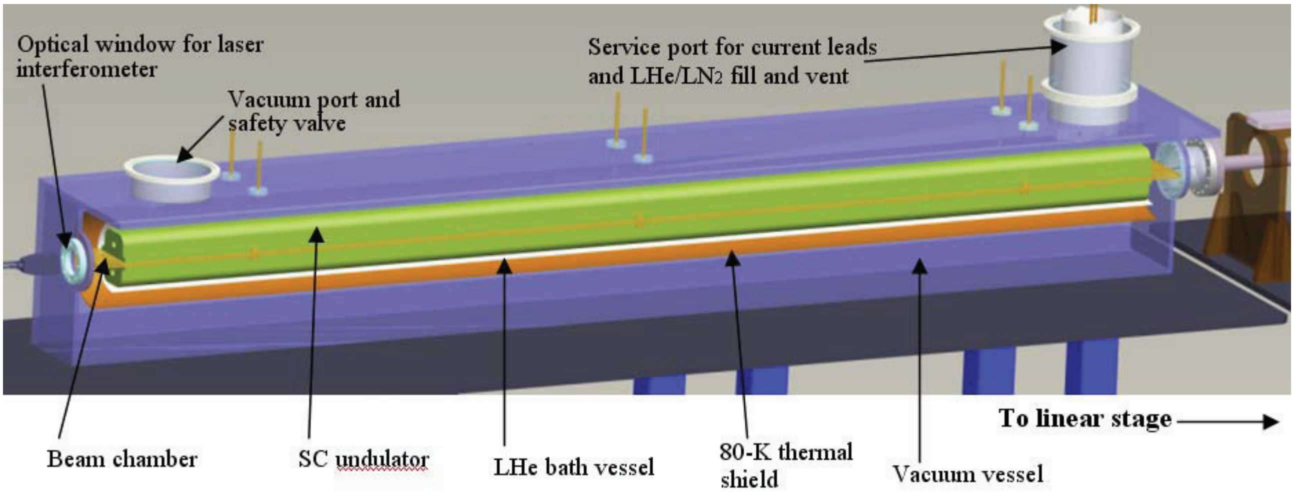

Figure 2: Cryostat system. The movable Hall probes and retro-reflector housing inside the beam chamber are not shown. The LHe vessel may be replaced with a 20-K thermal shield if the undulator is designed to cool down via LHe-flow conduits or thermal contacts with cold heads of cryocoolers.

contains the cold mass assembly, including the planar SC undulator magnet and provisions to connect to the linear unit. The outer thermal shield is cooled with liquid nitrogen (LN_2) and the inner vessel contains LHe. One end of the cryostat has an optical window that allows the use of a laser interferometer for position measurement of the Hall probe housing. The Hall probe housing contains a retro-reflector that reflects the laser beam back to the interferometer head for the position measurement. The Hall probe housing is mated to fit in the beam chamber of the SC undulator with close tolerances.

Linear Stage

The linear stage shown in Fig. 3 is to be attached to one end of the cryostat for measurements. The linear stage provides motion control for the Hall probe housing, which is connected to a 6-mm-diameter carbon fiber tube. The carbon fiber tube is supported by concentric rings on the inside of the bellows-flange connections. The linear stage incorporates a series of ten stainless steel bellows, each having a stroke of 0.35 m for an overall stroke of 3.5 m.

The bellows specifications are listed in Table 1. The bellows are at the same vacuum pressure as the SC undulator cold mass in the cryostat. The bellows are supported and guided by a guide rail system located directly above the bellows. The flange connection for each bellows is supported vertically and constrained horizontally, but is free to move along the longitudinal axis. The force required to keep the bellows at full extension is about 90 N.

The carbon fiber tube, which is attached to the Hall probe housing, is supported on the interior of each bellows-flange connection with a concentric Teflon disk. This allows the tube to slide relative to the flange

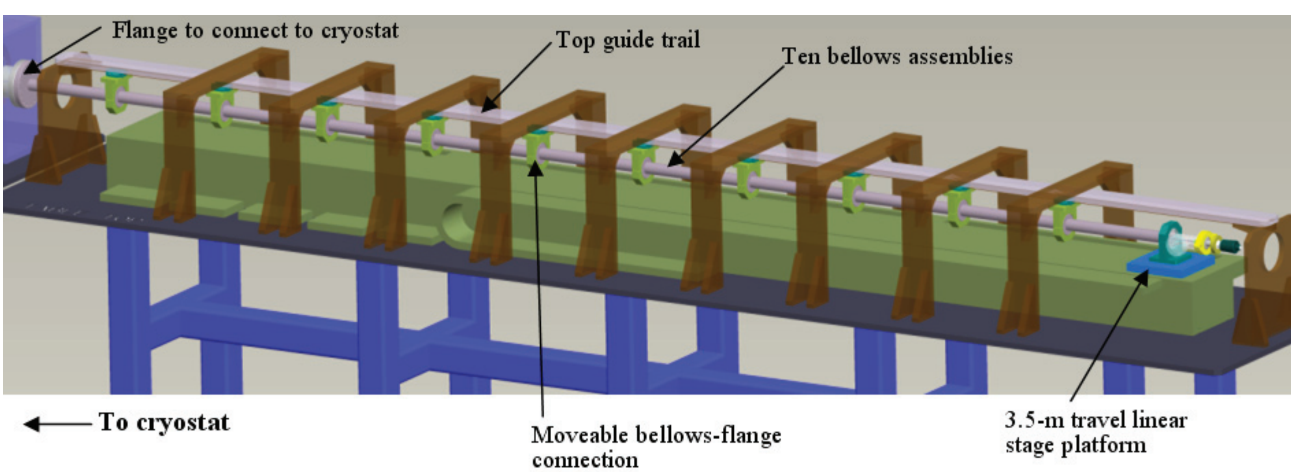

Figure 3: Linear stage. The stroke axial length of the bellows assemblies is 3.5 m. Details of the end section are shown in Fig. 4.

connections while still supporting the tube vertically and horizontally. The carbon fiber tube is attached to the linear stage platform and is coupled to a rotary stage for angular alignment of the Hall probe housing, as shown in Fig. 4. A linear encoder is used for motion control of the stage, but the precise position measurement of the Hall probes relies on the laser interferometer.

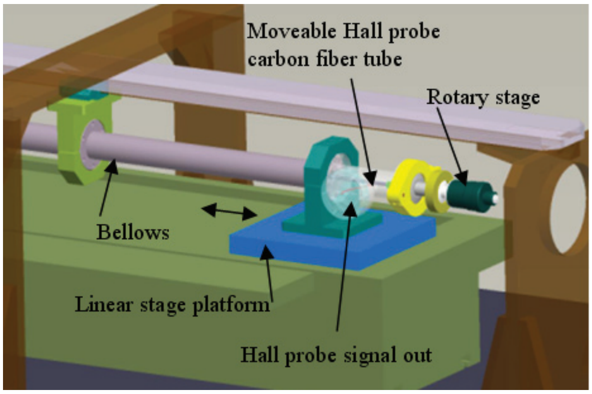

Figure 4: The end section of the linear stage.

Table 1: Specification of One Bellows Section

Inner diameter	19.0 mm
Outer diameter	37.0 mm
Thickness of one ply	0.130 mm
Number of convolutions	226
Compressed length	90.5 mm
Extended length	440.5 mm
Stroke axial	350 mm

Hall Probe Unit

The Hall probe unit will consist of several Hall probe elements attached to a ceramic substrate and housed in a 6-mm-diameter carbon fiber tube. A retro-reflector (corner cube) will be attached to the end of the tube assembly and will be used with the laser-interferometer-based linear encoder system to measure the position of the Hall probe unit as it travels along the length of the SC undulator. The Hall probe unit and carbon fiber tube will be supported and guided by the beam aperture of the undulator.

The laser head will be mounted externally on the end of the cryostat opposite the linear stage. The laser beam will pass through the optical window, and reflect off the Hall probe housing's retro-reflector, and return back to the laser head. Pulses from the laser linear interferometer will be used to trigger "on-the-fly" measurements of the Hall probe voltages at predetermined intervals. Feedback from the laser interferometer will also be used to detect a motor stall or any problems with the carbon fiber tube motion.

CONCLUDING REMARKS

The hardware components for the linear stage unit have been procured, and the assembly work is presently being planned to study its performance. A detailed cryostat design for the APS planar undulator will be conducted soon.

ACKNOWLEDGMENTS

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