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DESIGN AND COMMISSIONING OF MAGNETIC FIELD SCANNING SYSTEM FOR SRF CAVITIES*

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Abstract

Trapped magnetic vortices are one of the leading sources of residual losses in SRF cavities. Mechanisms of flux pinning depend on the materials treatment and cool-down conditions. A magnetic field scanning system using flux-gate magnetometers and Hall probes has been designed and built to allow measuring the local magnetic field of trapped vortices normal to the outer surface of 1.3 GHz single-cell SRF cavities at cryogenic temperatures. Such system will allow inferring the key information about the distribution and magnitude of trapped flux in the SRF cavities for different materials, surface preparations and cool-down conditions.

INTRODUCTION

Modern particle accelerators rely on Superconducting Radio Frequency (SRF) cavities. Various elements and alloys have been investigated which shows superconducting behaviour, i.e., having zero dc resistivity and very small ac resistivity and expulsion of magnetic fields upon the NC/SC phase transition (Meissner-Ochsenfeld effect). Due to a moderately high transition temperature bulk Niobium (Nb) is a material of choice for cavity fabrication. With the advancement in research and development of SRF cavities, the quality factor (Q) of SRF cavities is now routinely in range of 10^{10} to 10^{11} with peak magnetic field up to ≈ 200 mT, which corresponds to accelerating gradients E_{acc} ≈ (35 to 50) MV/m depending on the cavity shape. Desired parameters for high energy particle accelerator are accelerating gradient > 50 MV/m and a quality factor of $>10^{10}$. Due to RF losses in SRF cavities, it is challenging to reach both high quality factor and accelerating gradient. Ideally, all magnetic flux should be expelled when the cavity temperature is lowered below the transition temperature. However, disturbances such as lattice defects or impurities have the ability to inhibit the expulsion of an external field during the transition from normal conducting to the superconducting state and resulting in trapped vortices within the superconducting material. Vortices are known to be one cause of residual losses in superconducting Nb cavities [1,2]. The amount of trapped flux depends on cooldown condition and the ambient magnetic field [3,4]. Different techniques have been developed to investigate the losses mechanisms in SRF cavities. One of them is a thermometry system, developed and used in many laboratories around the world [5]. Such a system provides the spatial distribution of losses at hot-spots, however it could not explain the physics behind those lossy spots and several questions arise, such as: What is the distribution of the pinned vortices? How many vortices are pinned on the surface of cavity? How the trapped vortex bundles affect the surface resistance at strong RF field? What cool-down condition can minimized trapping of vortices in the cavities? Due to lack of experimental technique, these questions have been largely unanswered. Thus, additional diagnostic tools are required. A magnetic field mapping system is a new tool which will be used to tackle the physics of residual RF losses in SRF cavities.

EXPERIMENTAL DESIGN

Probes

Two types of probes are going to be used. One is a cryogenic Flux Gate Magnetometer (FGM) and the other is a cryogenic Hall Probe (HP). FGM is a single axis magnetometer probe (Mag-F from Bartington) which can measure magnetic flux as low as 0.1 nT and up to 0.2 mT. It has cylindrical shaped with a 6 mm diameter and 28 mm length. The cryogenic HP is a single-axis probe (HHP-VFS from Arepoc) with a 20 µm× 20 µm active area. Hall probes work on the Hall effect principle. A set of 16 Hall Probes have been calibrated by placing them in a uniform magnetic field produced by Helmholtz coils. A single FGM next to the HPs was used as a reference. The calibration was done at 10 K, 4.3 K and 2 K. The sensitivity is ~94 nV/µT and does not change with temperature between 10 K and 2 K. The experimental setup for the HPs calibration is shown in Fig. 1

Figure 1: Hall probes calibration setup.

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Brackets and Motors

Two brackets are used to attach the two types of sensors. Three stepper motors are used to move the system. The first stepper motor is mounted on the test stand top plate and performs motion along α angle, shown in Fig. 2. The other two are cryogenic stepper motors (VSS25.200.1,2 from Phytron) used to move the sensors along β and γ angles, also shown in Fig. 2. The range of angular movement in α direction is 360º and 60° in β and γ directions. In order to shield the cavity from the residual field of the stepper motors, they are enclosed in custom made magnetic shields (A4K, Amuneal) reducing the magnetic field to less than 1 mG at the cavity surface.

The brackets are designed to fit the contour of 1.3 GHz TESLA/XFEL single-cell cavities.

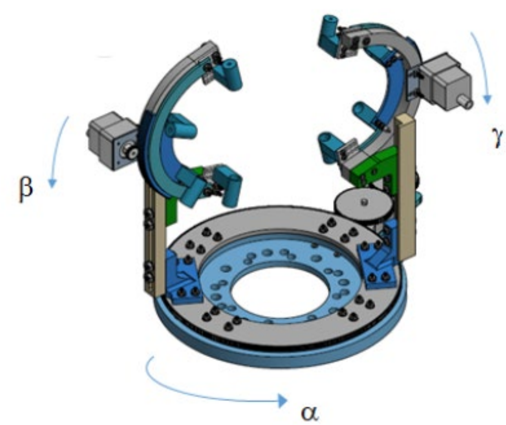

Figure 2: Bracket and associated motors system.

Because of the curved surface of cavity we are using brackets. Four sensors in each brackets are attached and two sensors on each bracket are stationary while two other are moved by a rack-and-pinion gear system. This dynamic nature of the system helps reduce the cost of experiment since each sensor cost > $600. It also allows for much better coverage of the surface.

The orientation of the sensors will be normal to the surface of the cavity wall, since the magnetic field of vortices exits the superconductor normal to the surface. The probes are held in contact with the cavity surface through spring-loaded holders. The HPs are set in a holder which keeps them at 120 µm from the surface, since these sensors are very delicate and should not make direct contact with the cavity

DATA ACQUISITION

For instrument control and data acquisition we will use a LabVIEW program. Arepoc's data acquisition module ETH2AD will be used to acquire data from Hall probes. Mag01H will be used to take data from fluxgate magnetometers. We will use a single Mag01H module and take data from all FGMs using the Keithley's multiplexing module (2701/7701). A four axis ethernet stepper motor controller (PMX-4ET-SA, from Arcus Technology) along with three single axis microstep drivers will be used for motion control. NI-9265 current source will be used for Helmholtz coils. A cryogenic temperature monitor (Model 18i, Cryocon) will be used for temperature measurement (see Fig. 3).

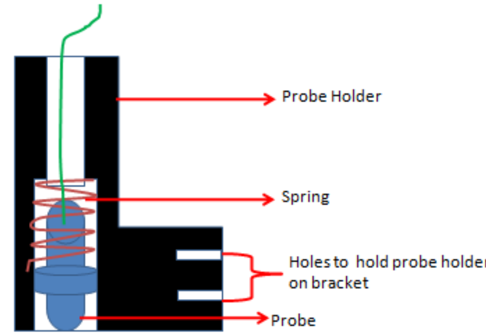

Figure 3: Schematic of probe holder along with probe.

PROGRESS

A picture of the setup assembled on a single-cell cavity is shown in Fig. 4.

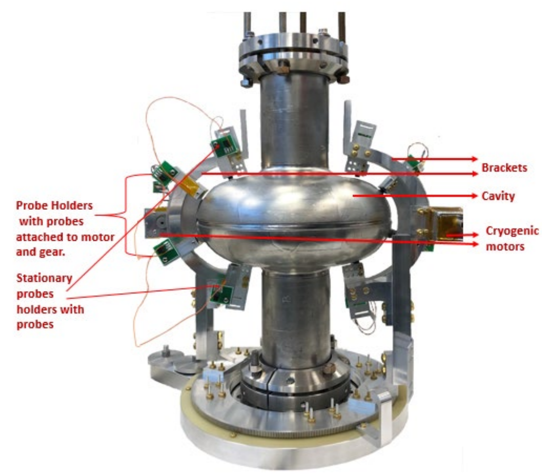

Figure 4: Scanning system with cavity.

For instrument control and data acquisition, a LabVIEW code has been written, and bench tested. The front panel of the program is shown in Fig. 5. This LabVIEW program can be run in two modes: Scan mode and monitor mode. Scan mode is automated mode. In scan mode, initially, all motors are in specified position. Once program run, the coordinate in β and γ directions increases by $\Delta\beta$ and $\Delta\gamma$, respectively, in the clockwise direction. Data are taken from all sensors after each angular increment. This increment continues until motors trigger their corresponding positive limit switches, $+L_\beta$ and $+L_\gamma$. Once the positive limit switch is triggered, the coordinate in β and γ direction decreases by $\Delta\beta$ and $\Delta\gamma$ and then moves in the counter-clockwise direction. Data are taken by sensors at each decrement. This decrement continues until motors trigger their negative limit switches $-L_\beta$ and $-L_\gamma$. When both positive limit switches or both negative limit switches are triggered, the coordinate in α direction is increased by $\Delta\alpha$. This process continues until the positive limit switch $+L_\alpha$, for α is triggered. Once $+L_\alpha$ is triggered the program

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is stopped. Three-dimensional map of the magnetic field distribution will be plotted in intensity graphs for HP and FGM separately. Temperature data from temperature sensors will be recorded as well and plotted in the graph. Data will be stored in the .txt format. In monitor mode: we can move motors up to fixed positions and take data continuously at chosen positions.

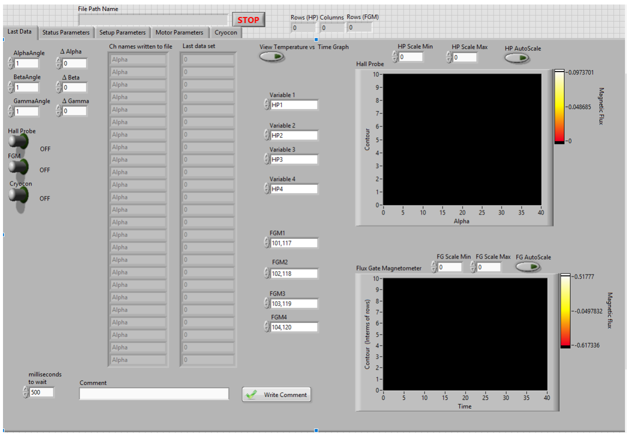

Figure 5: LabVIEW front panel for data acquisition.

FUTURE PLAN

After commissioning of the system at 4.3 K, we will do magnetic field measurement at the outer surface of the cavity. Before a measurement, the following process will be carried out.

- Surface preparation: We will prepare the surface of a cavity by first removing to the damaged surface layer using either BCP or EP. After that we will do low temperature baking and heat treatment. We will also do doping on the cavity.
- Cleaning by pure water i.e. high pressure rinsing and let it dry and then assemble RF probes and ultimately attach to a test stand for evacuation.
- Find quench locations and hot spots using temperature mapping while doing high power RF tests at 2 K.
- Warm up the cavity up to room temperature and remove temperature mapping system and assemble the magnetic mapping system and then return the cavity under vacuum to the testing dewar.
- Cool-down the cavity again to 2 K. Record the magnetic field data before and after the transition temperature. Do high power RF test again and map the magnetic field during the test.

Along with these steps, we will perform different cool-down procedures in varying magnetic fields using Helmholtz coils so as to get information about the amount of vortices being pinned in different conditions. Magnetic scanning of 1.3 GHz cavities made of both fine grain and large grain Nb will be performed following the process mentioned above. We will also do magnetic scanning of a Nb/Cu bimetallic 1.3 GHz cavity.

SUMMARY

A system for measuring the magnetic flux trapped in the walls of 1.3 GHz SRF cavities has been designed and built. The system allows for measuring magnetic fields using both FGMs and HPs and allows for scanning of the equator region. The system has been tested at room temperature and will be commissioned soon in a vertical cryostat filled with liquid Helium.

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