MEASUREMENT OF THE MAGNETIC FIELD PENETRATION INTO SUPERCONDUCTING THIN FILMS*

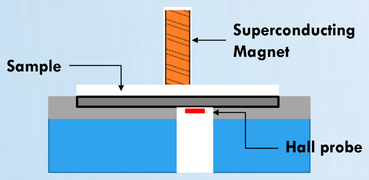
I. H. Senevirathne[1 #], G. Ciovati[1, 2], J. R. Delayen[1, 2]
[1]Center for Accelerator Science, Old Dominion University, Norfolk, VA 23529, USA
[2]Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA

ABSTRACT

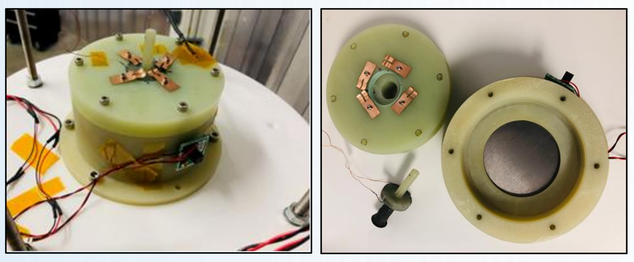
The magnetic field at which first flux penetrates is a fundamental parameter characterizing superconducting materials for SRF cavities. Therefore, simple, efficient and accurate tool is needed to measure the penetration of the magnetic field directly. The conventional magnetometers are inconvenient for thin superconducting film measurements because these measurements are strongly influenced by orientation, edge and shape effects. In order to measure the onset of field penetration in bulk, thin films and multi-layered superconductors, we have designed, built and calibrated a system combining a small superconducting solenoid capable of generating surface magnetic field higher than 500 mT and Hall probe to detect the first entry of vortices. This setup can be used to study various promising alternative materials to Nb, especially SIS multilayer coatings on Nb that have been recently proposed to delay the vortex penetration in Nb surface.

OBJECTIVE

Design, build and calibrate a simple, efficient and accurate tool to measure onset penetration directly through bulk, thin film and multilayer superconducting samples.



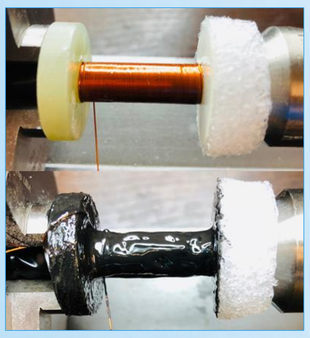
Basic Experiment Setup



External (left) and internal (right) view of nonmagnetic container which supports the sample, solenoid magnet, and Hall probe symmetrically.

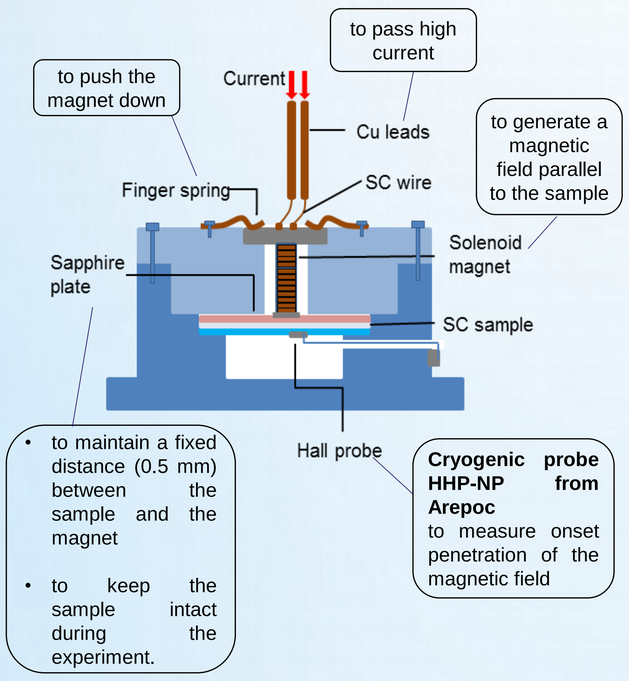
MAGNET

Magnetic coil was fabricated by winding NbTi thin wire carefully on dielectric spool using strategies followed in magnet fabrication. An epoxy was used after winding to obtain a good insulation and a monolithic structure which cannot allow any movement of the conductor inside the coil.

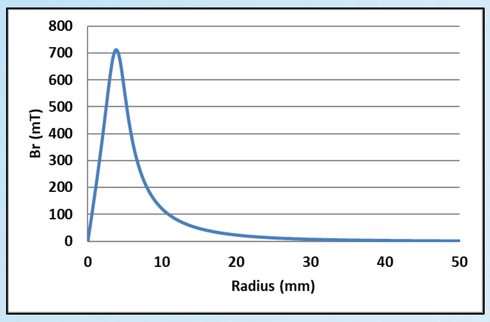


Superconducting solenoid magnet before (top) and after (bottom) applying an epoxy.

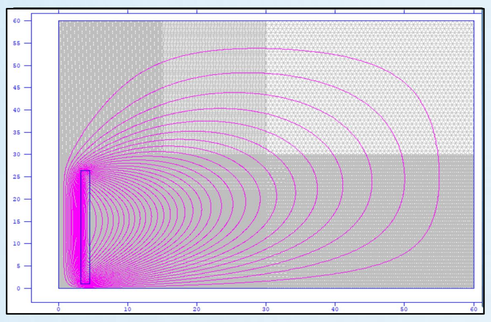
EXPERIMENTAL SETUP



FIELD FROM THE MAGNET ON THE SAMPLE



Variation of the radial magnetic field along the sample radius at 100 A (From Poisson Simulations)



Field lines from the right half of solenoid magnet placed at 1 mm above the superconducting sample (From Poisson Simulations)

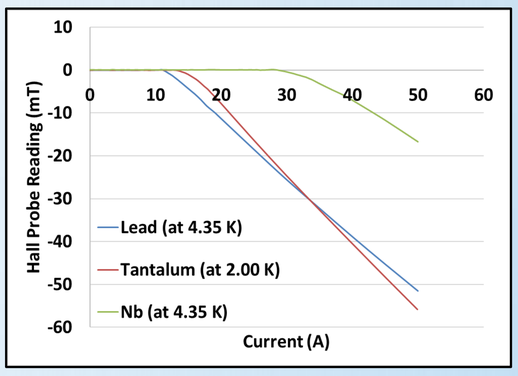
- In the Meissner state the sample acts as a magnetic mirror.
- Vertical component of the magnetic field cancels out.
- The field felt by the sample is equal to twice the radial component of the magnetic field.
- Since the radial magnetic field is parallel only to one side of the sample, this field configuration closely resembles the SRF cavities.

CONCLUSION AND FUTURE WORK

- The new experimental setup for magnetic field penetration measurements of superconducting samples was designed, built and calibrated successfully at Jefferson Lab. This experimental system is appropriate for bulk samples as well as thin films.
- The linearity of calibration curve confirms that the system is ready for the future measurements to study
  - the possible alternatives to Nb and multilayer system.
  - the dependence of field penetration on the sample thickness and different coating parameters which contribute to the film quality.

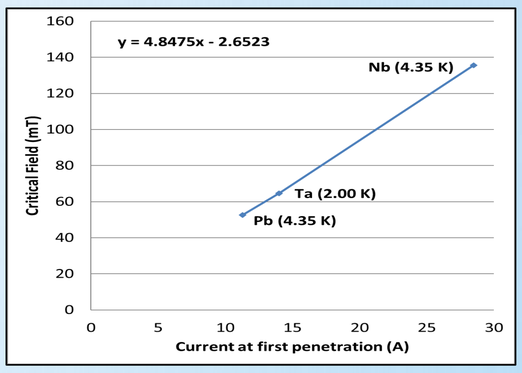
CALIBRATION WITH BULK SUPERCONDUCTORS

System was calibrated using 99.99 % pure bulk Lead (Pb), Tantalum (Ta) and Niobium (Nb) samples with 50 mm in diameter and 0.1 mm in thickness.



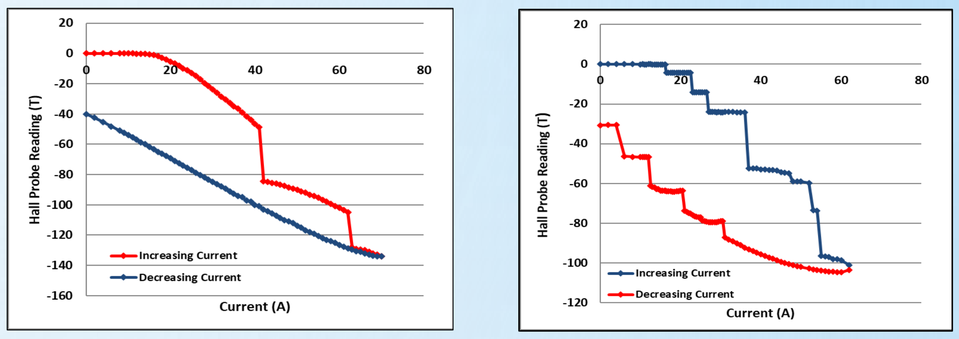
Hall Probe response against Pb, Ta, Nb samples while powering up the magnet with gradually increasing current

Details of the reference samples		
Reference sample	Critical Temperature (K)	Temperature at Measurements (K)
Pb	7.20	4.35
Ta	4.50	2.00
Nb	9.26	4.35

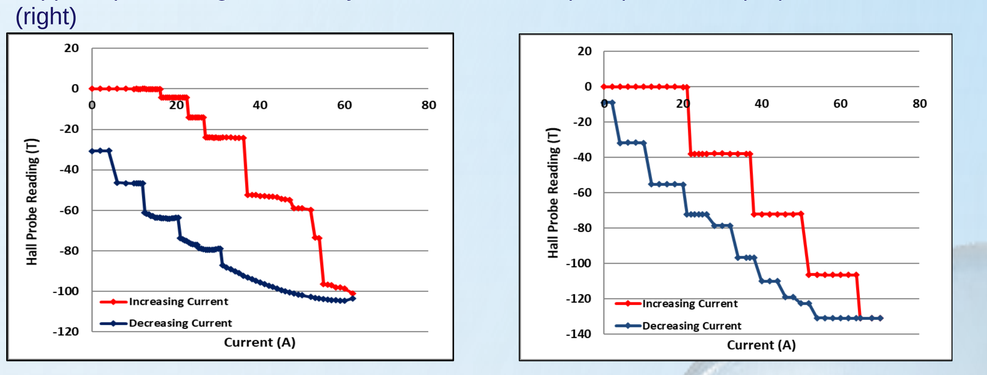


The calibration curve of the experimental setup

MEASUREMENTS OF THIN FILM SUPERCONDUCTORS

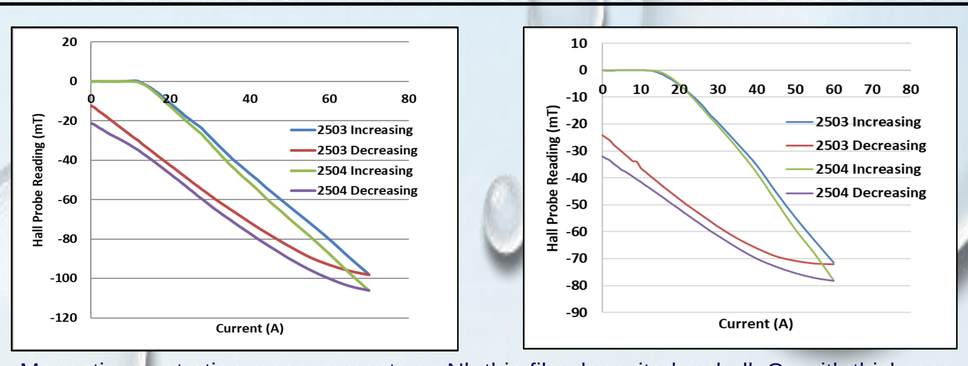


Magnetic penetration measurements on Nb thin film with thickness 2 µm deposited on sapphire plate using Electron Cyclotron Resonance (ECR) at 4.35 K (left) and 1.97 K (right)



Magnetic penetration measurements on Nb_3Sn thin film with thickness 1.5 µm deposited on sapphire plate using Magneton Sputtering at 4.35 K (left) and 1.97 K (right)

MEASUREMENTS OF THIN FILM SUPERCONDUCTORS ON BULK



Magnetic penetration measurements on Nb thin film deposited on bulk Cu with thickness 1 mm using Electron Cyclotron Resonance (ECR) at 4.35 K (left) and 1.97 K (right)

ACKNOWLEDGEMENT : Anne-Marie Valente-Feliciano
Nizam Sayeed
Jlab SRF staff and the machine shop staff

* Work supported by NSF Grants PHY-1734075 and PHY-1416051, and DOE Award DE-SC0010081

#isene001@odu.edu

REFERENCES

[1] N. Katyan, C. Z. Antoine, "Characterization of thin films using local magnetometer", presented at SRF 2015, Whistler, BC, Canada, paper TUPB058, pp. 712-715.

[2] G. Chanin, J. P. Torre, "Critical Field Curve of Superconducting Lead", *Phys. Rev. B*, Vol. 5, No. 11, 1972.

[3] C. H. Hinrichs, C. A. Swenson, "Superconducting critical field of tantalum as a function of temperature and pressure", *Phy. Rev.* Vol. 123, No. 4, 1961.

[4] T. Junginger, S. H. Abidi, R. D. Maffett, T. Buck, M. H. Dehn, S. Gheidi, R. Kiefl, P. Kolb, D. Storey, E. Thoeng, W. Wasserman, R. E. Laxdal, "Field of first magnetic flux entry and pinning strength of superconductors for rf application measured with muon spin rotation", *Phy. Rev. Accel. Beam* 21, 032002, 2018.