Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

Magnetic measurement of 4.3T conduction-cooled HEX superconducting wiggler

Toshi Tanabe

National Synchrotron Light Source-II

Date

Outline

- Current status of NSLS-II
- The High energy Engineering X-ray (HEX) Diffraction beamline
- HEX-Superconducting Wiggler
- In-Vacuum Hall probe bench
  - Field mapping result
- In-Vacuum flip coil system
  - Field integral measurement
- Summary

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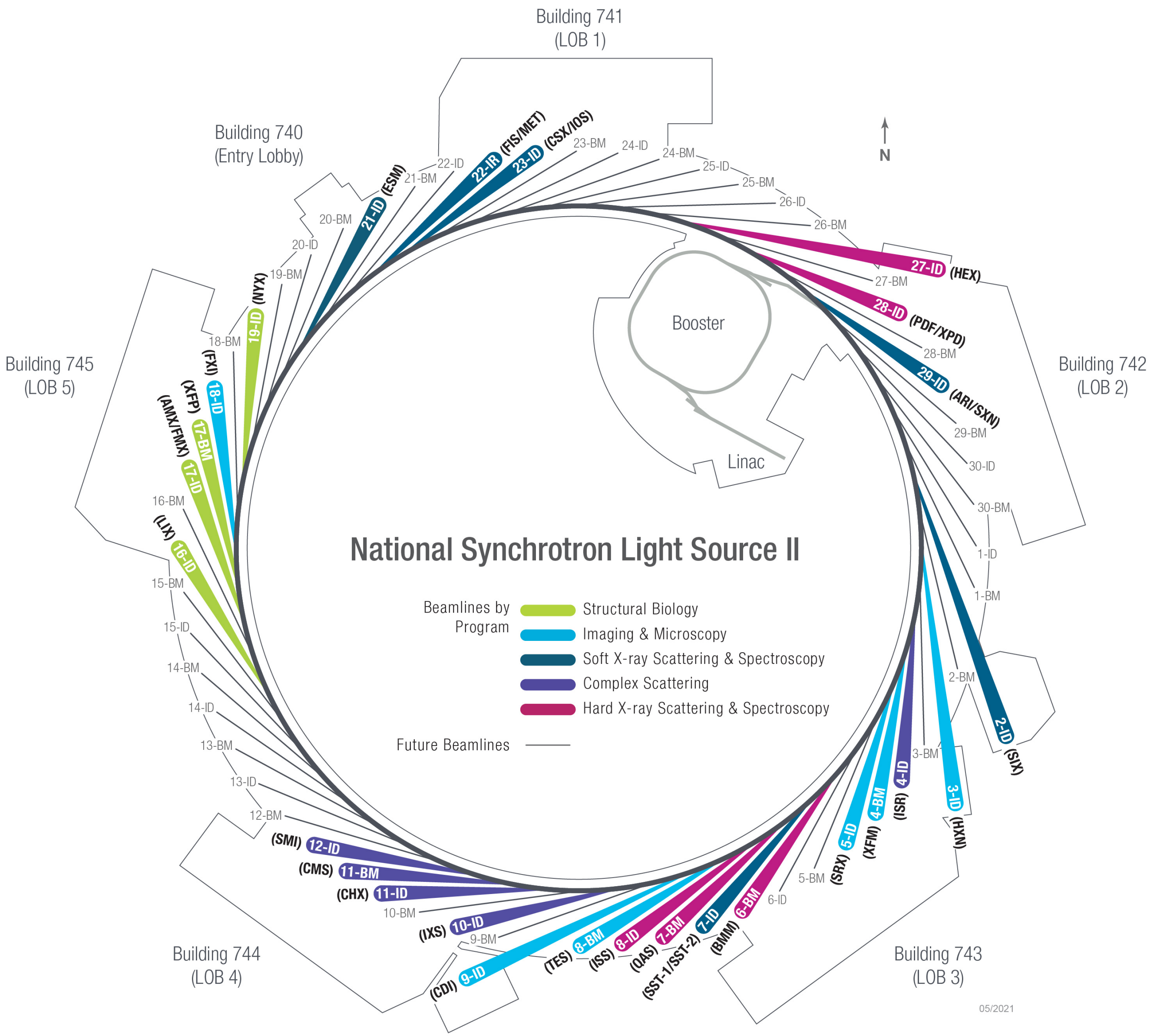
National Synchrotron Light Source –II Update



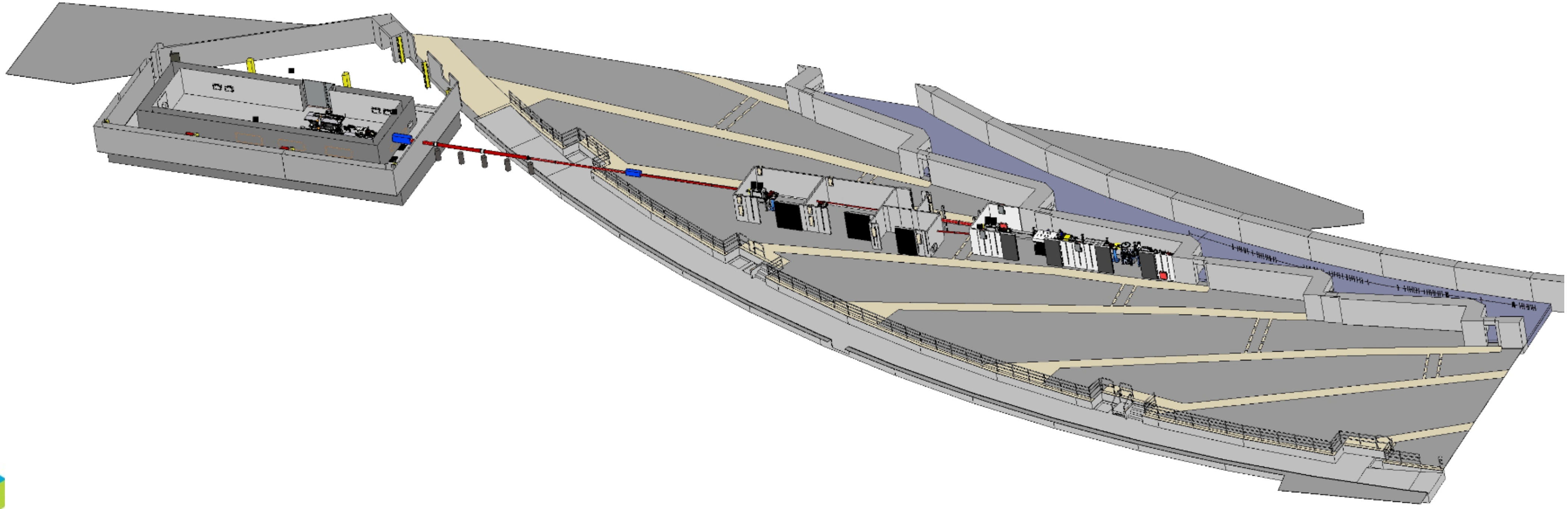
- Ring: I=400mA

Emittance:

- 0.8nm.rad (H) /30 or 8pm.rad(V)
- 500mA & 30pm.rad (V) operation starts from next FY
- 28 beamlines taking users, often remote
  - FY19 95% onsite
  - FY21 65% remote
- Currently, masks are again required on site while Suffolk County is in CDC “High” risk category

HEX Project Scope

- The HEX beamline is designed to cover the photon energy range from 20keV to 200keV and primarily funded by The New York State Energy Research and Development Authority (NYSERDA) and NSLS-II.
- A 1.2m-long SCW with peak field of 4.3T and period length of 70mm has been designed and fabricated with the collaboration with Bilfinger Noell GmbH in Germany.
- Complete beamline primarily funded by NYSERDA ($25M) and NSLS-II ($5M for Management and Oversight). First phase completion in 2023.



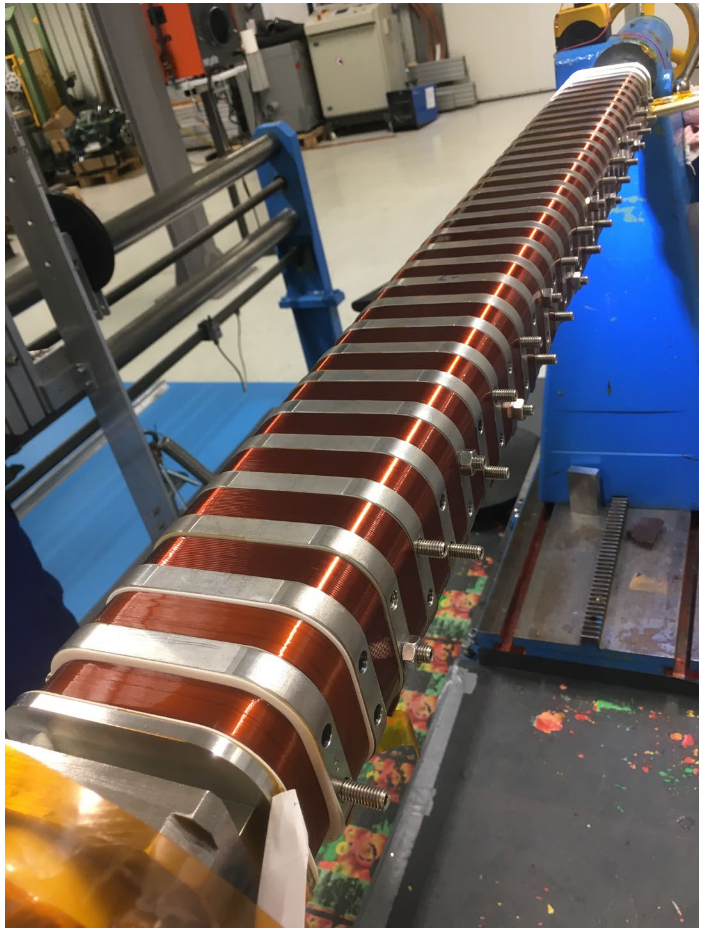
HEX-SCW

Vertically wound coils (1.2m long)

Conduction cooled (4 coolers)

Max field: 4.3T

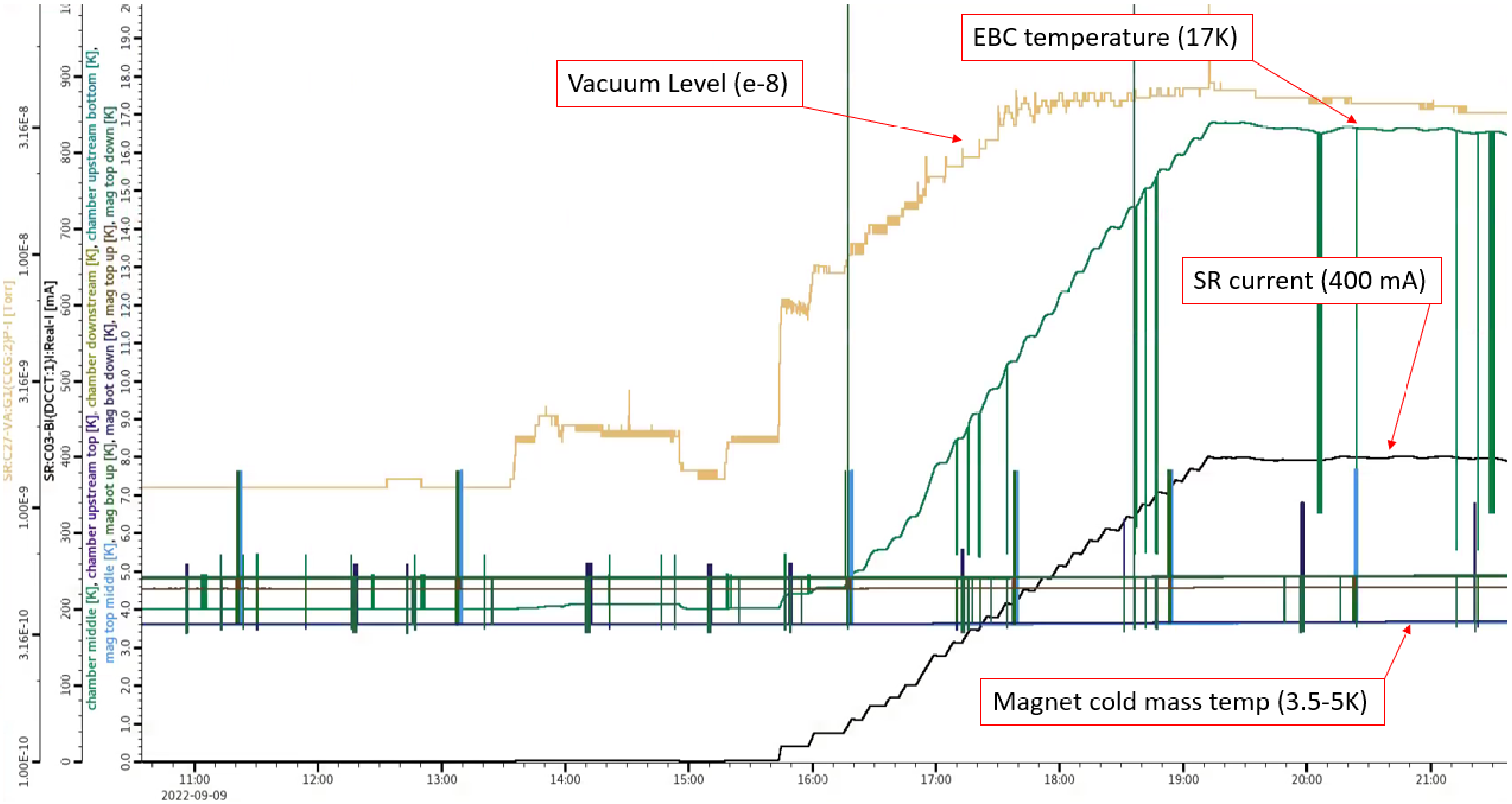
Vacuum Aperture: 8mm (Pole Gap=12mm)



Item		Parameter
Magnet Array length		≤1200 mm
Period Length		70.0 mm
Operating field (By) on axis		4.3T
Number of pole pairs @ full field		29
Number of pole pairs @ ¾ field		2
Number of pole pairs @ ¼ field		2
Electron beam chamber full vertical aperture		8mm
Electron beam chamber full horizontal aperture		76mm
Field stability ΔBy / By over two weeks		< 10^{-4}
Max. Stray field on axis at each end of the cryostat		10 G
Ramping time, 0 to 4.3 T up or down		≤ 30 minutes
Maximum temperature of magnet coil during quench		< 75 K
$\int_{-\infty}^{\infty} By(x,y,z)dz$	Requirement for the **Absolute Value** of 1st and 2nd Field Integral Error (|x|<10mm, y=0mm), (from 0 to 4.3T) (**with** correction coils)	≤50 G.cm
$\int_{-\infty}^{\infty} Bx(x,y,z)dz$		≤30 G.cm
$\int_{-\infty}^{\infty}\int_{-\infty}^{z} By(x,y,z')dz'dz$		≤10,000 G.cm.cm
$\int_{-\infty}^{\infty}\int_{-\infty}^{z} Bx(x,y,z')dz'dz$		≤5,000 G.cm.cm
Requirement for the **Absolute Value** of On-axis Electron Trajectory for ny longitudinal position		|x|<60 μm, |y|<5 μm and |y'|<10 μrad
Requirement for the **Absolute Value** of Integrated Multipole (|x|<10 mm, y n 0 to 4.3T)		Definition of Multipole Expansion about ($x = x_0$, $y = 0$)* $\int_{-\infty}^{\infty} dz(B_y + iB_x) \equiv \sum_{n=0}^{\infty}(b_n(x_0)+ia_n(x_0))(x-x_0+iy)^n$
Normal quadrupole (b1(x0))		50 G
Skew quadrupole (a1(x0))		50 G
Normal sextupole (b2(x0))		50 G/cm
Skew sextupole (a2(x0))		50 G/cm

Ref: T. Tanabe, D. A. Hidas, M. Musardo, J. Rank, R. Todd, M. Seegitz, M. Breitenbach, A. Hobl, and H. Wu, IEEE Transactions on Applied Superconductivity 32 (2022).

Initial Vacuum Commissioning (2022-9-9)



In-Vacuum Hall Probe Bench

In-Vacuum Magnetic Measurement System for CPMUs

Cryo-Material Test

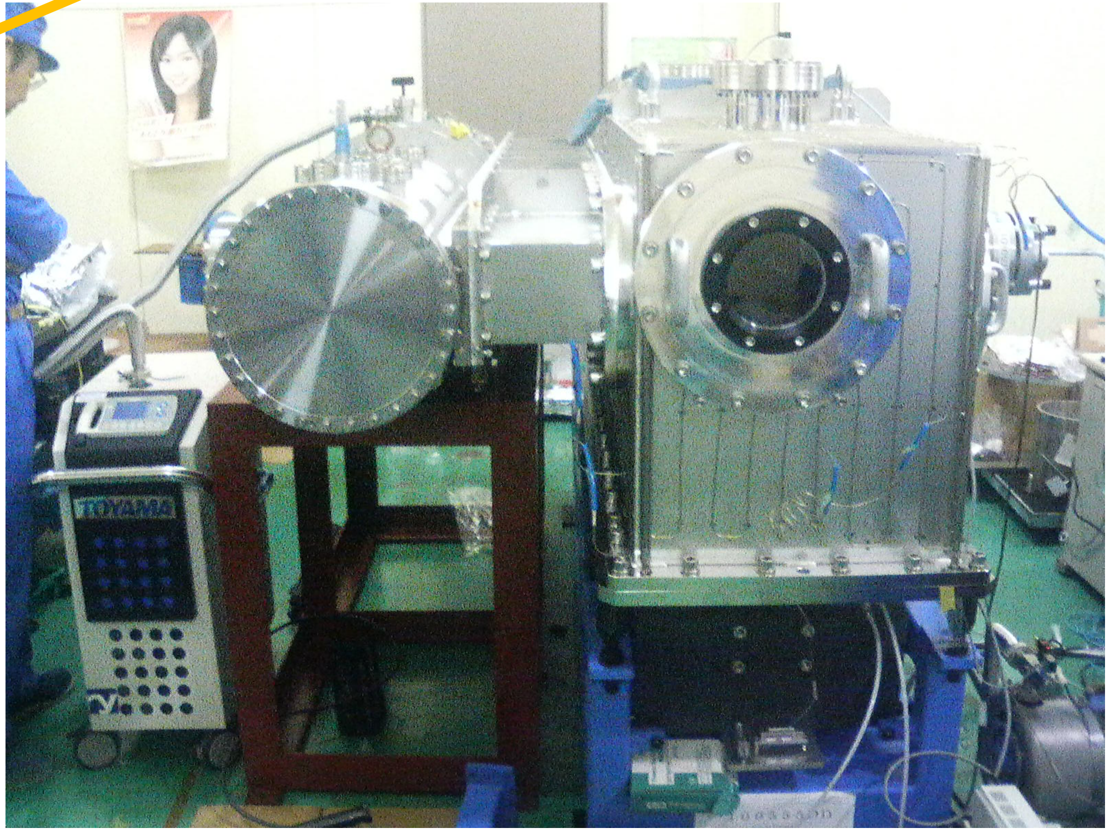
Sled with Lakeshore Hall probes and Cernoxs

Hall probe calibration

Measurement of PrFeB Magnet Arrays by IVMMS (2013)

The IVMMS was originally designed to be used as a Hall mapper for 1.5m-long CPMUs. It has a rectangular chamber with a side opening of 2000mm x 200mm which can connect to a mating side opening of a CPMU. The motion stages of the IVMMS consist of a longitudinal Z-axis carriage with a linear motor (AIREX LMC-P16)) driven by Elmo COR7/230. The nominal travel speed is 10 mm/s and the maximum speed is 8 m/min. The guide beam is made of stainless steel 316LN. The figure on the right shows Measurement of PrFeB undulator at 77K with the IVMMS.

Bakable PrFeB Arrays
λu=17mm, 47CR



Issues:Thermal load for cryogenic meas.
Vacuum compatible lubricant (Dicronite)

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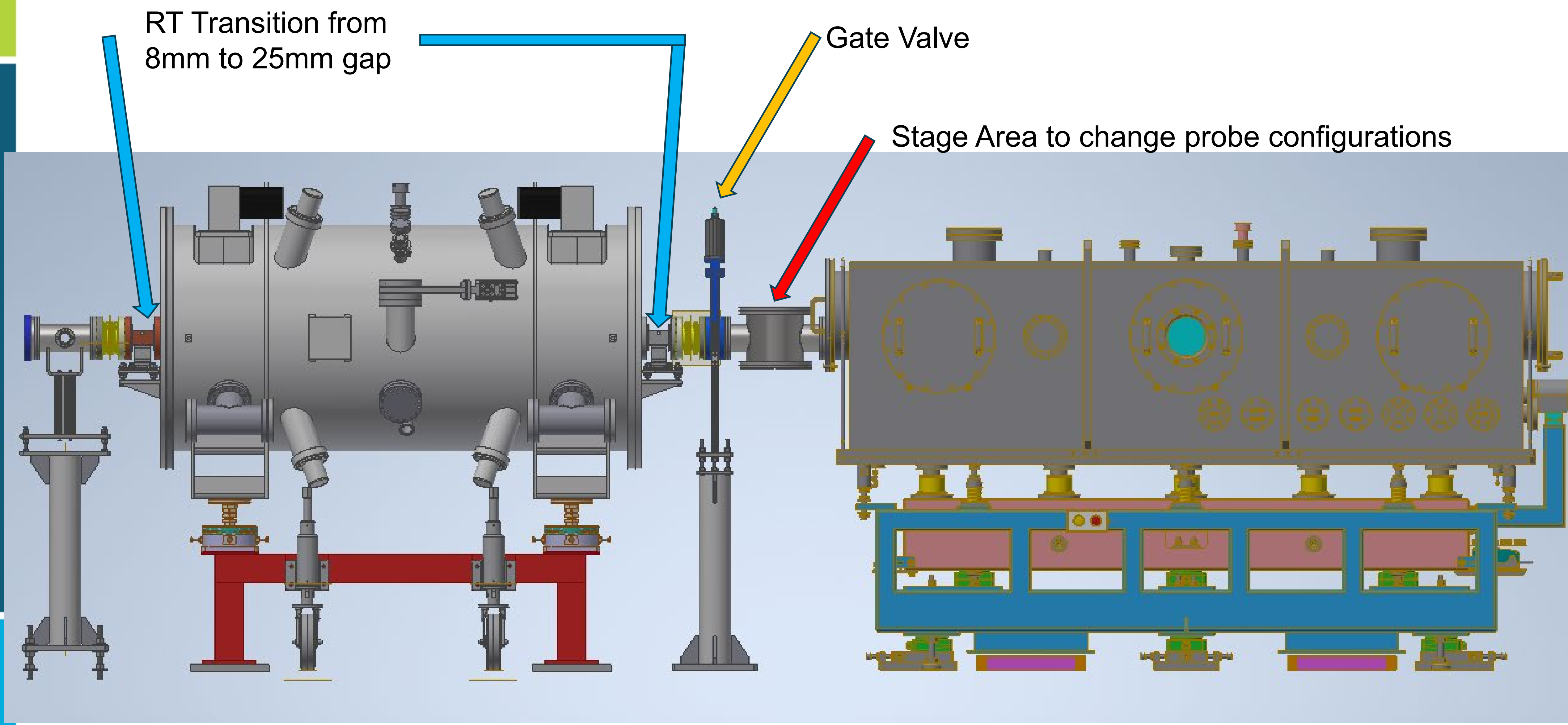
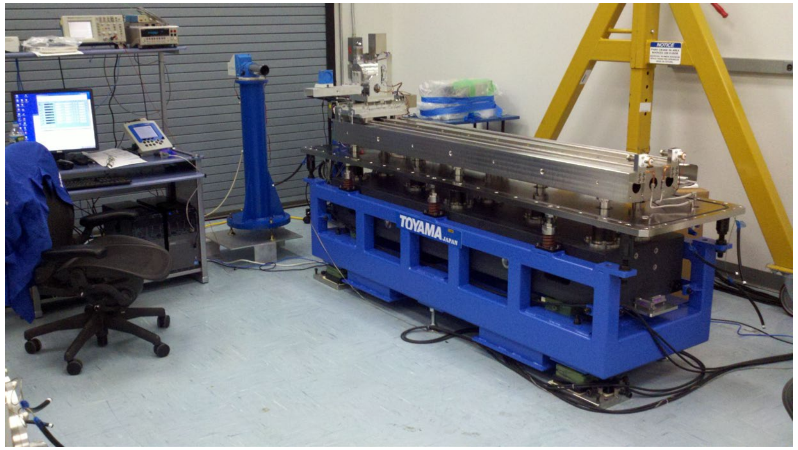
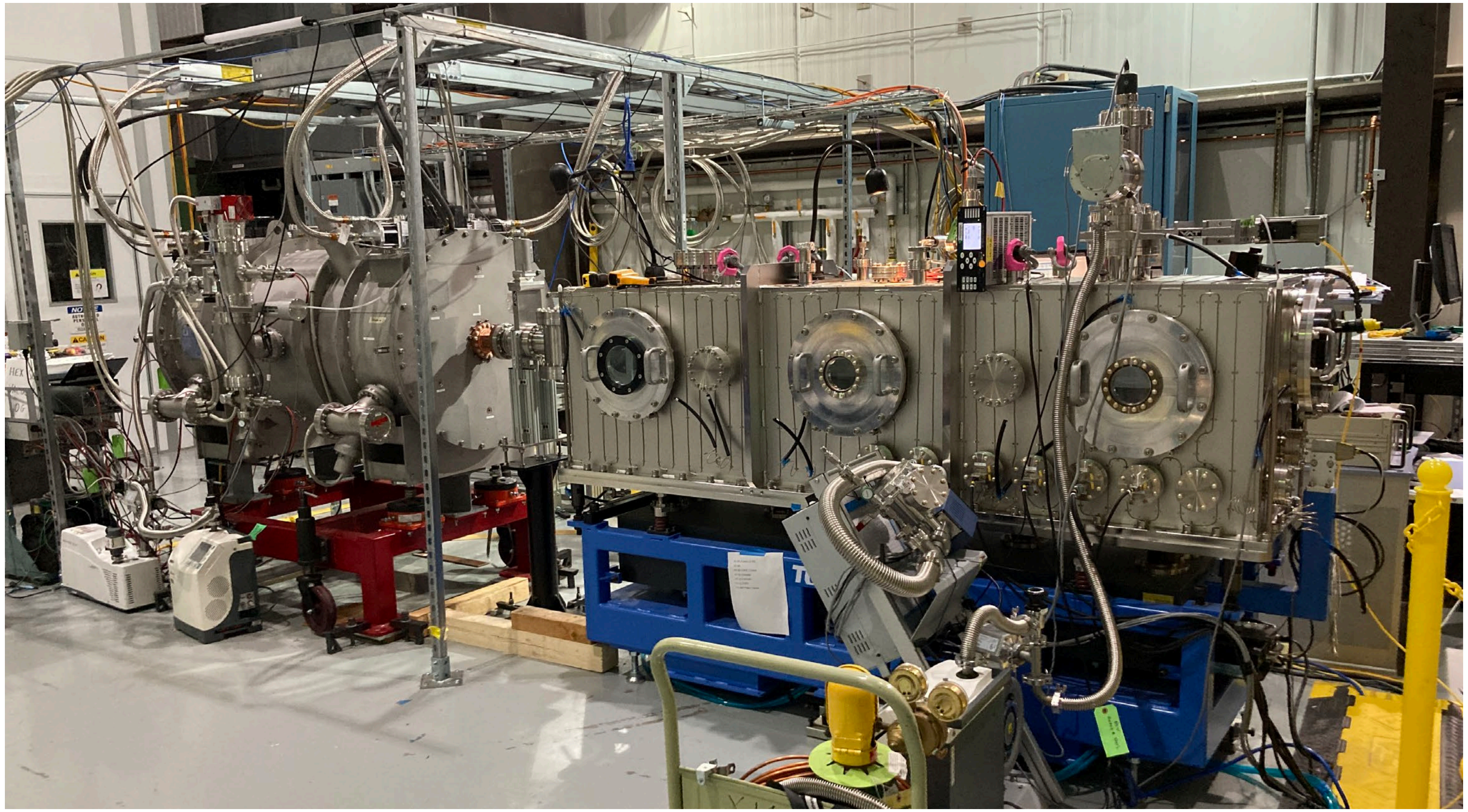
In-Vacuum Hall Probe Bench: Basic Configurations

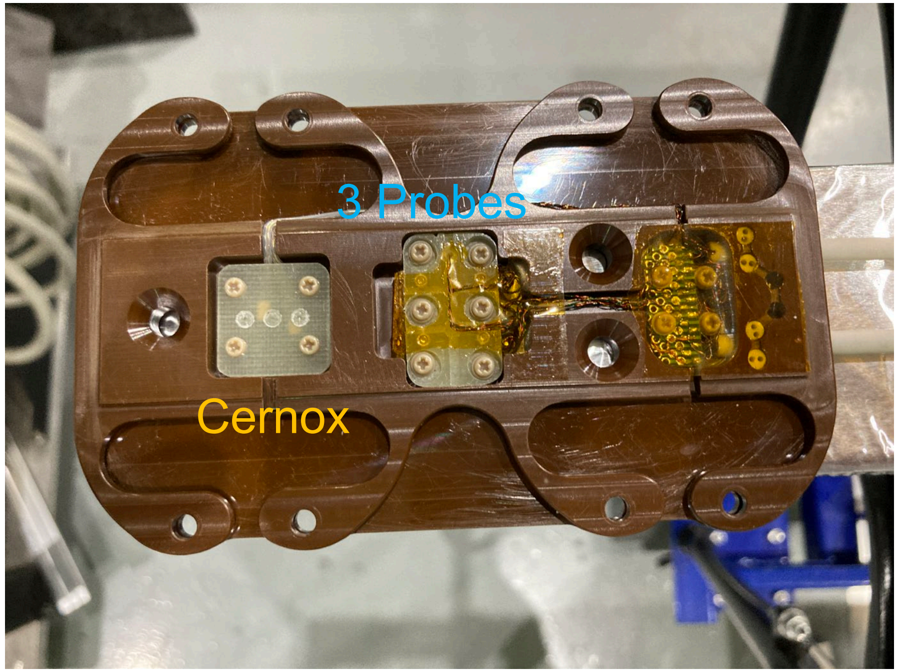


Measurement Conducted at ID-MMF

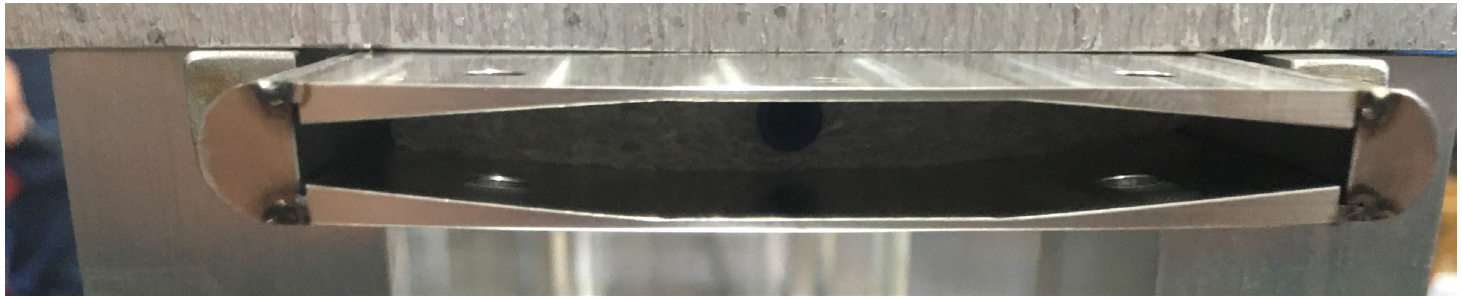
- In-vacuum linear motor stage of 1.75m stroke
- A second stage on top of the linear motor stage allows 1.95m travel
- Three Lakeshore Hall probe elements and two Cernox sensors attached to a Vespel® sled with alumina rods.
- Beam chamber is set to <20K.



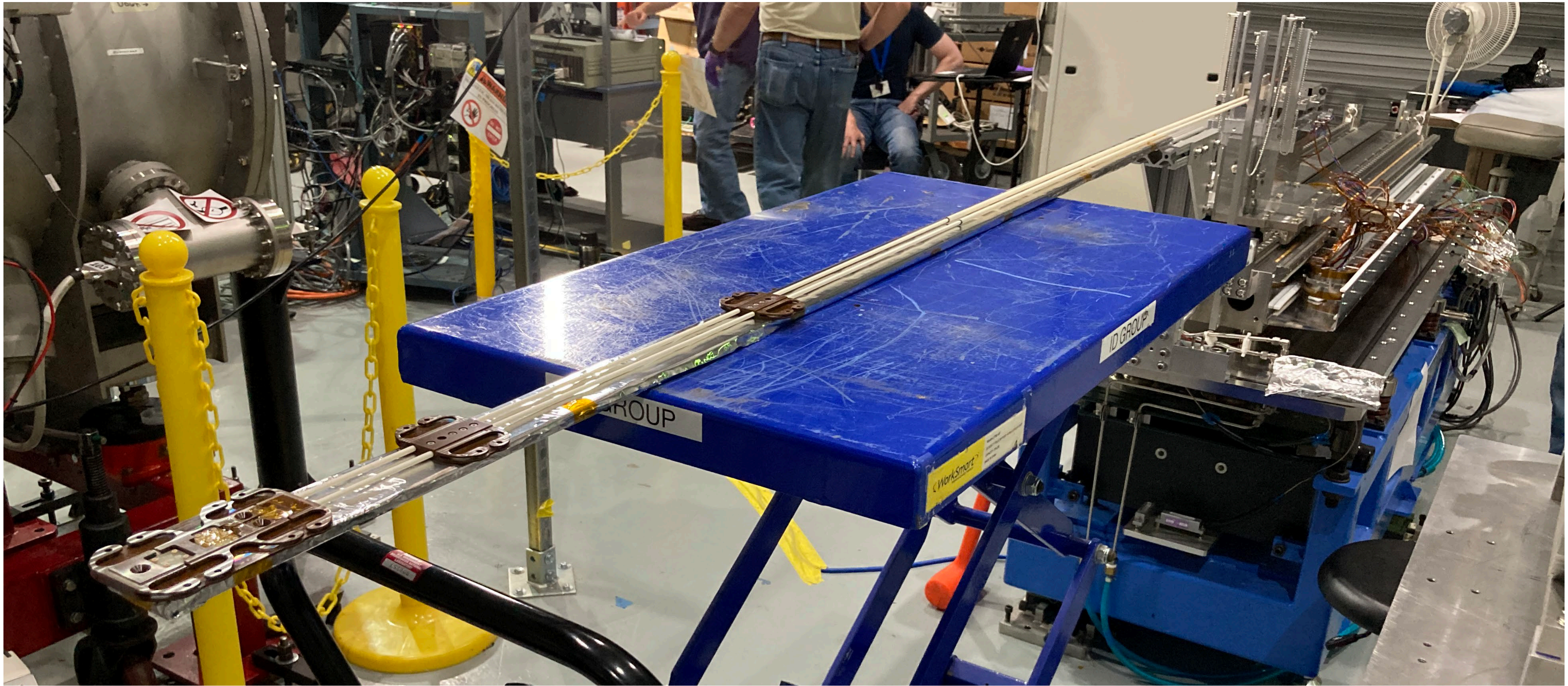




Vacuum Chamber & Hall Probe Arms

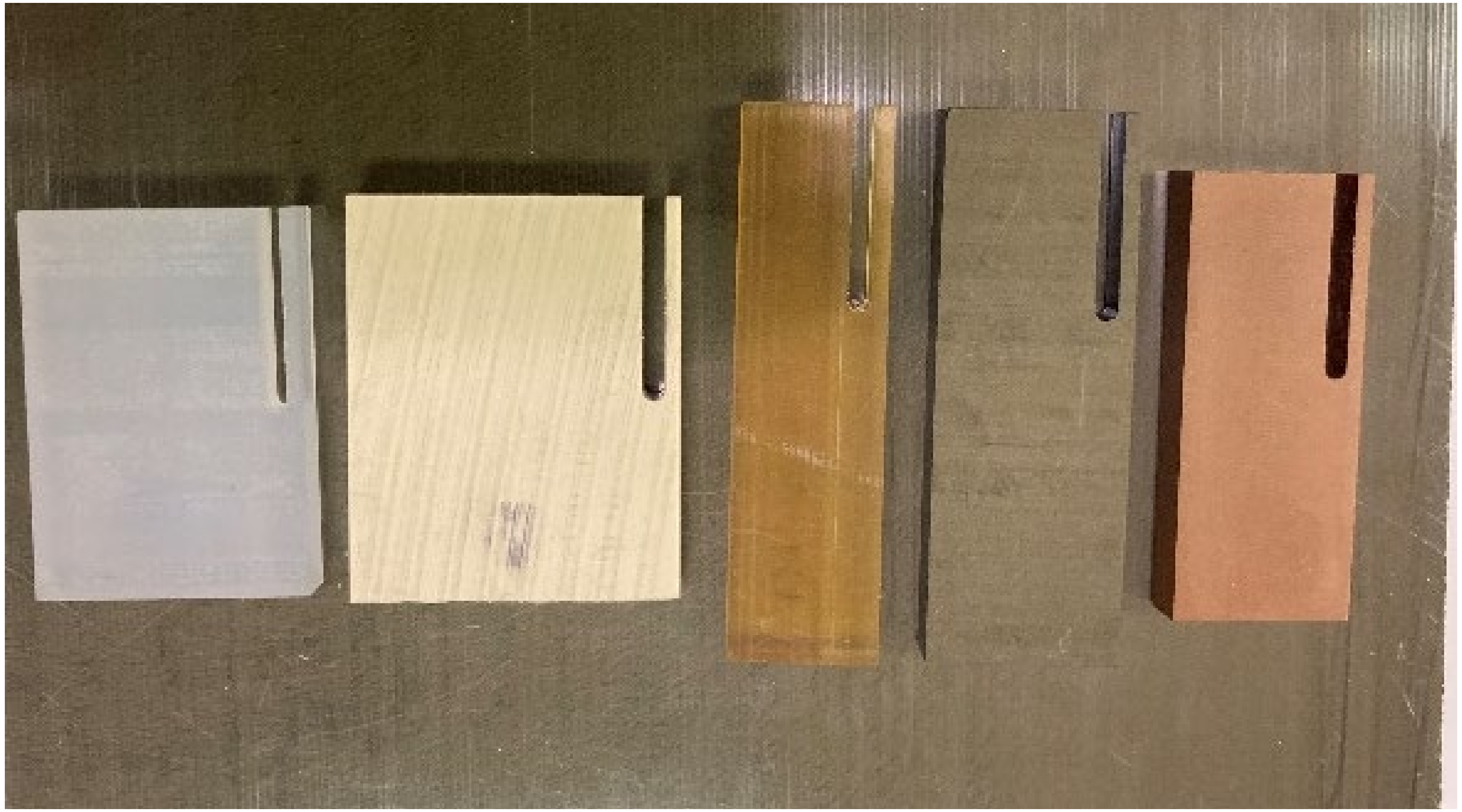


Octagonal Shape Stainless Chamber
76mm (H) x 8mm at center (V)
Cu coated +/- 12.5mm in Center



Cryo-Material Test

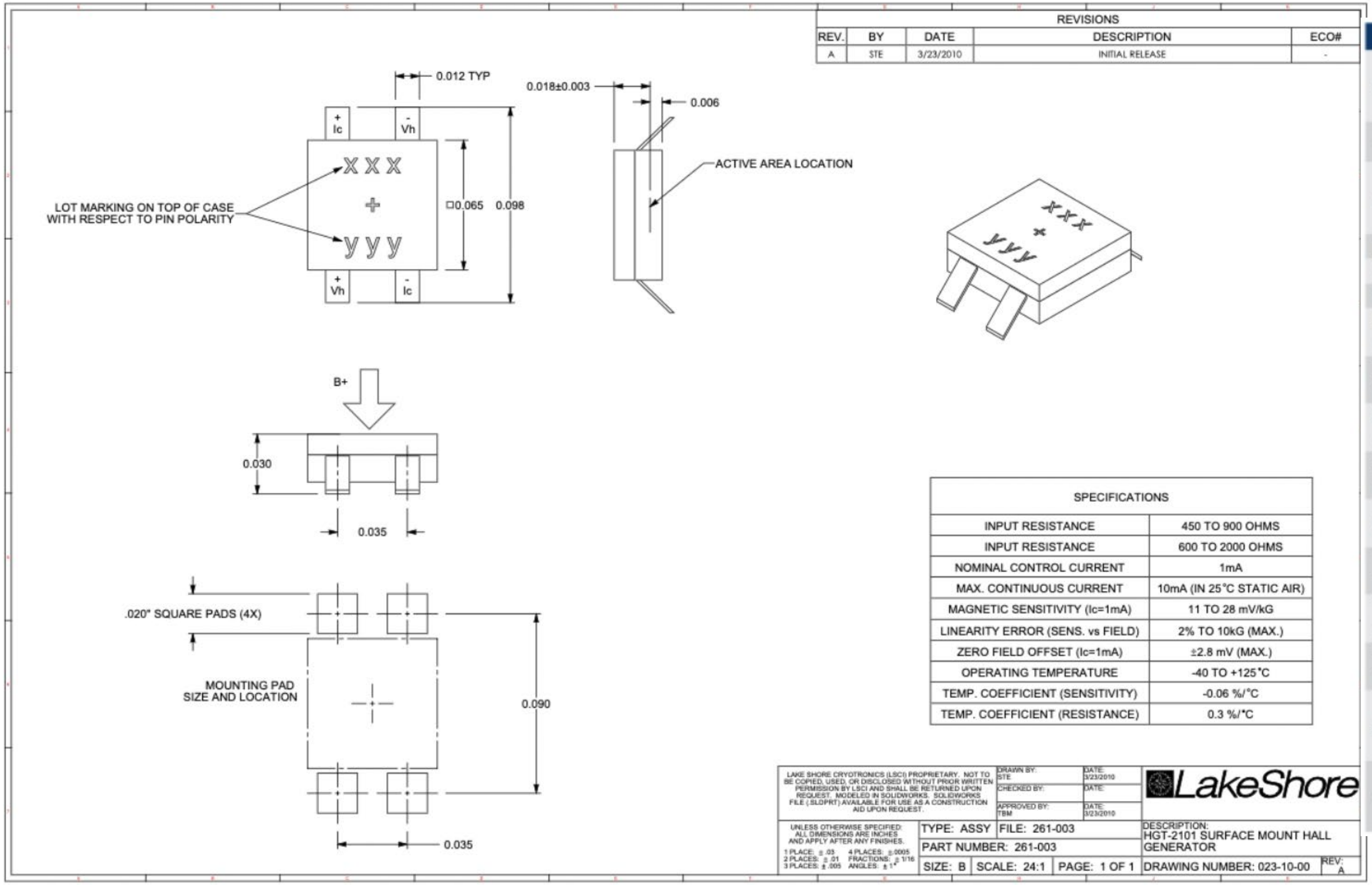
We have compared the flexibility of five different materials (kel-F® (PolyChloroTriFluoroEthylene), PEEK (polyetheretherketone) , Ultem® (polyetherimide), Torlon ® (polyamide-imide), and Vespel® Polyimide shown here. All the pieces are immersed in liquid nitrogen and two pieces with small cuts are pushed each other to see which material is the most flexible. We found that Torlon and Vespel appeared to be superior to the rest in terms of retaining flexibility in 77K.



Five different cryo-ready materials. From the left, Kel-F, PEEK, Ultem, Torlon and Vespel.

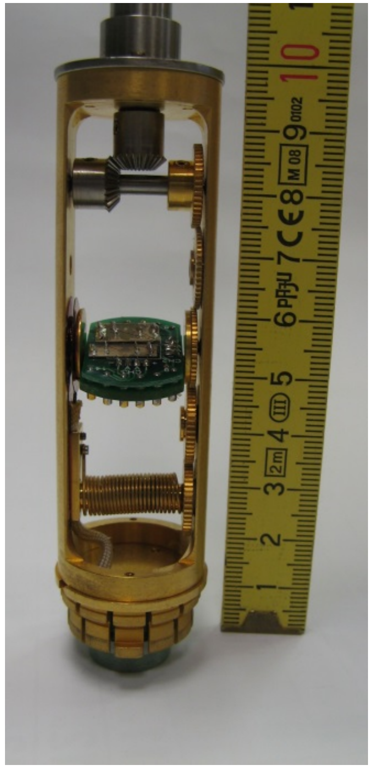
Hall Probe Used for HEX-SCW

LakeShore HGT-2101-10 **Hall Generator Qty 10**

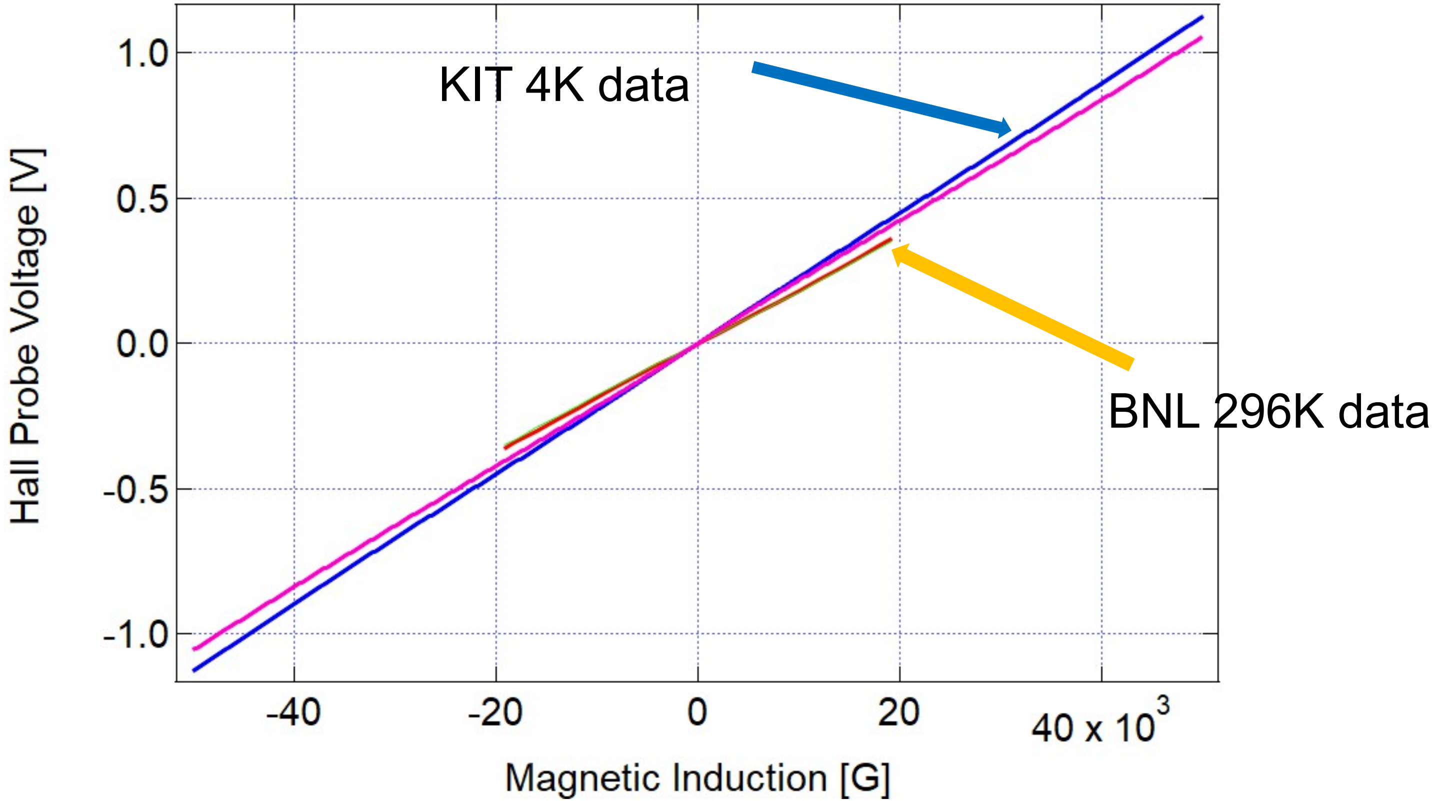


	HGT-2010*	HGT-2101*
Description	General purpose transverse; high sensitivity	Low cost; high sensitivity; surface mount
RoHS	No	Yes
Active area (approx)	0.127 mm (0.005 in) square	0.3 mm (0.012 in) diameter circle
Input resistance (approx)	450 Ω to 900 Ω	
Output resistance (approx)	550 Ω to 1350 Ω	600 Ω to 2000 Ω
Nominal control current (I_{CN})	1 mA	
Maximum continuous current (non-heat sinked, 25 °C)	10 mA	
Magnetic sensitivity (I_C = nominal control current)	11 mV/kG to 28 mV/kG	
Maximum linearity error (sensitivity versus field)	±1% rdg (-10 to 10 kG) ±2% rdg (-20 to 20 kG)	±2.0% rdg (-10 to 10 kG)
Zero field offset voltage (I_C = nominal control current)	±2.8 mV (max)	
Operating temperature range	C to +100 °C	-40 °C to +125 °C
Temperature coefficient of magnetic sensitivity	-0.06%/°C (max)	
Temperature coefficient of offset (I_C = nominal control current)	±1.2 µV/°C (approx)	±6 µV/°C (approx)
Temperature coefficient of resistance	+0.15%/°C (approx)	+0.3%/°C (approx)
Leads	34 AWG copper with poly-nylon insulation	NA
Data	Single sensitivity value at I_C = 1 mA	Uncalibrated

Hall Probe Calibration



- Two probes have been calibrated by KIT for +/- 5T at 4K on the courtesy of A. Grau.
- BNL RT calibration dipole can go only +/- 2T



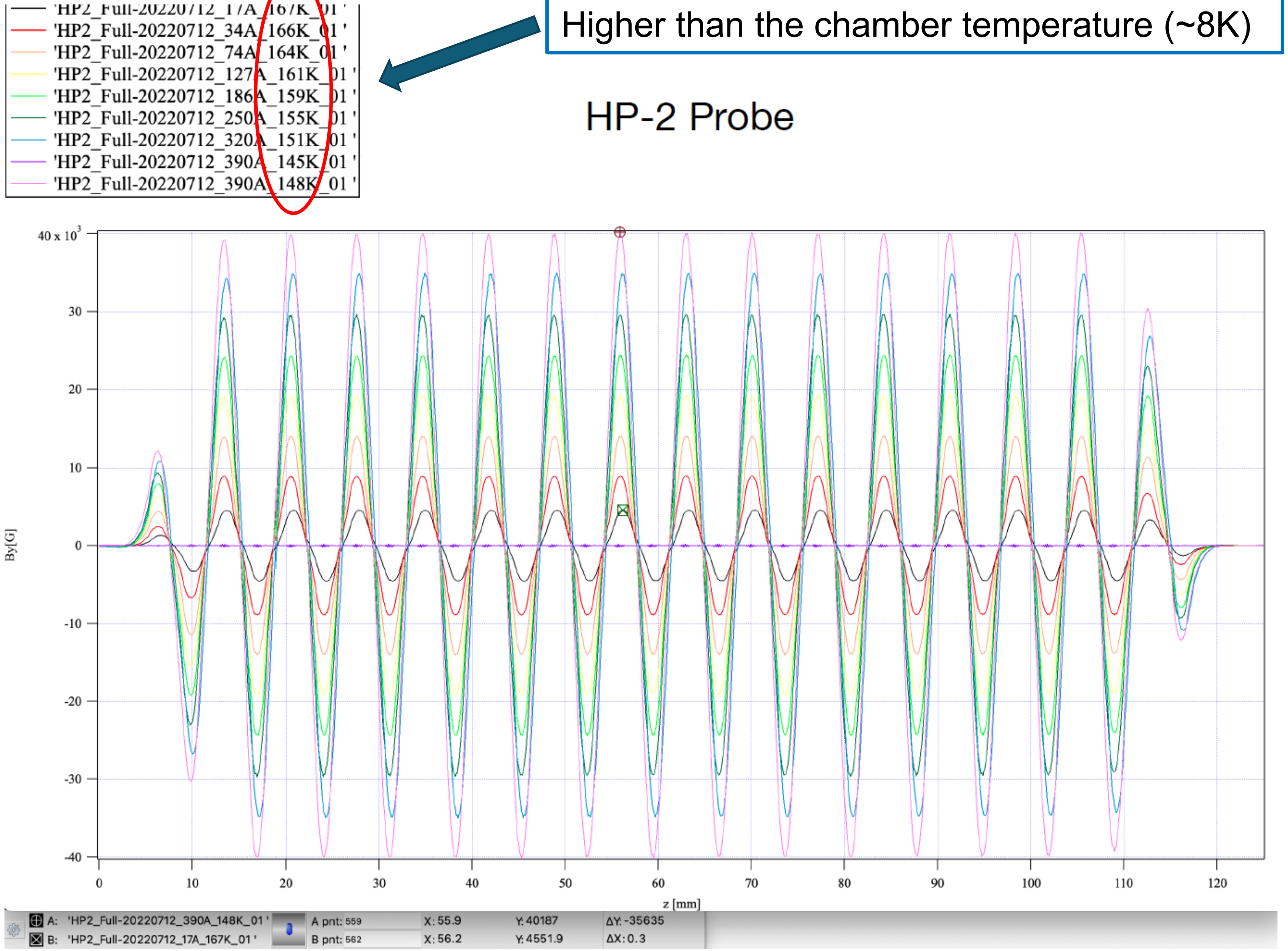
While the manufacture's specified temperature coefficient of sensitivity of the type of prove is -0.06%/K which translates to 18% change over 296K, the measured changes are approximately 20% for probe 1 and 16% for probe 2.

Hall Probe Measurement Results

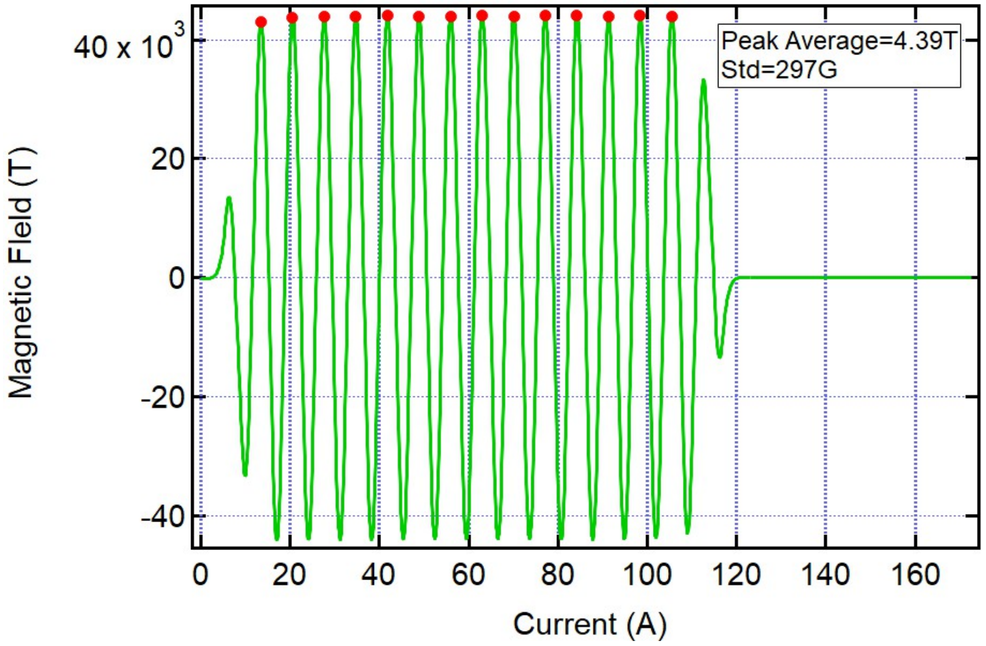
Field Mapping with Varying Current

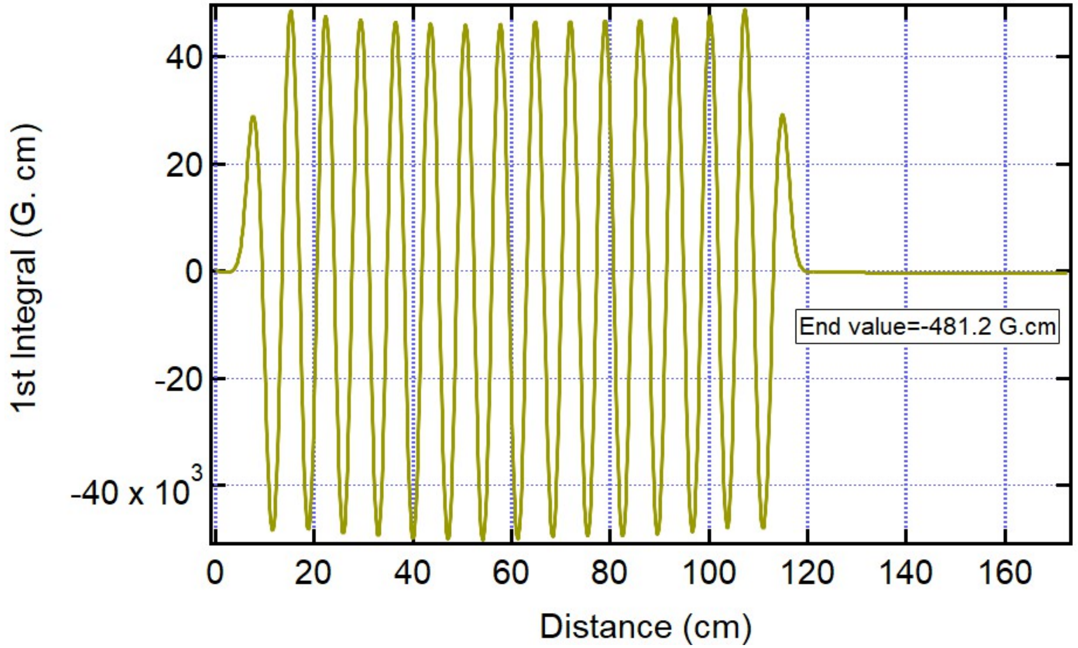
Higher than the chamber temperature (~8K)

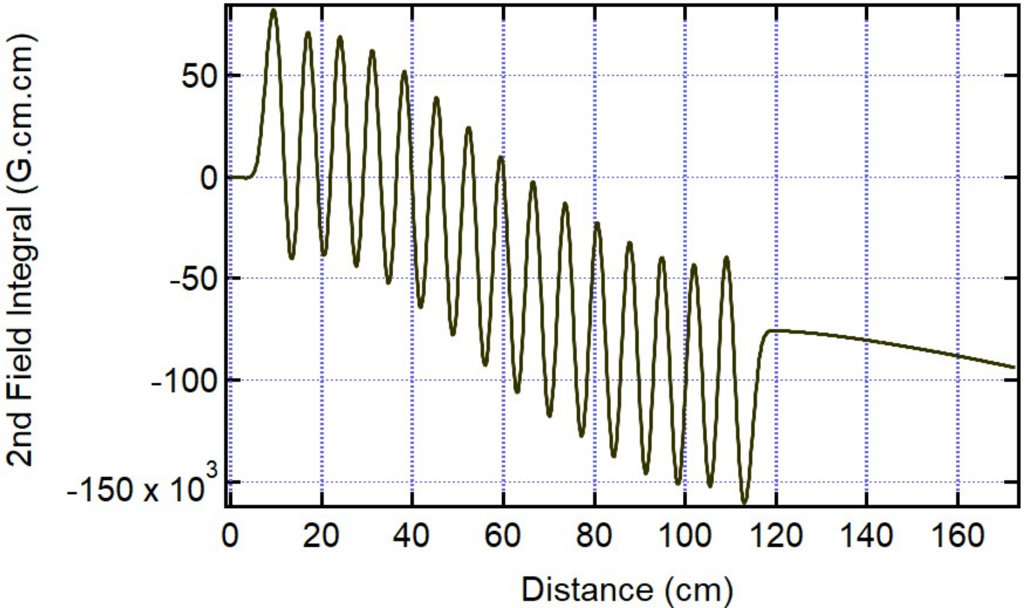
HP-2 Probe



Flux Density, 1st Integral & 2nd Integral at 440 A





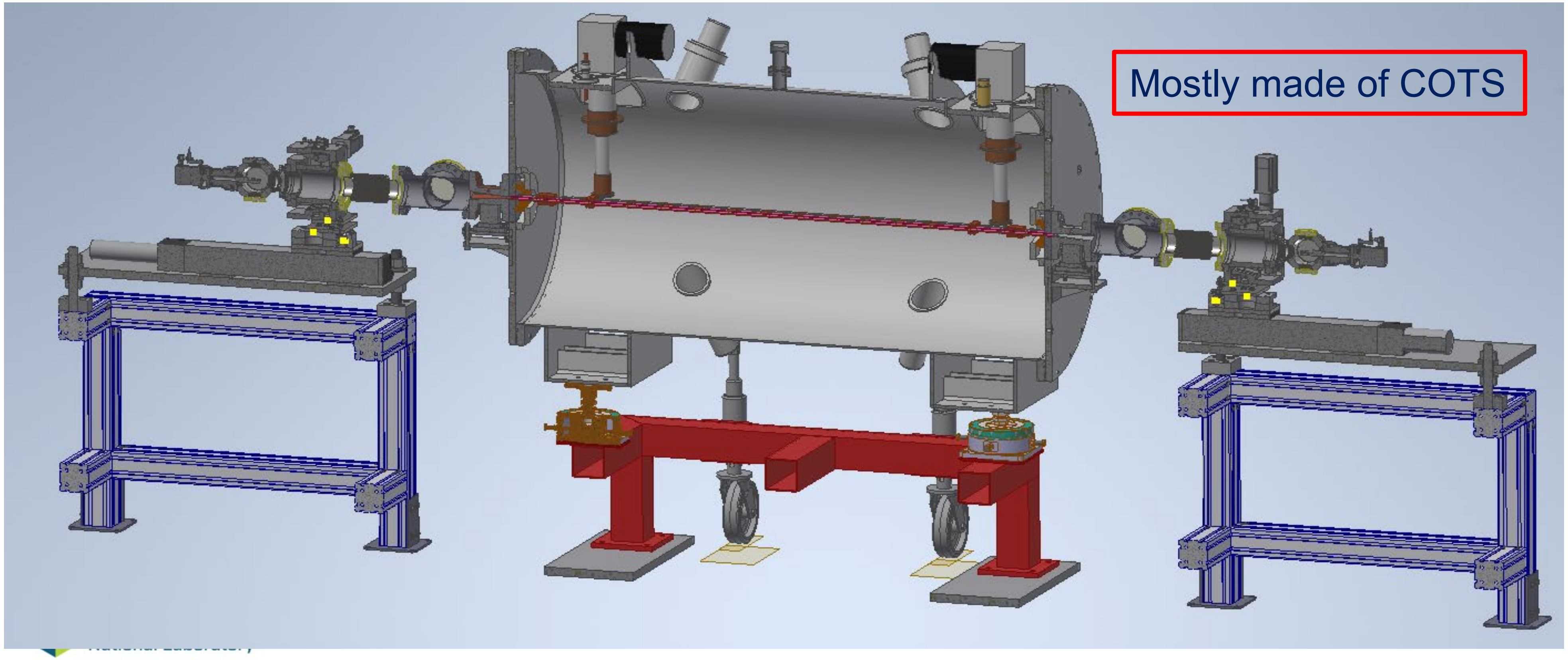


In-Vacuum Flip Coil System

Basic Configurations

Main issue:

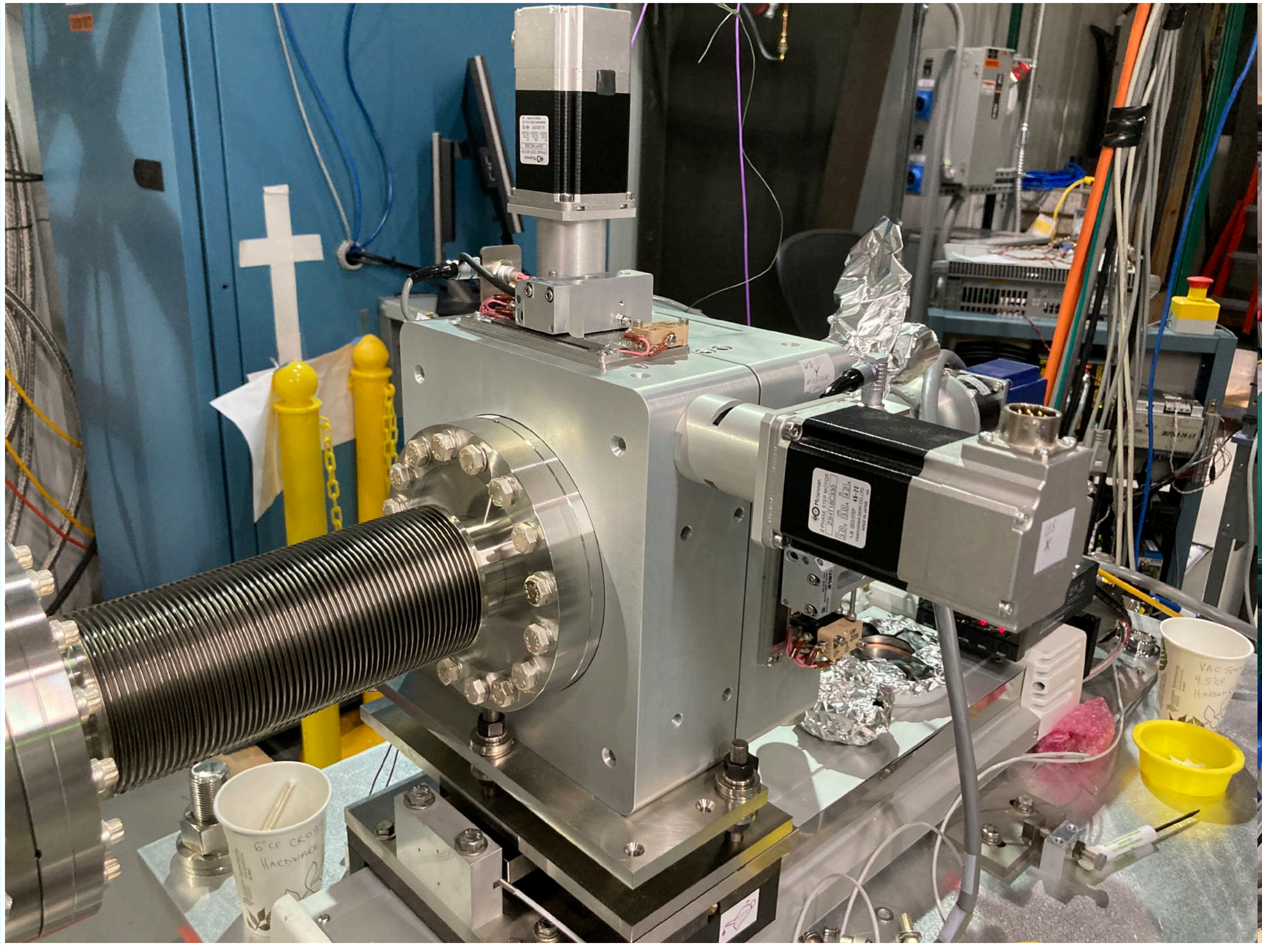
- The device must be warmed up in order to stretch wires.
- Needs a special tool to insert 10-turn BeCu coil
- Coil tension is monitored by load-cells but changes with surrounding temperature
- Appears to be sensitive to mechanical vibration

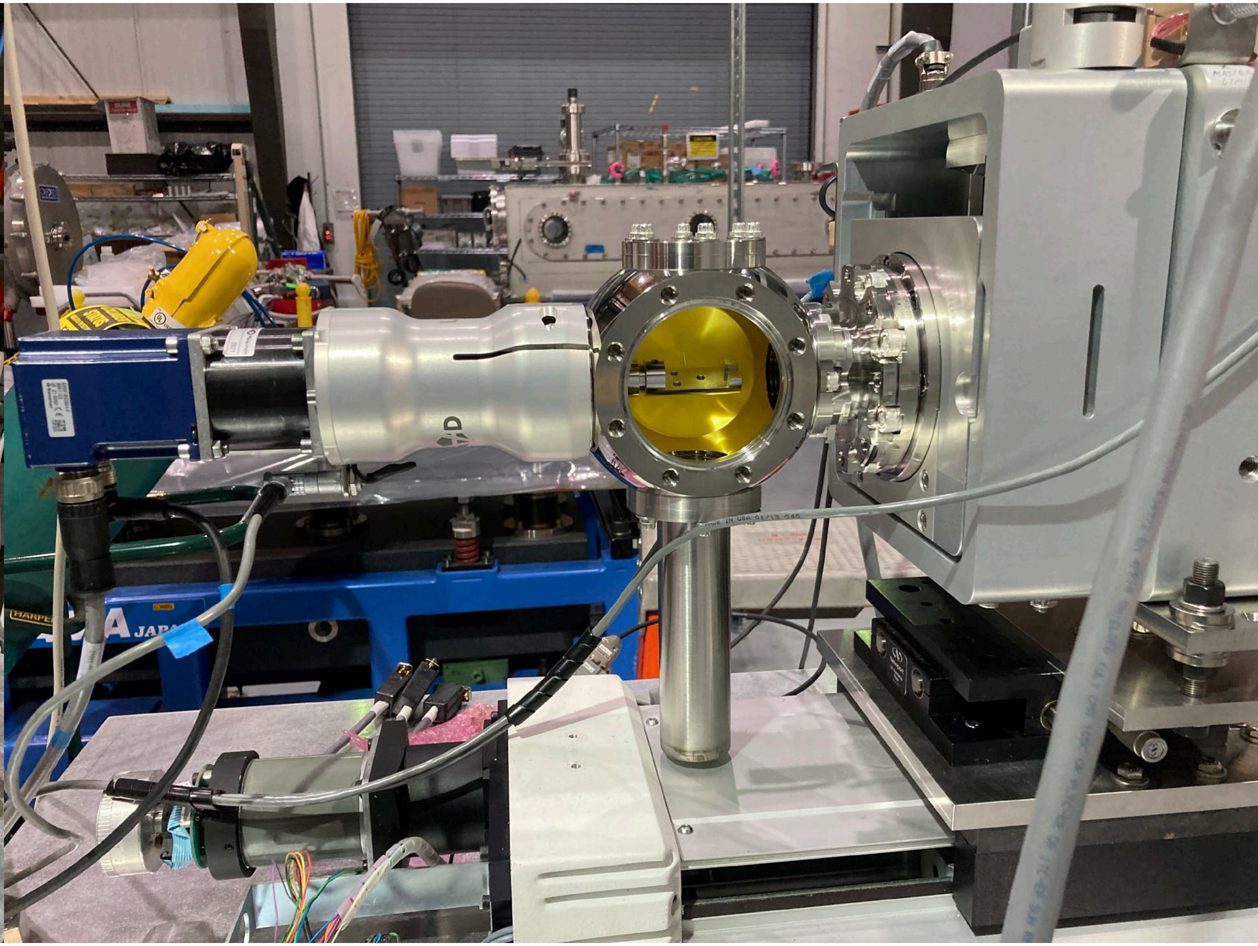


In-Vacuum X-Y & Rotary Stage

X-Y Stage: Special order stages of X31 by UHV designs made with 316L and strokes of +/- 22mm. Fitted with Renishaw LM10 encoders with .244 micron resolution.

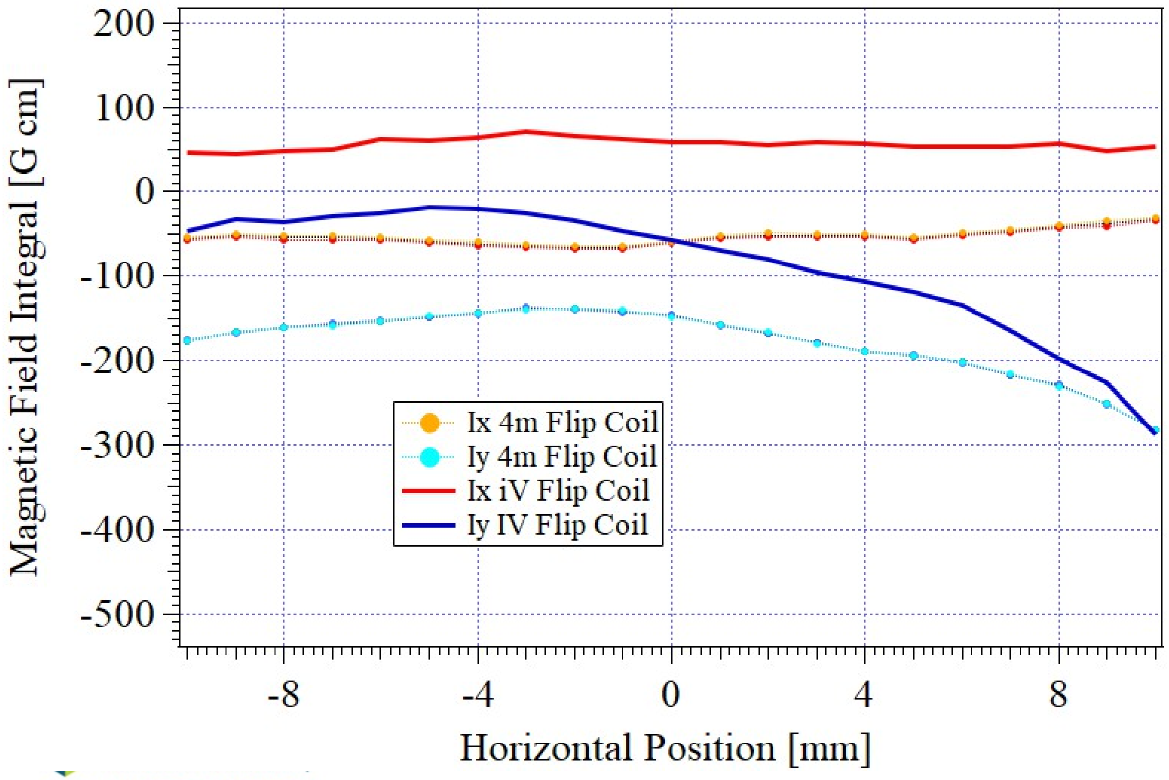
Rotary Stage: Custom motorized MD40 MagiDrive (MD40ISES2X000Z) mounted on a CF40 (2-3/4" OD CF) flange. Fitted with an inline-mounted stepper motor pre-wired to M12 connector with rotary encoder, slotted optical home sensor, customized one-piece solid Al shaft (initially had excessive runout → needed to be corrected)





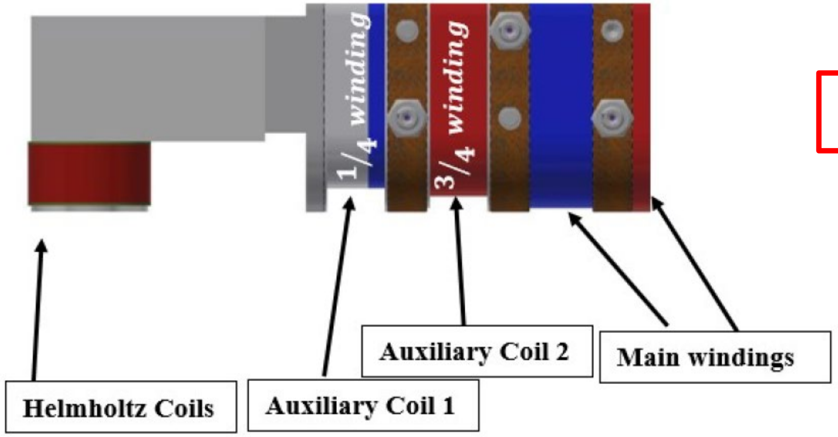
Cross Calibration with a Small Undulator in Air

- Small PM undulator is used to cross calibrate the in-vacuum flip coil with our standard flip coil in the temperature stabilized clean room.



Flip Coil Measurement Results

First Integral Measurements at 0A and 440A with Correctors On

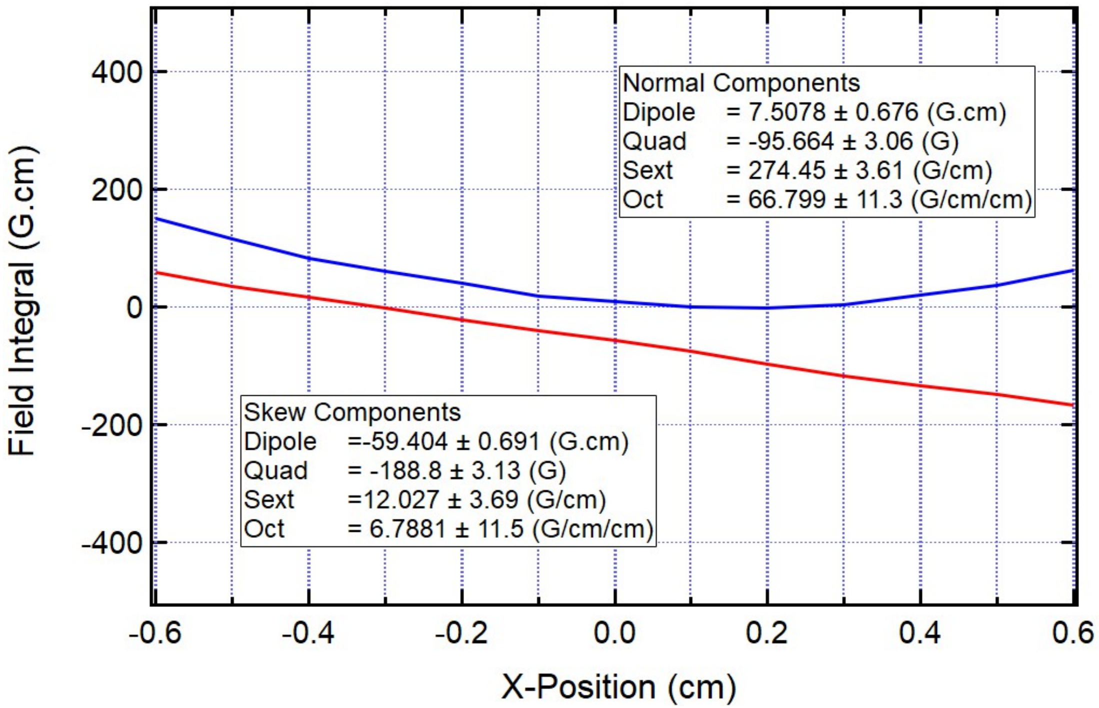


Three By correctors on each side of the arrays

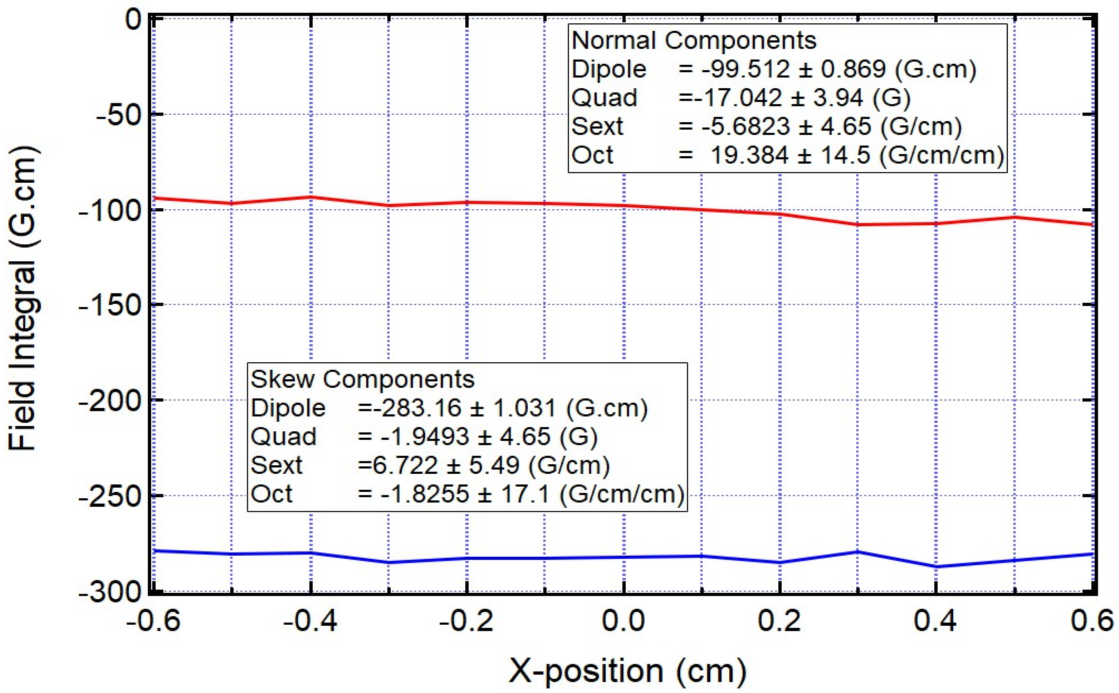
Repeatablity of Integral Measurement

Iy=3.3 G.cm, Ix=2.9 G.cm

I=440A (By=4.39T)



I=0A (By=0T)



Summary

- A conduction cooled 1.2m-long superconducting wiggler with the maximum field of 4.3T has been fabricated and installed in the NSLS-II ring. Chamber temperature and vacuum level are as predicted with 400mA beam current.
- In-vacuum Hall probe mapper with a stroke of 1.9m has been created using a former "In-Vacuum Magnetic Measurement System" originally intended for CPMU measurement. Probe sled was made by Vespel® which appears to be superior to other cryo materials in terms of flexibility at cryo temperature.
- Hall probes have been calibrated at 4K with +/- 5T solenoid by the courtesy of KIT.
- Even though the chamber temperature was around 8K, the Hall probe temperature went down to only 110K after more than 16 hours. Therefore, a minor correction is needed for the results.
- In-vacuum flip coil system has been fabricated by mostly COTS products.
- Field integral measurement shows that the device's contribution was not negligible.

Back up materials

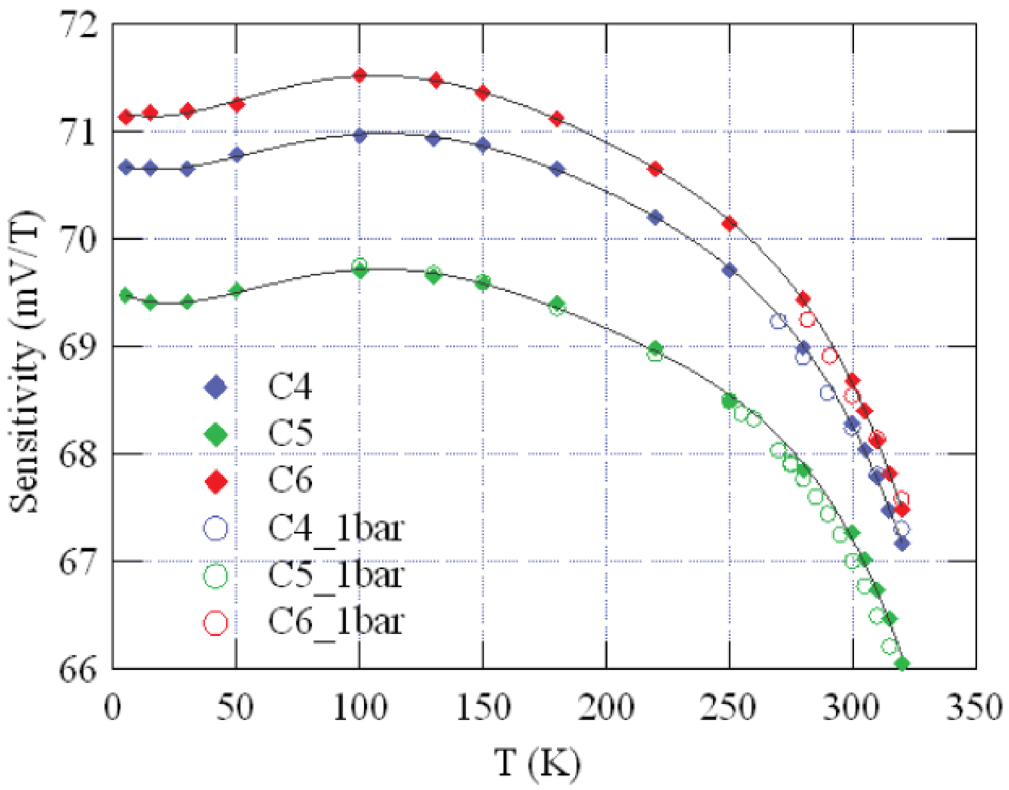
Proceedings of 2011 Particle Accelerator Conference, New York, NY, USA TUP219

TEMPERATURE-DEPENDENT CALIBRATION OF HALL PROBES AT CRYOGENIC TEMPERATURE*

M. Abliz, I. Vasserman, Y. Ivanyushenkov, and C. Doose, Advanced Photon Source, Argonne National Laboratory, 9700 S. Cass Ave., Argonne, IL 60439, U.S.A

Abstract

and field range of 5 – 320 K and ±1.5 T.



Sensitivity of Arepoc probes are almost constant (+/- 0.1%) between 5K and 150K despite up to 1.5T

Job opening for electrical engineer

Apply Now

Electrical Engineer

Job ID: 2950

Date posted: 12/20/2021

Essential Duties and Responsibilities:

- Design and build electrical circuits such as amplifiers and signal filter to improve performance of off-the-shelf measurement equipment.
- Build and evaluate prototypes and models and construction and test of systems/equipment.
- Maintain Hall probe bench with associated compressor controls.

Position Requirements

Required Knowledge, Skills, and Abilities:

- Bachelor's degree in Electrical Engineering or Physics.
- Minimum of (7) seven years of full time relevant progressively responsible related work experience.
- Proficient in the use of electronic test equipment for diagnostics and troubleshooting.
- Demonstrated ability to work from circuit diagrams and schematics.
- Experience wiring electronic chassis and signal cables
- Demonstrated commitment to working safely under strict guidelines.

Preferred Knowledge, Skills, and Abilities:

- Experience performing magnetic field measurement in experimental equipment.
- Experience working with permanent magnets, ultra high vacuum (leak checking and operation of vacuum pumps and gauges), cryogenic, motion control and water-cooling systems.
- Experience working with software such as MS Office, 3D-CAD programs, LabView and remote meeting software such as Zoom and MS Teams.
- Knowledge of metrology and the use of precision inspection tools to the micron level.
- Knowledgeable to troubleshoot and fix analog and digital electronics down to the component level.