Calibration of Hall Probes at Cryogenic Temperatures

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Introduction

- The Hall probe output not only depends the field itself but also its temperature, material, and dimension.
- A superconducting planar undulator is under development at the Advanced Photon Source [1].
- In the vertical LHe cryostat, the magnetic structure and the Hall probe are immersed in liquid helium at 4.2 K.
- The field profile of the undulator magnetic structure is being measured in a vertical liquid helium cryostat and will be measured when the magnetic structure is incorporated into a horizontal cryostat.
- For correct measurements of the magnetic field the behavior of Hall probes at those temperatures should be known.
- Therefore, a facility for calibration of Hall sensors at cryogenic temperatures has been set up at the APS.

[1] Y. Ivanyushenkov et al., "Status of R&D on a Superconducting Undulator for the APS," PAC 2009, Vancouver, May, 2009.

Hall probe calibration facility at the Advanced Photon Source

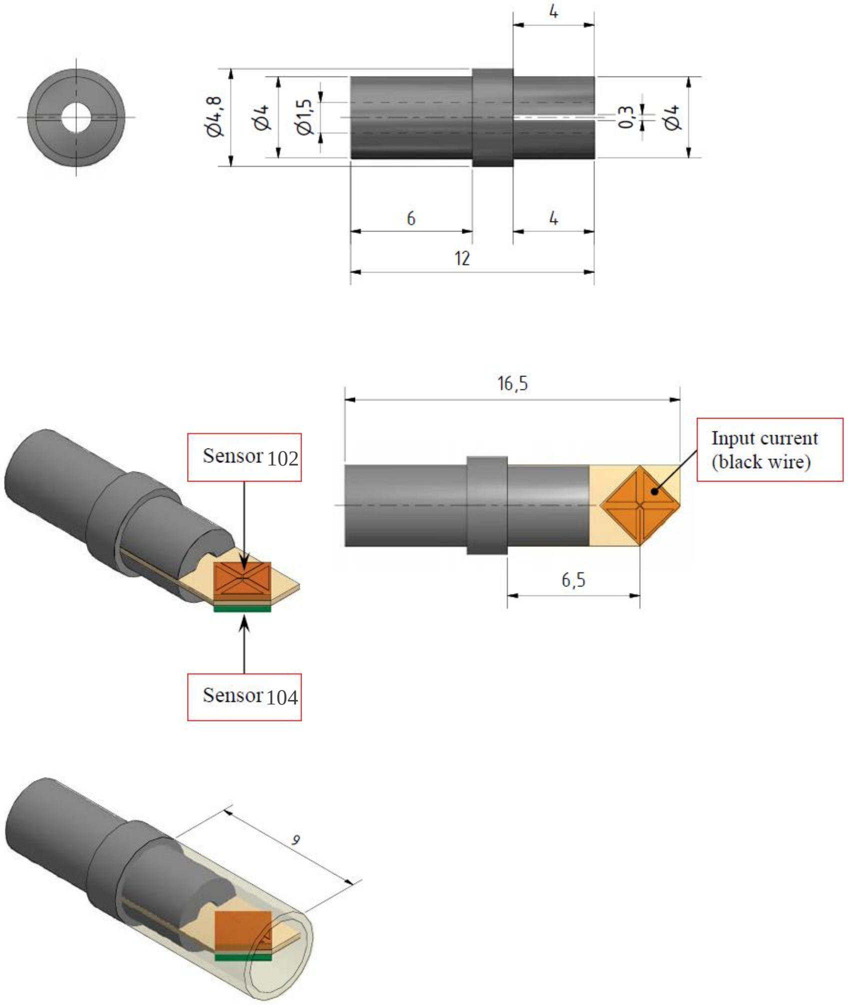
Electromagnet with a set of NMR probes

Janis cryostat with vacuum jacket removed

A custom-made Hall probe holder attached to a cold finger

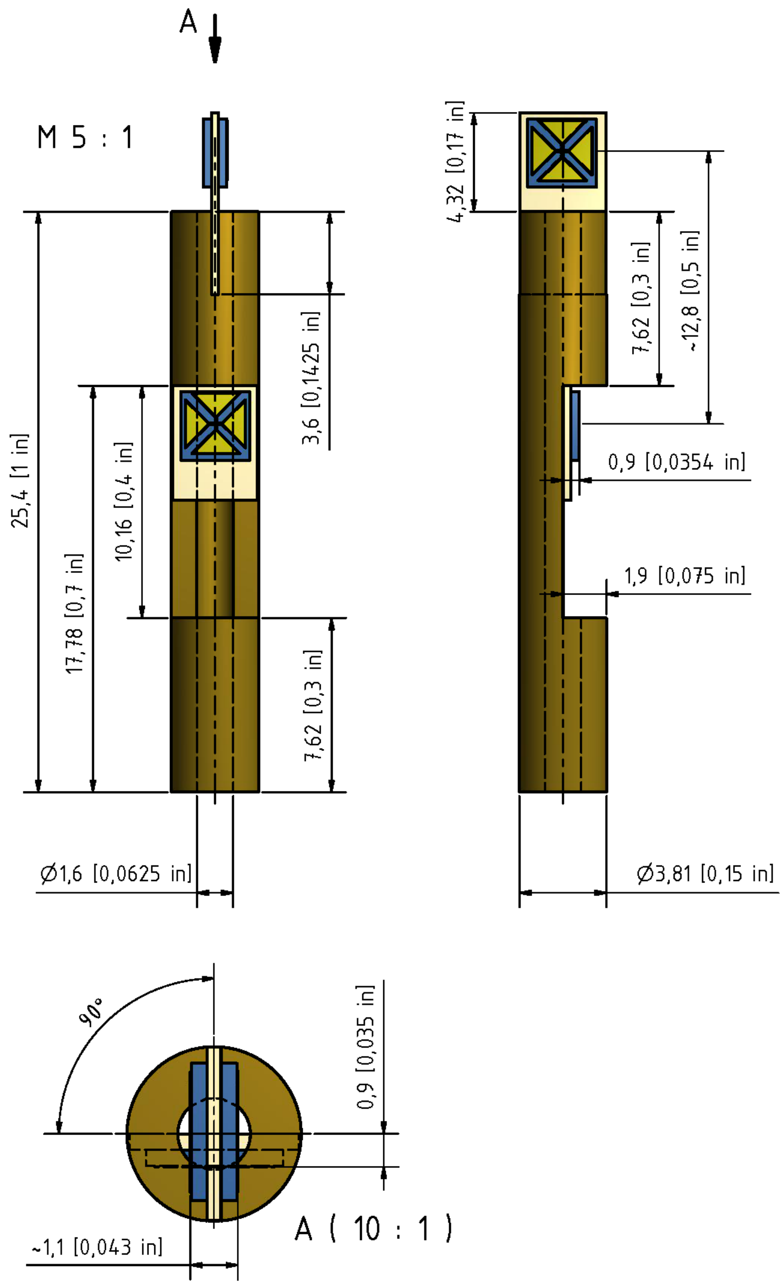
- The magnetic field of the electromagnet is measured with NMR probes.
- A small research liquid helium cryostat by Janis is employed to calibrate Hall sensors at temperatures between 5 K and 300 K.

Hall probe description



- A custom-made Hall probe PHE-3B by AREPOC S.R.O., Bratislava, Slovakia.
- Probe includes two Hall sensors mounted back to back on a ceramic plate inside circular packaging (see next slide for explanation).
- Orientation of Hall sensors is chosen for planar effect compensation [2].
- Electrical specifications:
  - Nominal control current 10 mA
  - Sensitivity ≈ 90 mV / T .
- Hall sensors are calibrated by vendor at 25 C.

[2] I. Vasserman et al., "Compensation of the Planar Hall Effect Voltage Using a New Two-Sensor Hall Probe Design," PAC 2009, Vancouver, May, 2009.


A
M 5 : 1
25,4 [1 in]
17,78 [0,7 in]
10,16 [0,4 in]
3,6 [0,1425 in]
7,62 [0,3 in]
Ø1,6 [0,0625 in]
4,32 [0,17 in]
7,62 [0,3 in]
~12,8 [0,5 in]
0,9 [0,0354 in]
1,9 [0,075 in]
Ø3,81 [0,15 in]
90°
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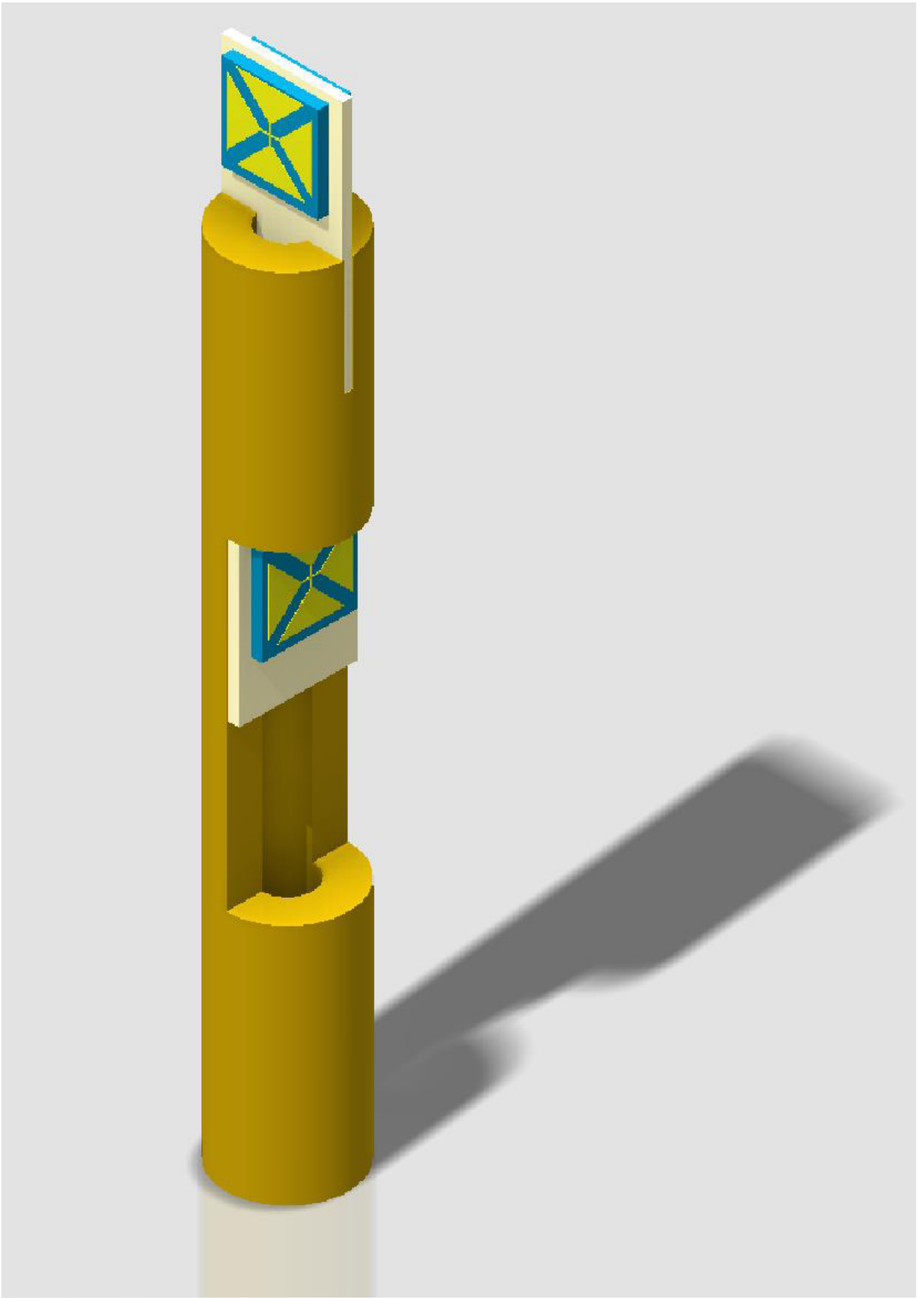
A (10 : 1)



Two-sensor Hall probe

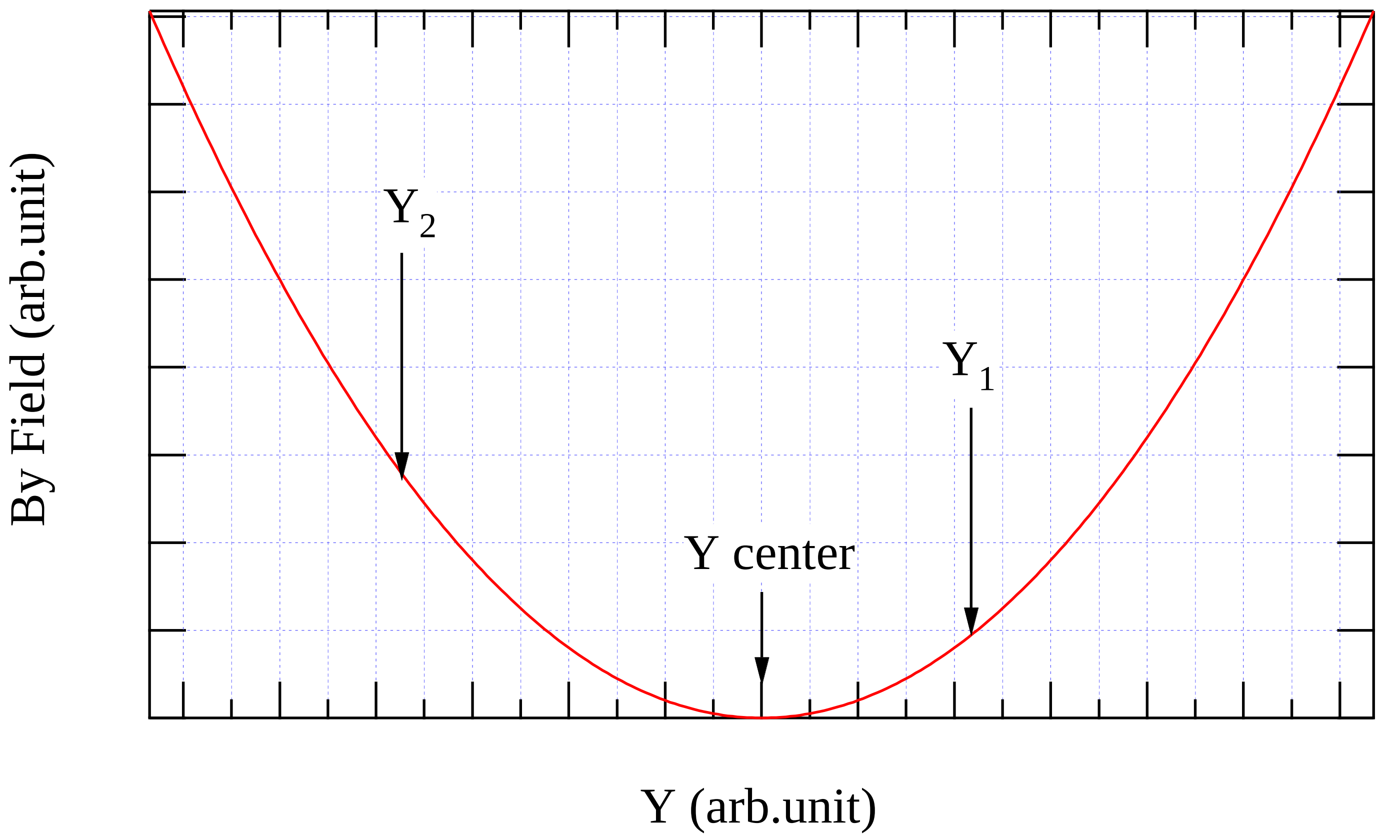
- It will be difficult to know the vertical position of the Hall sensor when it is being used to measure the field of the superconducting undulator.
- We hope to measure the actual vertical position of the Hall probe by using two sensors separated vertically by a fixed gap ΔY.
- Then assuming that the field profile in the vertical direction is known, one can find the exact position of the sensor by solving the following system of equations

$$B_{1y} = B_0 \cosh(2\pi Y_1 / \lambda)$$

$$B_{2y} = B_0 \cosh(2\pi Y_2 / \lambda)$$

$$Y_2 = Y_1 + \Delta Y$$

The way to find the Y center with two sensors



If the sensors Y-center is shifted 10 micron, it gives a field difference about 9 G from these two sensors at 5000 G vertical field.

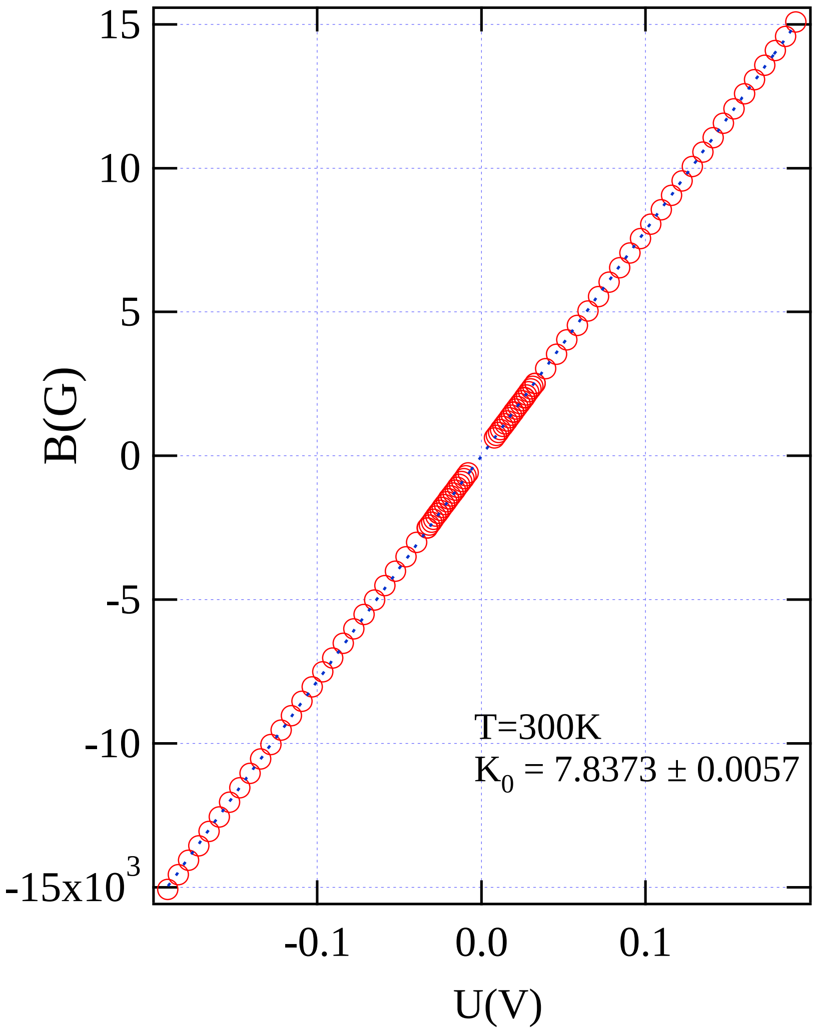
Calibration of Hall probe sensors

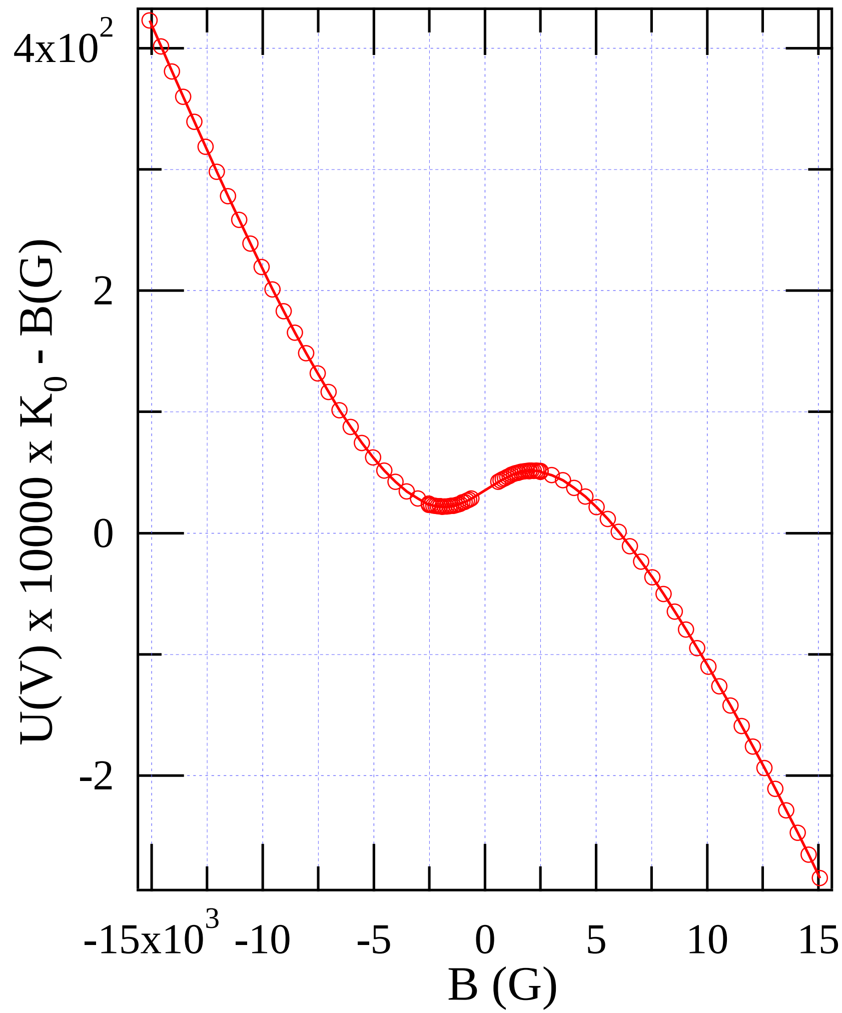
- The magnetic field $B_{mes}=f(V)$ from Hall probe voltage measurements can be written as : $B_{mes}=k(V)V$, where B_{mes} is the magnetic field measured with Hall sensor, *V* is the voltage of Hall sensor, and k(V) is a nonlinear coefficient:

$$k(V)=k_0 + k_1 \; V + k_2 \; V^2 + k_3 \; V^3 + \ldots$$

- A linear fit with least square method of $B_{mes}=k(V)V$ determines k_0 , $B_{mes} \approx k_0 V$, where k_0 is the linear part of the coefficient called Hall probe sensitivity.
- Then the difference of $k_0 V - B_{ref}$ as a function of B_{ref} shows the nonlinearity of the probe, where magnetic field B_{ref} is measured with a reference NMR probe
- Our goal was to measure dependence of Hall probe calibration coefficient on the temperature

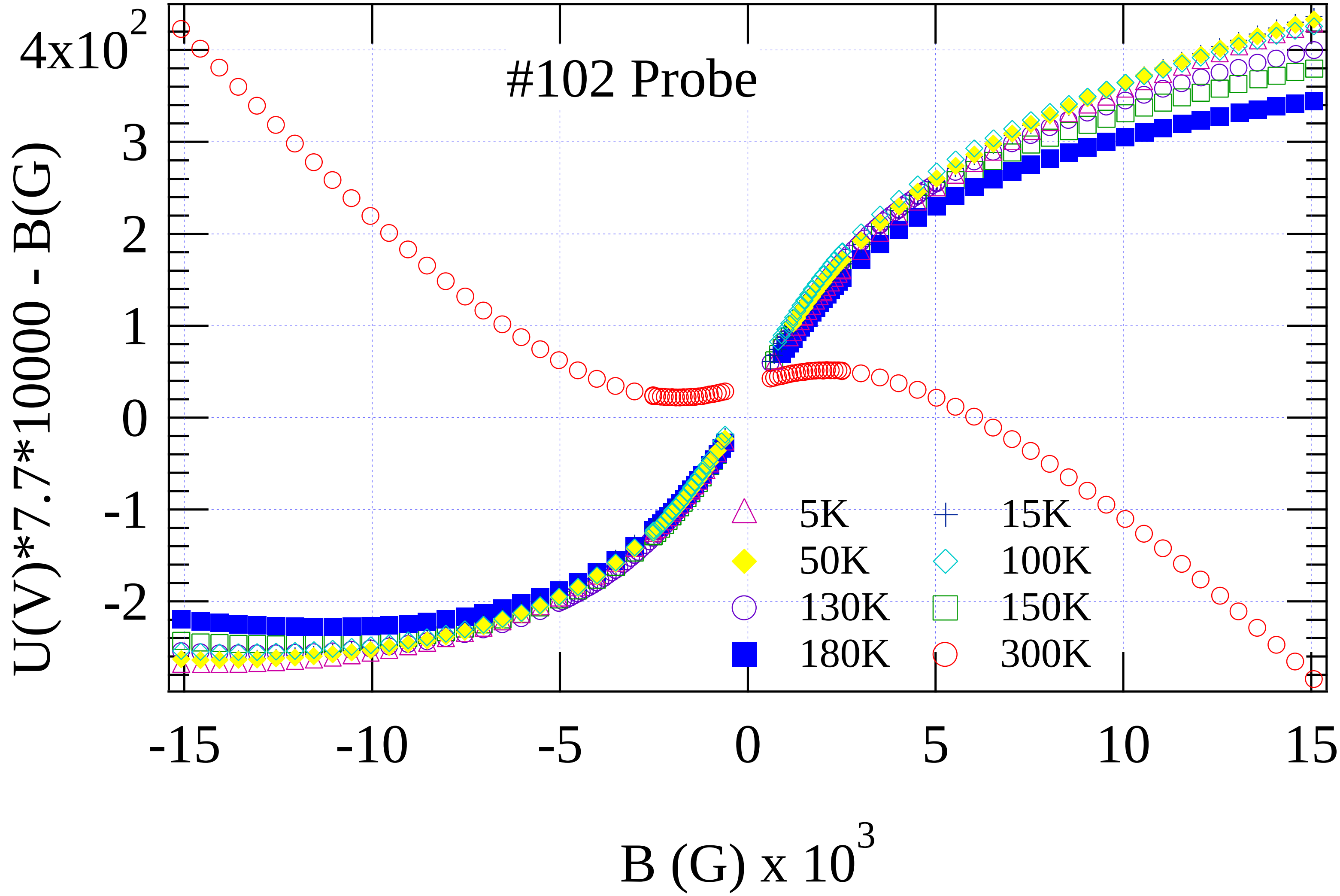
Hall sensor response to magnetic field



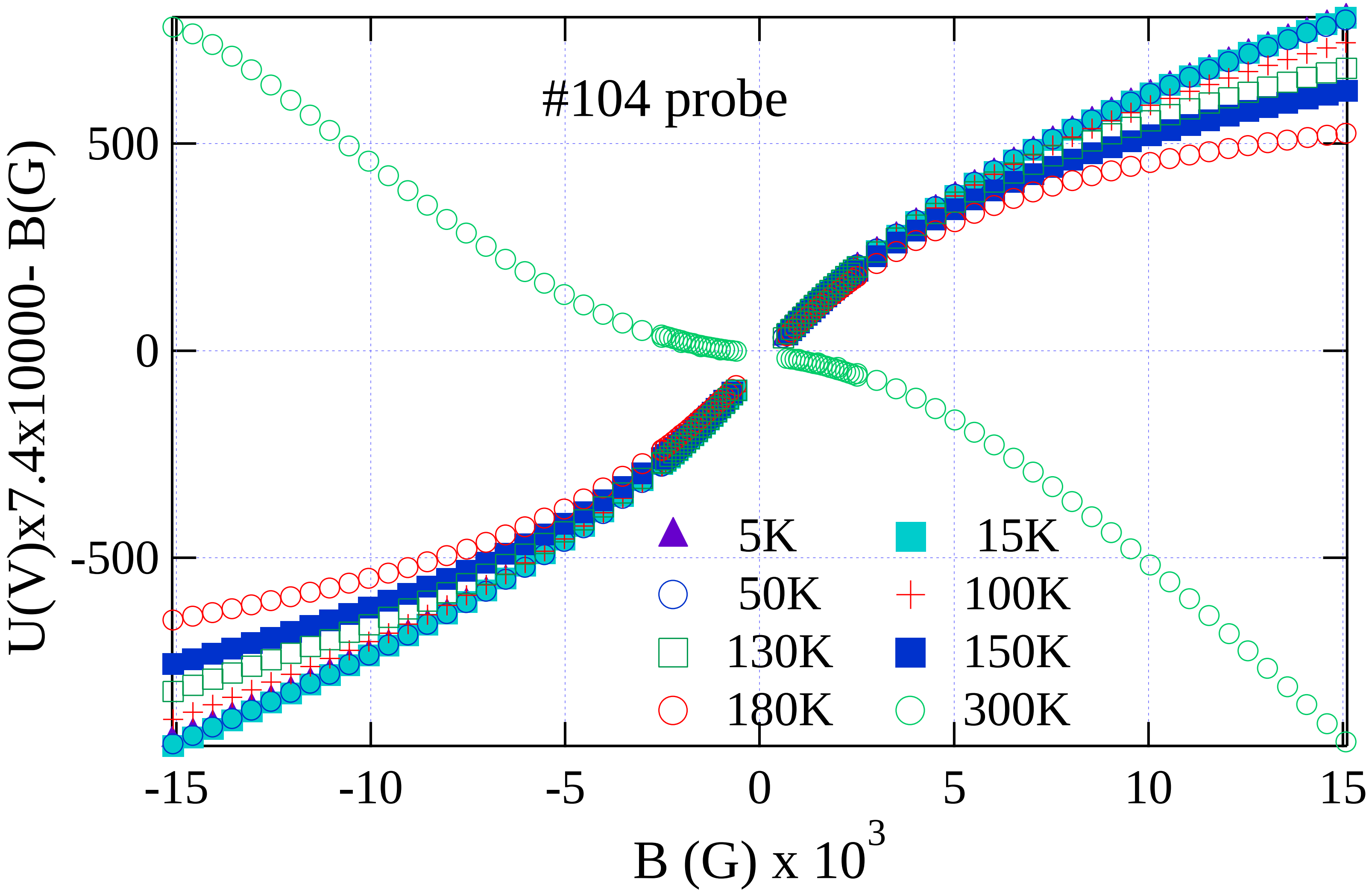


Hall sensor #102 calibration at 300 K

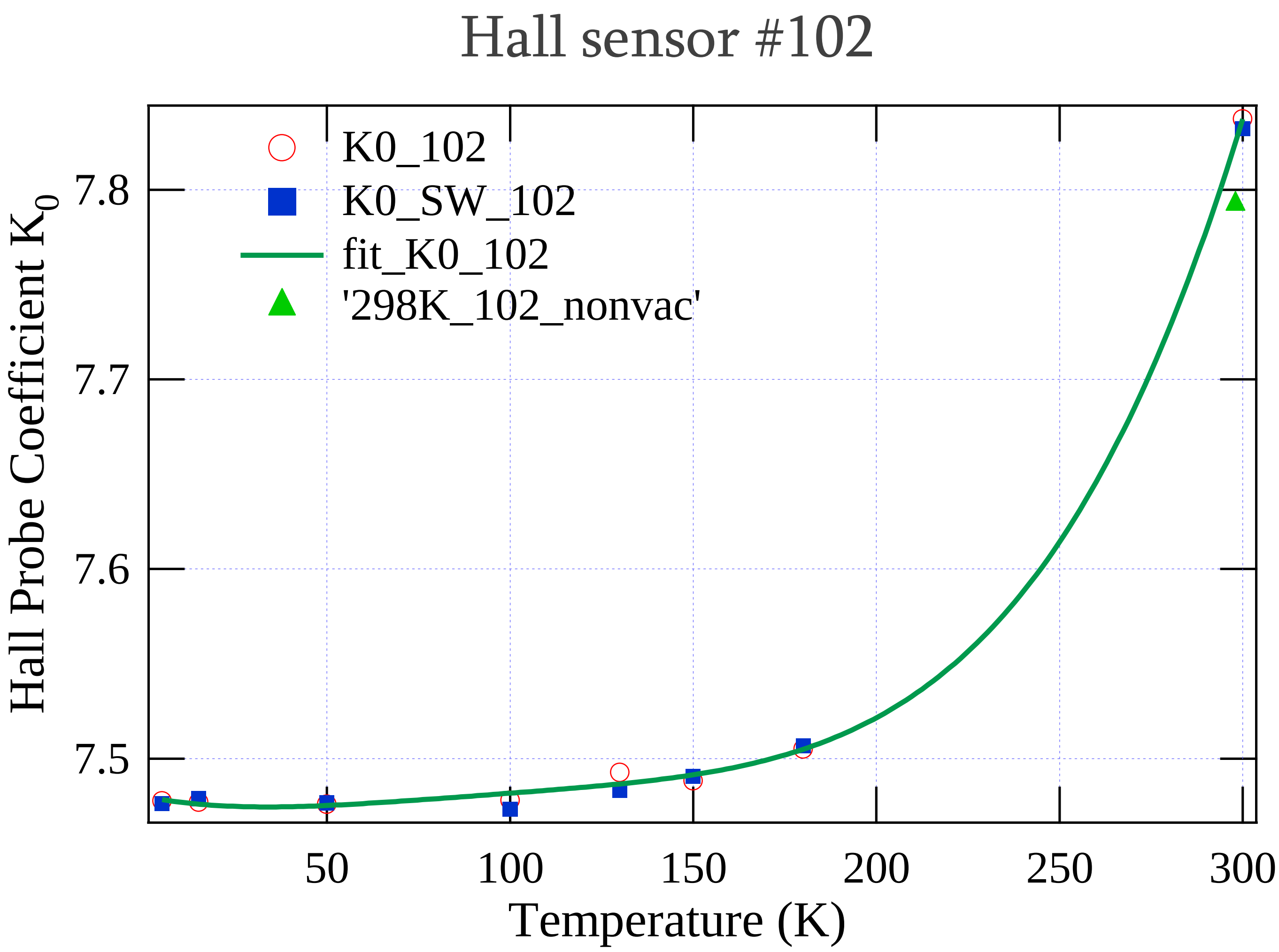
Nonlinearity of sensitivity at different temperatures



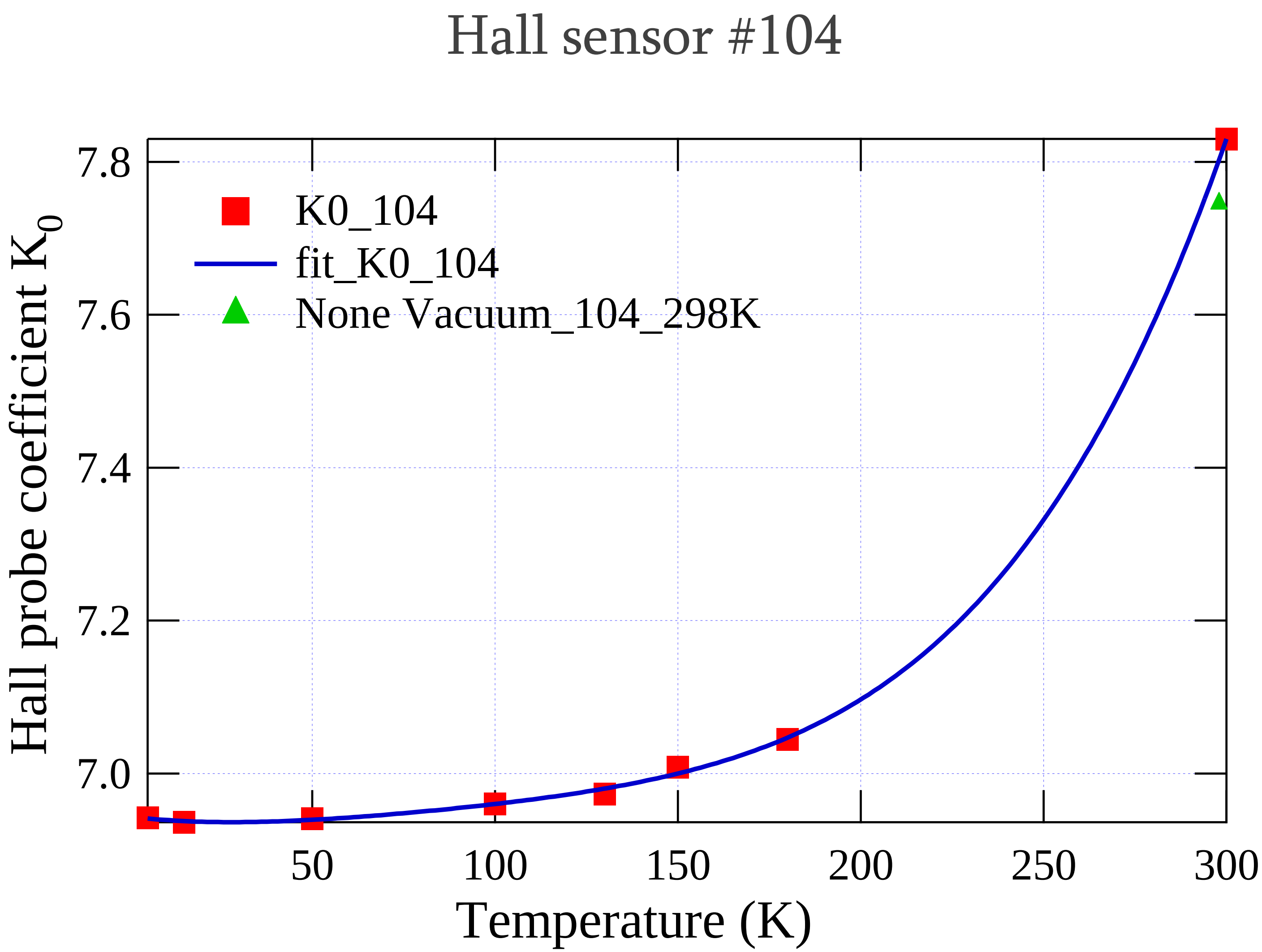
Nonlinearity of sensitivity at different temperatures



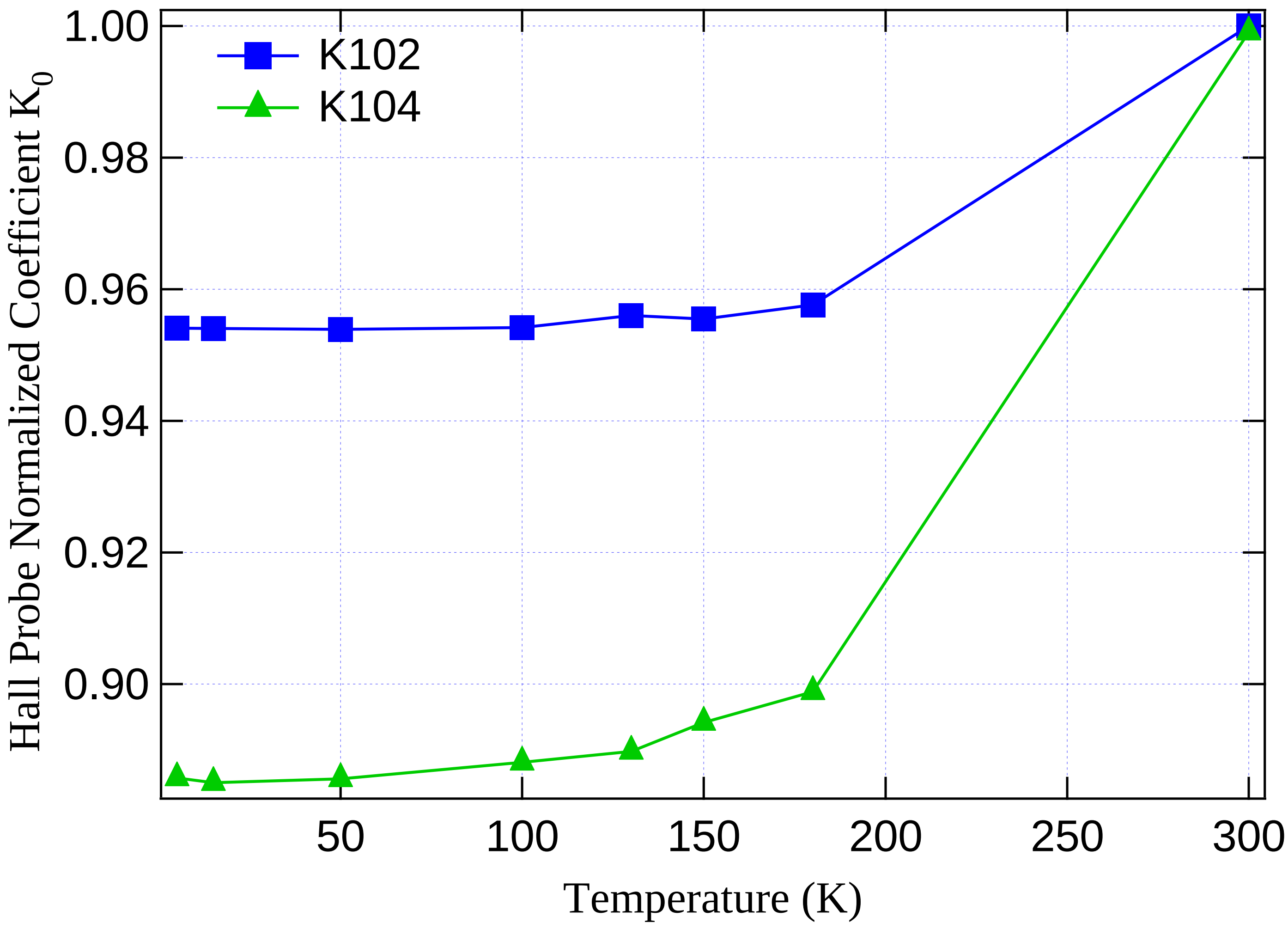
Hall probe sensitivity vs. temperature



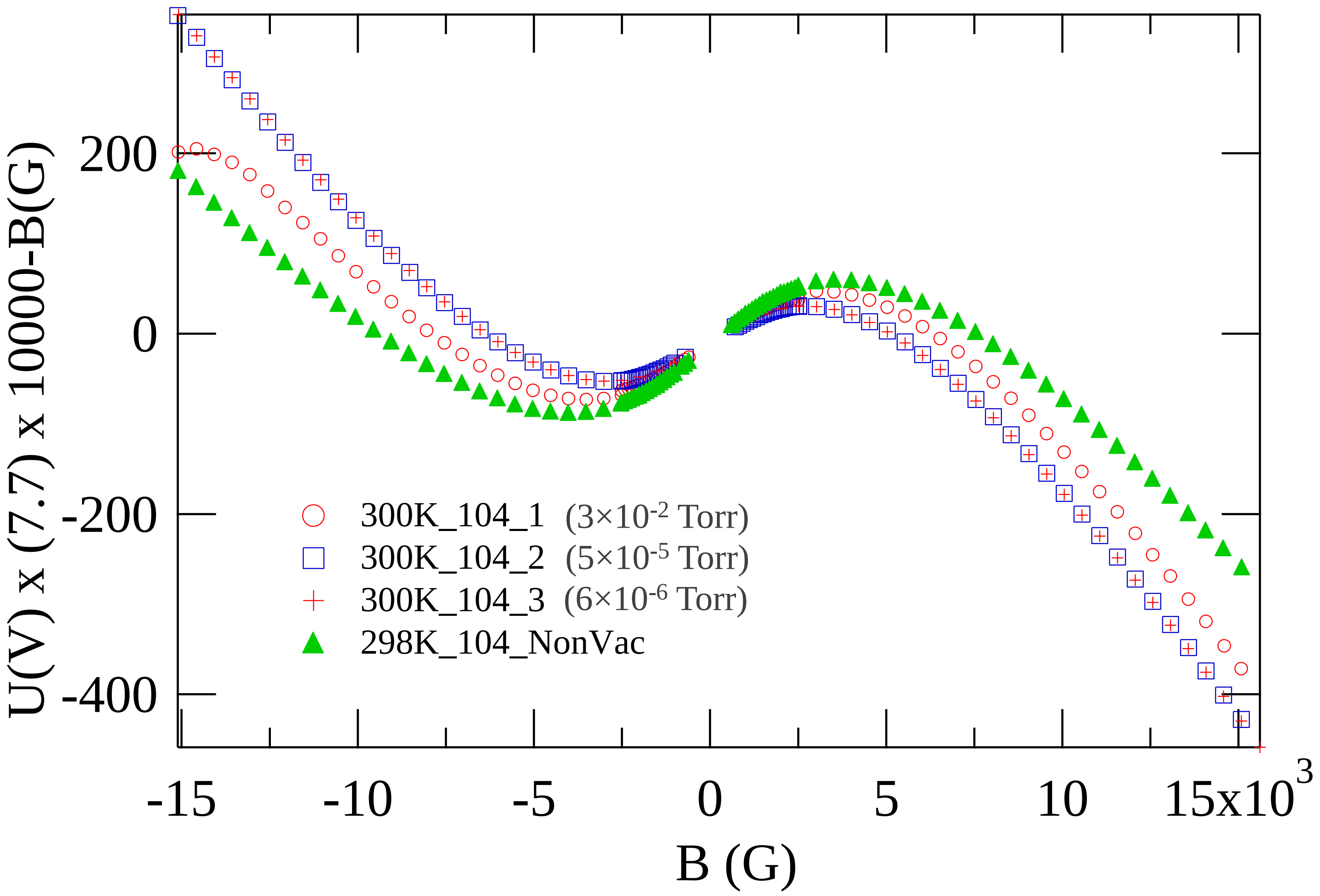
Hall probe sensitivity vs. temperature



Hall sensor sensitivity normalized to room temperature



Effect of pressure on Hall sensor response



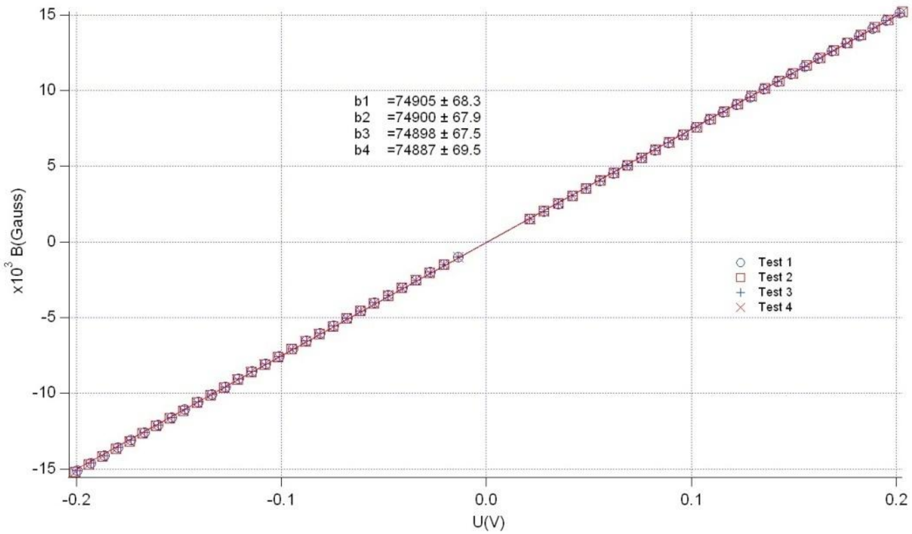
Results and discussion

- Two Hall sensors (both are in the same probe package) were calibrated at temperatures between 5 K and 300 K.
- The sensitivity increases by about 4.5 % for one sensor and by almost 12 % for the other when the temperature is decreased from 300 K to 5 K.
- The Hall probe sensitivity increases quickly between 300 K and about 150 K and then is constant between 50 K and 5 K.
- At room temperature, the Hall probe response is sensitive to the pressure in the cryostat.

Conclusion

- A facility for Hall probe calibration at cryogenic temperatures is now in operation at the Advanced Photon Source.
- The Hall probe sensitivity is strongly temperature dependent between 300 K and 150 K, changing by up to 12 %.
- The Hall probe sensitivity is nearly temperature independent below 50 K.
- The Hall probe sensitivity varies with the level of vacuum in the cryostat.
- We will continue systematic studies of behavior of Hall sensors of different types at cryogenic temperatures.

System stability



- We checked for changes in the sensor calibration due to thermal cycling by repeatedly warming to room temperature, cooling to 15 K, and re-measuring at 15 K.

- Reproducibility of results is within few gauss.