POLARITY CHECK OF THE FRIB CRYOMODULE SOLENOIDS BY MEASURING LEAKAGE MAGNETIC FIELD*

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Abstract

The leakage magnetic field of a 50-cm length 8 T solenoid outside a FRIB cryomodule was observed. The investigation took place to check the polarity of superconducting solenoid using the leakage fields. The maximum leakage field was 1.5 G on the outer surface of the vacuum vessel, and this value agrees very well with calculations. The leakage residual magnetic fields observed thorough the degaussing process of the solenoid can use to establish a basic degaussing procedure. This polarity check procedure has been accepted in FRIB checking lists and to be performed before an integration test and commissioning of the FRIB linac.

INTRODUCTION

A FRIB cryomodule includes superconducting solenoid packages for beam focussing and steering (Fig. 1). These solenoid packages consist of three components: a main 8 T solenoid coil for beam focussing, one pair of bucking coils to cancel the fringe field from the solenoid, which is connected to the main solenoid in series, and one pair of dipole coil for beam steering. All of the magnet polarities have to be confirmed after the installation before the start of the beam commissioning. Normal conducting magnets are easily accessed and checked with a hall probe, but the superconducting solenoids installed in the cryomodule are not straightforward.

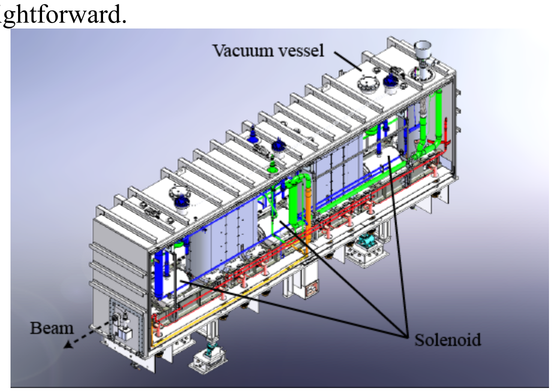

Figure 1: FRIB β=0.085 cryomodule.

The leakage magnetic fields from these magnets was observed outside the FRIB cryomodule [1, 2] to check the polarity of these magnets. The leakage field from the 50-cm superconducting solenoid equipped in the FRIB-1 cryomodule (Fig. 1) was roughly estimated and found to be detectable. The peak field of the main solenoid is 8 T at 92 A and the dipoles vertically and horizontally beam bending are 0.06 Tm at 20 A. After that the rough estimation, the leakage field was calculated more precisely using a 3D model and compered with measurement results. The following section will describe each of these parts in more detail.

ESTIMATION OF LEAKAGE FIELD

First, the strength of magnetic field leakage outside the cryomodule was roughly estimated with POISSON. The solenoid coil dimensions used a FRIB initial design. Assuming a cylindrically symmetric vacuum vessel made of iron with μ=1000 and a thickness of 0.75", and an operating current of 86 A for the solenoid, a leakage magnetic field of 0.8 G was estimated (Fig. 2), which is fully detectable by using a milli-gauss range magnetometer.

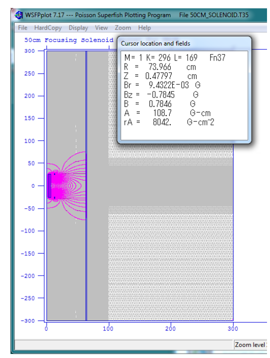

Figure 2: POISSON calculation.

As a next step, the 3D leakage field from the solenoid calculated with ANSYS Maxwell in more detail. The 3D model (Fig. 3) includes the exactly same dimensions as the solenoid of the FRIB-1 cryomodule. This calculation used the B-H curve of steel 1010.

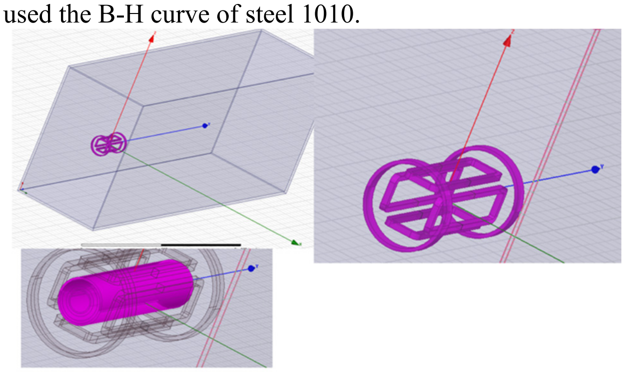

Figure 3: (Upper left) Cryostat with solenoid inside, (Upper right) Dipole coils and background coils, (Lower left) Nested solenoids.

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Figure 4 shows the contour plot between 0 and 5 G of the calculated magnetic field. These results show the external field is approximately 1.5 G and the dipole fields have similar field level (approximately 1 G) outside the cryomodule.

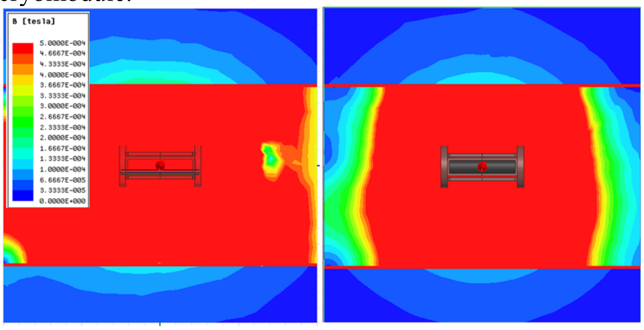

Figure 4: Top cross-section view of the cryomodule. (Left) Solenoid and bucking coil excited, (Right) Vertically bending dipole excited.

MEASUREMENT OF LEAKAGE FIELD

The leakage magnetic fields from #3 solenoid (most downstream side in the cryomodule) were measured with a 3-axis milligauss meter with a sensitivity up to 2 G. The milligauss meter was calibrated in a mu-metal shield and then attached on the cryomodule vacuum vessel (Fig. 5). The sensor was positioned at the approximately same height as the beamline. Figure 6 shows the magnetic field directions excited by the positive current.

Figure 5: (Left) Calibration, (Right) measurement setup.

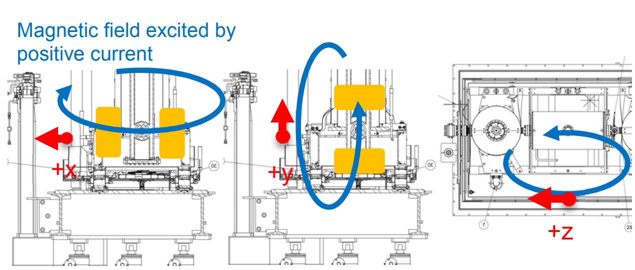

Figure 6: Measurement point and magnetic field direction excited by positive current: (Left) vertically bending dipole, (Middle) horizontally bending dipole, (Right) solenoid.

All the magnets were excited by bipolar power supplies. The magnetic fields were measured two times, which started from zero to the maximum current and then repeated from the maximum to minimum cycle two times. These measurements included the earth magnetic field as background. However, since the sensor was attached on the vacuum vessel surface made of iron, it was less than 0.1 G. Figure 7 shows the measurement result. The polarities are consistent with the design shown in Fig. 6. The maximum magnetic fields of z- and x-direction were 1.5 G and 1 G, respectively. These values agree very well with the 3D calculations.

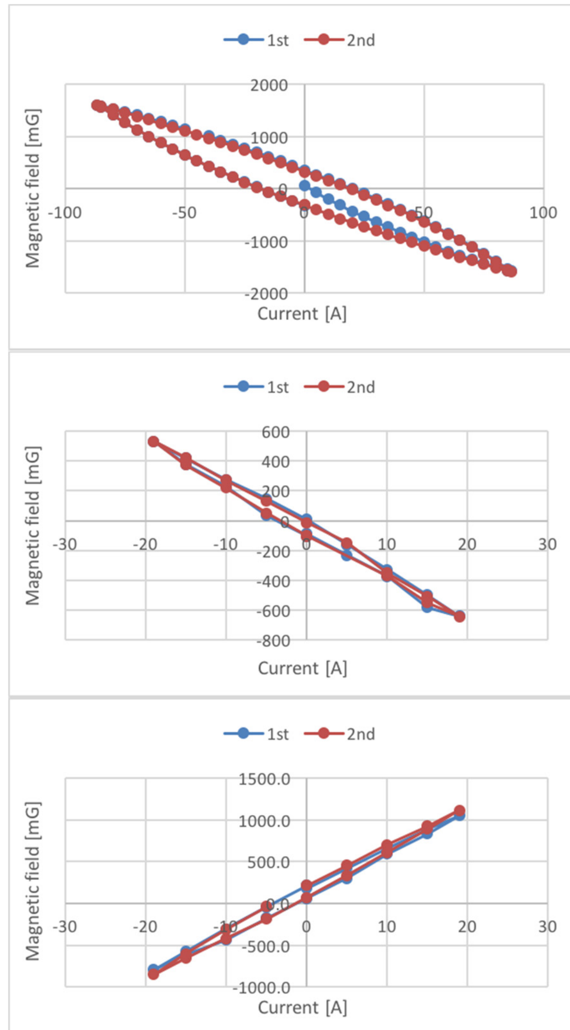

Figure 7: Magnetic field vs. excited current. (Upper) z-direction, (Middle) y-direction, (Bottom) x-direction.

DEGAUSSING EFFECT

The degaussing effect on the surface of the vacuum vessel was also evaluated quantitatively to establish the degaussing procedure of the solenoid packages. The operation current was decreased by 25% step in each iteration.

Figure 8 shows the decreasing of the z-direction magnetic field trough the degaussing process of the solenoid. The residual leakage magnetic field is almost saturated more than 5th iteration in degaussing process. Figure 9 and 10 show the decreasing of the y-and x-direction magnetic fields, respectively. The residual leakage magnetic field is almost saturated more than 4th iteration.

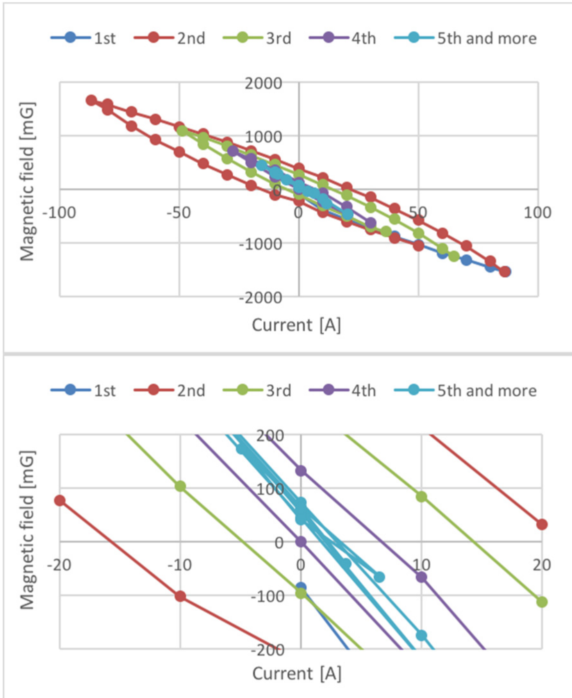

Figure 8: Magnetic field (z-direction: solenoid) vs. excited current. Lower is an enlarged view around the center of the upper plot.

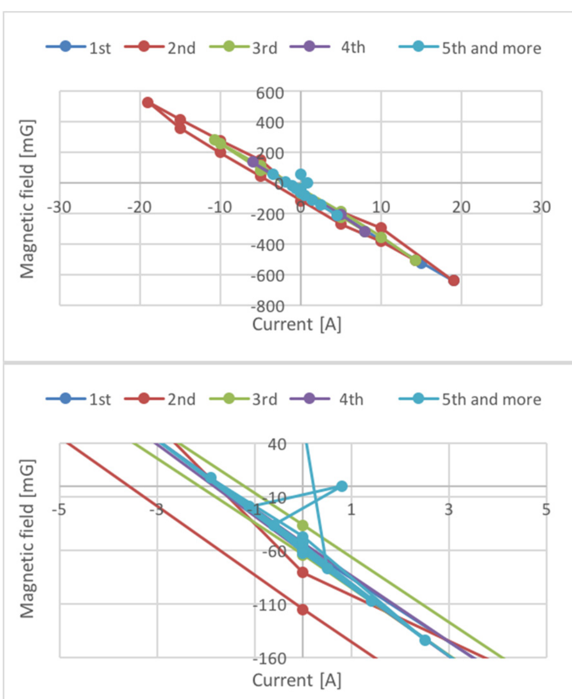

Figure 9: Magnetic field (y-direction: vertically bending dipole) vs. excited current. Lower is an enlarged view.

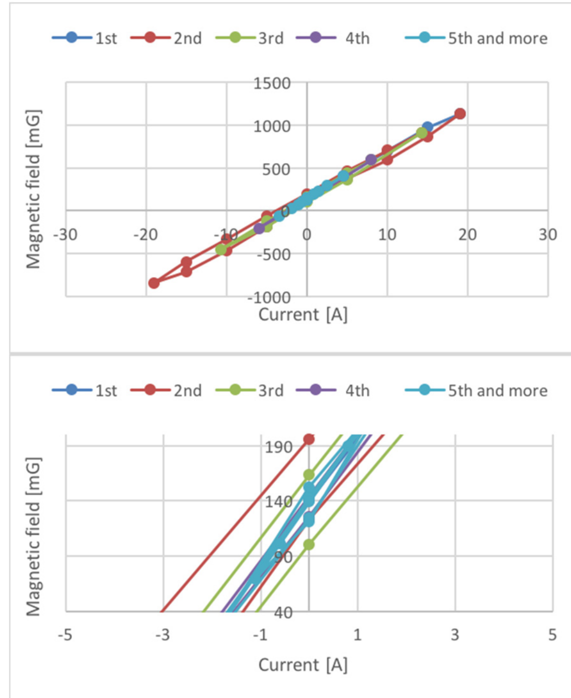

Figure 10: Magnetic field (z-direction: horizontally bending dipole) vs. excited current. Lower is an enlarged view.

In these results there was no information regarding the residual magnet field inside of the cryomodule. Thus, at least five iterations are required for the effective degaussing procedure.

SUMMARY

We successfully demonstrated that the solenoid polarity can be checked by measuring the leakage magnetic field outside the cryomodule. The leakage field was 1.5 G at a maximum, which could be easily measured by a milligauss meter. The measurement results agree very well with the calculations.

The polarity check procedure of a superconducting solenoid based on these results was already accepted in checking lists and to be performed as a devise test before an integration test and commissioning of the FRIB linac.

REFERENCES

[1] J. Wei *et al.*, "FRIB accelerator design and construction status", HIAT'15, Yokohama, Japan, Sep. 2015, pp. 7-10.

[2] K. Saito *et al.,* "FRIB project: moving to production phase", SRF'15, Whistler, BC, Canada, Sep. 2015, pp. 1-13.

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