CHARACTERIZATION OF A SNS TRANSFER LINE DIPOLE*

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Abstract

The performance of a magnetic dipole for the High Energy Beam Transfer line (HEBT) of the Spallation Neutron Source (SNS) has been studied extensively with simulations and measurements. The measurements employ a high precision Digital Tesla Meter (DTM) and a very sensitive Translational Coil Mapper (TCM). The system is controlled by a Labview program for data acquisition, transfer and analyses. Both magnetic field and integrated field are obtained in the measurements. The non-uniformity of the field and non-linear coefficients of the integrated field are determined. The experimental results are found in good agreement with OPERA-3d/TOSCA simulations. This paper reports the development of our measurement system, 3D simulations of the magnet design, and experimental results.

1 INTRTODUCTION

Magnetic dipoles are required in the SNS high-energy beam transfer line to guide the beam from its linac to an accumulation ring. The dipoles are designed by Brookhaven National Lab. Their dimensions are: 532.511 cm core length, 8.001 cm gap, and 50.80 cm pole-tip width, with a good field region of 5.6 cm (V) x 15 cm (H). For a 1 GeV H^- beam being bent for 11.25 degree by each dipole, the required integrated field is 1.11 T-m at a magnet current of about 550 A. Due to the C-shape structure of ion, the magnets have a gradient across the horizontal dimension, superimposed with the dipole field. The design calls for less than 1/1000 for this unwanted term.

At Oak Ridge National Lab where the SNS is being built, we have a task to characterize the dipole magnets and determine their performance parameters through measurements. First, we have run computer simulations of the dipole magnets by using the codes OPERA-2d and OPERA-3d/TOSCA. Many important parameters are obtained from this practice. The simulations have provided us guidance in experiments. The details of the simulations are described in Section 2. In our newly established magnet measurement lab we have tested the dipole prototype extensively and compared the results with the simulations. In Section 3 the experimental setup is presented. This includes the development of a universal test stand, a highly sensitive translational coil, electronics equipment, and a Labview program for instrumentation control and data analyses. Reported in Section 4 are the measurement results such as the field uniformity, integrated field, transfer function, longitudinal field distribution, effective length, etc.

2 SIMULATIONS

The codes OPERA-2d and OPERA-3d/TOSCA [1] are employed in computer simulations of the dipole magnets. Figure 1 shows the magnet under simulations. Note that the magnetic flux lines (arrows) inside the ion mainly follow the C-shape structure that creates a field gradient in the gap. This non-uniformity of the dipole field on the median plane at z=0 is depicted in Fig. 2. At a magnet current of 559 A in simulations, the field difference from x=-7.5 cm to x=7.5 cm is 1.844 G while the field at the magnet center is 2088.172 G.

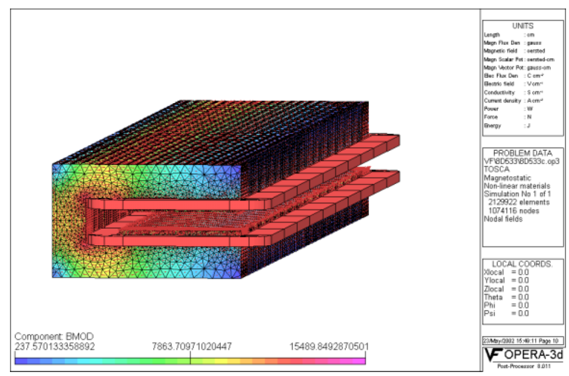

Fig. 1 8D533 in simulations.

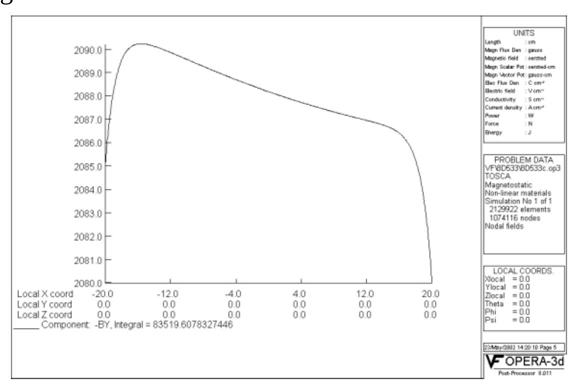

Fig. 2 Field distribution along the x-axis at y=z=0.

A typical longitudinal field distribution at x=y=0 is shown in Fig. 3, which yields the integrated field of 1.1328 T-m. The flat region inside the magnetic core has an average field of 2.0880 kG. Thus, the effective magnet length is 542.48 cm. The fringe field extends to about z=400 cm where it reaches below the earth field level. By evaluating the integrated field at different x, we can obtain the integrated field uniformity as shown in Fig. 4. The power series presentation of the curve in Fig. 4 gives rise to the linear gradient term and other higher order terms. In this case the linear fitting coefficient for the gradient term is –7.0E-5 T and the non-uniformity is 0.92/1000. Since the magnet is more than 5 m long, it requires a large number of subdivisions in the longitudinal mesh in order

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# On leave from Los Alamos National Lab.

to achieve good accuracy. In the simulations more than 1 million nodes are used for this magnet.

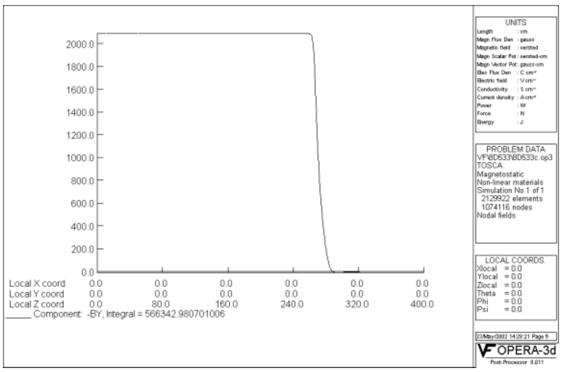

Fig. 3 Longitudinal field distribution.

Fig. 4 Integrated field non-uniformity.

3 EXPERIMENTAL SETUP

A block diagram of the experimental setup is shown in Fig. 5. It consists of a universal test stand, a translational coil, electronics equipment, a current power supply, and a desktop PC to control the system operation and to do data analysis. The software is written in the Labview program.

The universal test stand is a mechanical structure we have developed to support the mapping coil in the magnet gap and provide the mechanism of sweeping the coil inside the gap. The stand has the ability to adjust the coil position in the x-y plane and can fit any magnet length. It can also be used for mapping of other big magnets for the SNS.

The mapping coil is a translational one. It has a dimension of 1 cm in width and 6.33 m in length. The coil is made of 50 turns with multifilar conductor wire. The coil can be moved in the x-direction from x=-10 cm to x=+10 cm in many small steps, which are usually set to 40 in the program. The coil in every step of movement can produce a flux change of about 1.7E-5 V.s predicted by the simulation result in Fig. 4.

The electronics equipment consists of a high Precision Digital Integrator PDI-5025 [2], a Group 3 Digital Tesla Meter DTM-151 [3], a multi-channel Digital Voltage Meter Keithley 2700 [4], and other components. The digital integrator accepts the electric signal produced in the mapping coil, and performs piece-wise, seamless integration to produce the flux change in the coil. The DTM-151 is a high precision tesla meter employed to monitor magnetic fields directly inside the magnet gap. The digital voltage meter has multi-channel functions used with other sensors to process the magnet current, voltage, temperature, flow rate, pressure, etc.

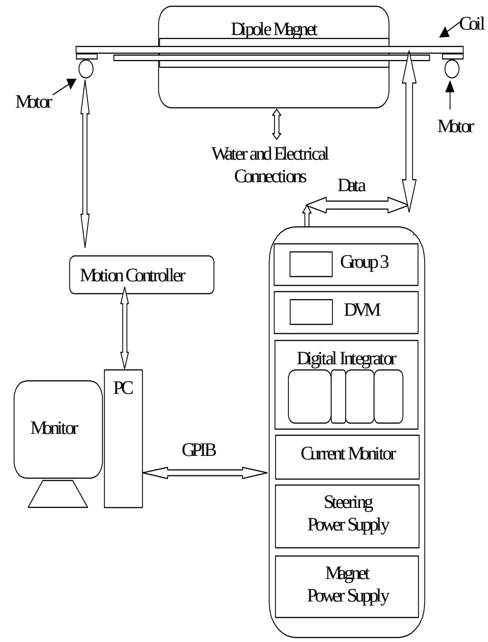

Fig. 5 Experimental setup.

The Labview [5] has been adopted in the measurements. We have developed a Labview program for our translational coil mapper. The program controls the equipment through the GPIB interface and also performs data analyses. The program is modularized to include magnet warm-up, motion control, data acquisition (DAQ) for the non-uniformity test, data analysis, and the measurement of the integrated field as a function of magnet current.

4 MEASUREMENTS

The first parameter in test is the non-uniformity of the integrated dipole field. This is done by sweeping the mapping coil across the magnet gap, and measuring the magnetic flux change as a function of the x-position. A typical signal from the digital integrator is shown in Fig. 6, where the first and the last ten data points are the off-set of the integrator, while the middle forty points are the flux changes in each of the forty steps when the coil moves from x=-10 cm to x=10 cm. Figure 7 shows the test results for both 1 GeV and 1.3 GeV operations. The non-uniformity for 1 GeV is about 0.62/1000, while 0.90/1000 for 1.3 GeV. They meet the design specifications. The simulation result for 1.0 GeV from Fig. 4 is also drawn for comparison.

In calculation of the non-uniformity we need to know the integrated field at x=0, in addition to its change along the x-axis. By locating the mapping coil at x=y=0 and changing the magnet current from the operation current to zero, we can measure the total flux change, as well as the integrated field. Figure 8 plots the integrated dipole field as a function of the magnet current. At 553 A for 1 GeV operation, the bending power of the magnet is 1.108 T-m, while it is 1.328 T-m for 1.3 GeV at 666 A. The data is re-plotted as the Integrated Transfer Function (ITF) in Fig. 9, where the nonlinear effect can be seen clearly. To verify the performance of the mapping coil, we scan the magnetic field along the z-axis on the median plane with the digital tesla meter. The result is plotted in Fig. 10, which yields an integrated field of 1.113 T-m at 553 A. By using both the measured integrated field and the magnetic field at the magnet center, we can calculated the effective magnet length, which is 5.432 m at x=y=0 for 1.0 GeV.

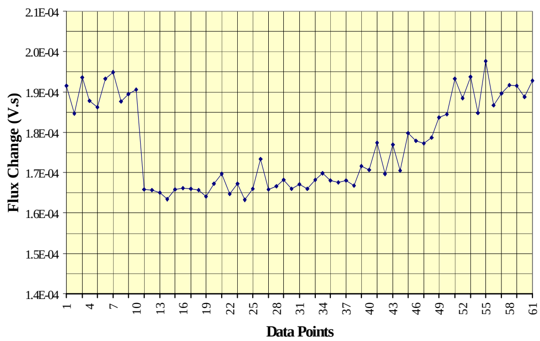

Fig. 6 Typical coil signal from integrator.

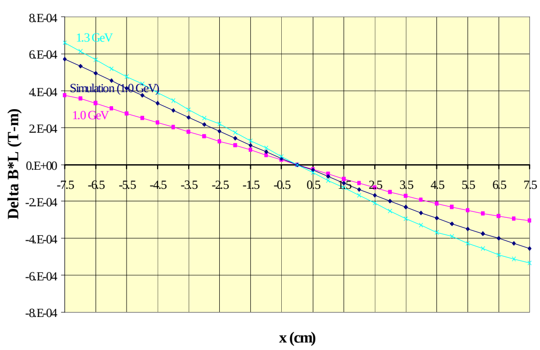

Fig. 7 Non-uniformity of integrated field.

In our initial measurement, the non-uniformity of the integrated dipole field was about 1.4/1000, which is larger than the design value. Later, we found that the non-uniformity sensitively depends on the procedure of magnet warm-up. A down-ramp to the operation point would provide a more uniform field than an up-ramp case. In the initial test, we followed a standard warm-up procedure. The magnet was first energized to a maximum current I_{max} and then brought down to the operation current I, where I_{max}/I was 1.1. The further study and test shows that the higher the I_{max} in warm-up, the smaller the non-uniformity. Qualitatively, this is due to the slightly different non-linear properties at the opening and the closing ends of the C-shape structure. In obtaining the result in Fig. 6, a maximum warm-up current of 750 A is used, which is 30% more than the 1.0 GeV operation current.

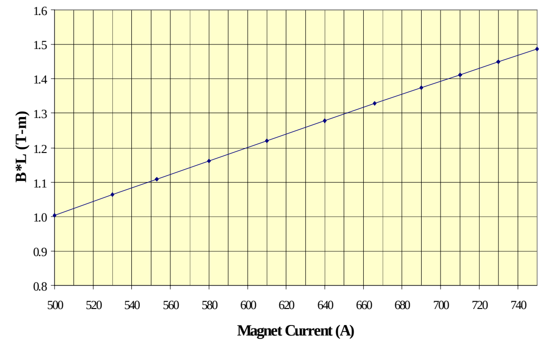

Fig. 8 Integrated fields vs. current.

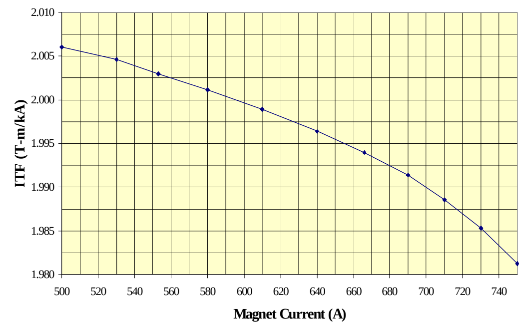

Fig. 9 Integrated transfer function.

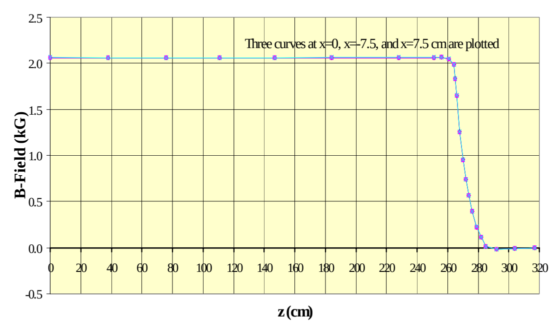

Fig. 10 Longitudinal field distribution.

5 REFERENCES

[1] OPERA is an OPerating environment for Electromagnetic Research and Analysis developed by Vector Fields Limited, England.

[2] PDI-5025 is a high precision digital integrator manufactured by METROLAB Instruments SA, Switzerland.

[3] DTM-151 is a digital teslameter manufactured by Group 3 Technology Ltd, New Zealand.

[4] Keithley 2700 is a multi-channel digital voltage meter manufactured by Keithley Instruments.

[5] Labview is a graphical programming language developed by National Instruments Corp.