Development of an integrated field measurement system (IFMS) for NSLS II

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Abstract. This paper describes the mechanical design, control instrumentation and test results for the Integrated Field Measurement System (IFMS) for the Magnetic Measurement Lab for the National Synchrotron Light Source II (NSLS-II) project at Brookhaven National Laboratory.

1. Overview

Insertion devices (IDs) at NSLS II need to be accurately surveyed using an integrated field measurement system prior to insertion into the storage ring. The IFMS, in Figure 1 below, is a fast and precise measurement system required in order to determine the ID magnetic field integrals.

![Figure 1: Integrated field measurement system (IFMS)](image1)

![Figure 2: IFMS with the four meter moving coil G10 board](image2)

The design takes several approaches to integrated field measurement. First is a flip coil, which consists of a long narrow width coil with 20-30 turns that is rotated in the undulator field. Second is a moving coil, which consists of a long board supporting fixed vertical and horizontal coils, 10 and 150 turns, respectively. One leg of this coil is inserted into the ID field and the return path is far outside the field. Finally, a stretched wire similar to the moving coil mentioned above, where one leg of a single turn coil is passed through the field and the return leg is far outside the field.

All three methods are supported by two sets of 3-axis (X, Y, Z) precision linear and two precision rotary positioning stages mounted to granite pedestals. A PC running WIN XP is the primary control unit. Eight servo motors are controlled by a Delta-Tau GeoBrick PMAC-2 Controller. One integrator is installed for data acquisition with a custom switching card to select the measurement source.

The IFMS is shown in figure 2 above. This view shows the left and right pedestals with the four meter moving coil G10 board shown between them. Below the moving coil board, the channel for
the return lines that complete the loop can be seen. The pedestals are made from granite to extremely tight tolerance for flatness on the upper surface. Each pedestal has three leveling feet that also provide 10 mm adjustment in the X and Y directions and 50 mm in the vertical direction. Aluminum plates have been added to the top and two sides of the granite to make EMO switch, cable bracket mounting, as well as future mounting changes, easier.

2. Linear Stages

The IFMS uses six of ADC’s ultra-high precision linear stages. The Y and Z axes have 125 mm travel and the X axis has 300 mm travel. All linear axes have a Renishaw invar linear encoder with +/- 1 um accuracy and .1 um resolution. All axes have limit switches for both directions. Several tooling holes are provided for survey targets consisting of a ¼-20 threaded hole and a ¼” reamed hole. A list of axis specifications is shown below in table 1.

|                     | X-Axis | Y-Axis | Z-Axis |
|---------------------|--------|--------|--------|
| Travel Range        | 300 mm | 125 mm | 125 mm |
| Position Resolution | 0.1µm  | 0.1µm  | 0.1µm  |
| Absolute Position Accuracy | ±5µm   | ±5µm   | ±5µm   |
| Relative Position Accuracy | ±1µm   | ±1µm   | ±1µm   |
| Minimum Speed       | 20 mm/min | 20 mm/min | 20 mm/min |
| Maximum Speed       | 300 mm/min | 300 mm/min | 300 mm/min |

3. Rotary Stages

Two rotary direct drive servos made by Yaskawa are used to achieve the 1 revolution per second (1 RPS) flip coil requirement. The Yaskawa motors can achieve 2.5 RPS while providing up to 1.4 million encoder counts per rev. The details are shown below in table 2.

|                     |          |
|---------------------|----------|
| Minimum Travel Range | ±180º    |
| Angular Positioning Resolution | 0.005º |
| Angular Positioning Accuracy | <40 arc sec |
| Angular Positioning Repeatability | <2 arc sec |
| Reversal Error       | <20 arc sec |
| Eccentricity         | <5 µm |
| Wobble               | <10 arc sec |

4. Flip Coil

The flip coil mounts to a special spool on the rotary axis located on each granite pedestal. 25 turns of 38 AWG beryllium copper wire is strung between these spools to form one continuous loop. An ADC custom circuit card amplifies and drives the long line signal back to a Keithley 2701 integrator. The coil spacing is set by a replaceable grooved plastic part. Wires are soldered to gold pins mounted within the spool. The connecting cable is light AWG coax. The cable is tensioned with a lanyard to prevent tangling as the spool revolves. The flip coil has a tension sensor located in the bobbin as shown in figure 3 below. Mounting the tension sensor in the bobbin removes the need to use a free slide under the stages, thus improving the stability of the XYZ stack. The flip coil measures first and second integrals. The first integral is measured inside the area of the coil, while the second integral is measured by twisting one end by 180 degrees, essentially reducing this area to zero by forming two equal but opposite areas.

**Figure 3:** Rotary Servo with Tension Sensor
5. Moving Coil

The moving coil also measures the first and second integrals. This design is based on a similar concept developed for LCLS at SLAC [1, 2]. The moving coil consists of 150 turns of wire formed from a flat cable with ten, 38 AWG, wires. The cable is held in a slot cut into a board made from a special fiberglass, made by Strongwell called “Extren”, which is similar to G10. This coil is oriented horizontally to pick up the vertical field. A second coil, wound vertically, consists of 10 turns and measures the horizontal field.

The board is a single piece, 4 meters long. The slot that carries the wires is milled into the 100 mil edge of the board. The board must be flat to function properly. For this reason, the thicker portion is mounted to a G10 I-Beam that is 10 cm tall and 5 cm wide. The board is attached to the I-Beam with a set of push-pull screws that are held captive by another set of locking screws.

The moving coil consists of ten, 38 AWG, wires bonded to a flat ribbon. These are very delicate and must be assembled carefully. The ribbon is first laid into the slot in the front of the board and returns through an aluminum channel supported by the pedestals. 15 loops are made. A custom circuit board joins the wires into one 150 turn coil. The board must be removed for shimming. Provisions are made to clip the return channel to the board for local transport. Bull’s-eye levels are mounted to each end of the board.

6. Stretched Wire

The stretched wire is similar to the moving coil in that only one leg of the coil is in the field during the measurement. The return wire is outside the field. The stretched wire consists of a single beryllium copper wire with a diameter of .125 mm. The wire is tensioned with a weight as shown below in figure 4. The return wire lies along the floor. The stretched wire is moved in the field to produce a signal which is very small and needs approximately 100x amplification. ADC designed and built a special instrument amplifier for this purpose.

7. Electrical Design

The control system provides 8 axis of servo control and has a position synchronized triggering on 3 axes, X, Y and rotary. The motion control system is based on a Delta-Tau Geobrick controller. Four axes (X, Y, Z, and Theta) are master and four are slaves, so each direction consists of a master and a slave. The flip coil can be tensioned by the Z master slave combination. The electronic controls are housed in a standard 48cm rack cabinet 106 cm high; see figure 5 below. A Dell precision T3500 PC forms the central control point and operator interface. The PC runs Wavemetrics IGOR 6.0 which is a graphical analysis software package. ESRF’s B2E was also included. The IGOR XOP (external operations) Toolkit 6.0 is provided.
8. Keithley Integrator

This instrument (DVM 2701) integrates the voltage between external triggers. These triggers can be time or special based. The resolution is 1 microvolt on the lowest gain setting. There are 10 internal gain settings. The coils can connect directly to the input of this device. Triggers are generated by the Delta-Tau.

9. Custom Multiplexer Card

Since there are potentially 4 sources of signals that can be input to the Integrator (i.e. the flip coil, vertical moving coil, horizontal moving coil, and single wire), and 5 triggers (Upstream and Downstream X, Y, and Timed), ADC designed a custom card to multiplex the analog and trigger signals into the integrator. The selection is made with IO lines available from the Geo-Brick.

10. Results

The following is a background field measurement taken with the Flip coil. This plot shows 11 samples at essentially the same position. This constitutes a static measurement. The green line represents the Y (horizontal) field the blue line represents the Y (vertical) field. The specification required a repeatability of .5 Gcm. As one can see, the repeatability achieved was .43 Gcm X and .51 Gcm Y, 1st standard deviation [3].

References

[1] Zachary Wolf, Yurii Levashov “Undulator Long Coil Measurement System Tests” LCLS-TN-07-03, SLAC, April 2, 2007
[2] Zachary Wolf “Undulator Field Integral Measurements” LCLS-TN-05-22, SLAC, August 5, 2005.
[3] A. Deyhim, D. Waterman, J. Kulesza, E. Van Every, PORTABLE MAGNETIC MEASUREMENT SYSTEM; European Particle Accelerator Conference, EPAC’08, Genoa, Italy, 23 to 27 June 2008.