A NEW DATA ACQUISITION SOFTWARE AND ANALYSIS FOR ACCURATE MAGNETIC FIELD INTEGRAL MEASUREMENT AT BNL INSERTION DEVICES LABORATORY*

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Abstract

A new data acquisition software has been developed in LabVIEW to measure the first and second magnetic field integral distributions of Insertion Devices (IDs).

The main characteristics of the control system and the control interface program are presented. The new system has the advantage to make automatic and synchronized measurements as a function of gap and/or phase of an ID. The automatic gap and phase control is a real-time communication based on EPICS system and the eight servomotors of the measurement system are controlled using a Delta Tau GeoBrick PMAC-2.

The methods and the measurement techniques are described and the performance of the system together with the recent results will be discussed.

INTRODUCTION

The National Synchrotron Light Source II (NSLS-II) at Brookhaven National Laboratory is a new 3 GeV electron storage ring of third generation designed to provide synchrotron radiation with a very broad energy range and an ultra high brightness and intense flux using advanced insertion devices [1]. In order to validate that IDs delivered to NLSL-II meet the tight specification, they are accurately surveyed before installation into the storage ring. Two benches, a Hall probe bench for local field measurement and the Integrated Field Measurement System (IFMS), have been purchased to magnetically survey the IDs [2]. The IFMS supplied by ADC USA Inc, is a set of three field integral measurement systems, a stretch wire bench, a moving wire and a flip coils. An upgrade program has been started; this article reports the first stage of the IFMS upgrade, focused on the flip coil system.

FLIP COIL MEASUREMENT SYSTEM

The measuring bench consists of a long coil of 10 turns of 38 AWG beryllium copper wire stretched between two granite blocks located on both sides of an ID. Each support includes three linear motorized stages to position and move the coil in the horizontal and vertical axes and a rotary stage employed to rotate the coil of 360° with an angular accuracy of 40 arcsec and encoder resolution of about 0.005 deg. It is equipped with rotary encoders mounted to the vertical axis linear stage in horizontal orientation. The flip coil mounts to a special spool on the rotary axis located on each pedestal, it is looped between these spools to form one continuous loop. The width of the coil is 4 mm and the length is about 5 m. In order to reduce the coil sagging the longitudinal axis stage can be tensioned and adjusted manually by varying the zero position. A tensiometer placed in the bobbin give an indirect value of the gravitational sagging of the coil. The tension sensor is made by Omega Engineering and has a range of 100 pounds and a resolution of ± 0.2% of full scale. All stages are assembled on the pedestals, which have an extremely flat tolerance on the top surface of about ±10 µm. Each pedestal has three leveling feet that also provide 10 mm adjustment in the horizontal X and longitudinal Z directions and 50 mm in the vertical Y direction. All linear axes have a Renishaw RELM linear encoder feedback with 0.1 µm resolution and ±1 µm accuracy. The Y and Z axes have 150 mm travel and the X axis have 300 mm travel, which is sufficient to ensure a measuring range appropriate for each magnetic device. Each axis has a brushless DC motor operated in closed loop mode with limit switches and a home limit switch that is used to tell the motion controller that it is near the home pulse located on the encoder. The linear encoders on the motors provide velocity, acceleration and position feedback. The motion control system is based on a Delta Tau GeoBrick PMAC-2 controller, which is responsible for the coordinated motion of four pairs of motors in a master-slave configuration. A serial communication is used to control and synchronize the various hardware components of Delta Tau. Geo-Brick generates the spatial and temporal triggers and convert the analog tension signal to digital. It provides eight axis of servo control and has a position synchronized triggering on four axes, X, Y, Z and rotary. Delta Tau GeoBrick PMAC-2 is a fully programmable motion controller and several software parameters must be configured to properly control each motor.

A digital multimeter Keithley DMM 2701 is used to record sensitive induced voltage signals from the coil. Model 2701 is a $6^{1/2}$-digit high-performance multimeter data acquisition system. It is equipped with a custom switching card to select the measurement source. Results of the DMM are transmitted to the host computer using a standard communication serial RS232 port. Keithley

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provides a high rate of sampling with a good stability. The integration time used is 16.67 msec (1 PLCs), which is a good compromise between higher sensitivity and better spatial resolution. To help maintain a good stability and accuracy during the measurements a digital filter has been selected. It takes a selected number of reading conversions, averages them, and yields a reading. The filter is then cleared and starts collecting conversions all over again. An external trigger is provided by Delta Tau, the encoder signal is fed to the multimeter while the motor itself is controlled independently. There are two types of triggers planned, spatial and temporal, both are generated by the GeoBrick.

DATA ACQUISITION SOFTWARE

In order to perform accurate and precise synchronized measurements as a function of gap and/or phase adaptable for each device and to ensure that the integral multipole components are maintained within the specification requirements a new data acquisition software for the IFMS has been developed. This software has been written in LabView, which is a graphical programming platform from National Instruments.

The complete control of the measuring bench, such as homing, multi-axis positioning and movement have been implemented. The main features of the new software include the data acquisition and magnetic analysis, setting and reading of the gap and phase for any device and an user-friendly control panel to perform field integral measurements on the transverse plane in automatic gap and phase control.

Additional expert control panels are under development. They will be available for testing and configuration of the field integral measurement system, in particular some diagnostic tools will be necessary for the monitoring and tuning of the Delta Tau amplifiers. Further specific functionality will allow to view and manipulate basic system settings and controls with an extensive support for accessing to the instrumentation hardware.

The LabVIEW application software was developed on a PC which is the central control unit and operator interface of the measurement system. PC was configured to utilize a channel access for Experimental Physics and Industrial Control System (EPICS). It is used extensively in particle accelerators throughout the world and is the main control system used at NSLS-II; because it is run from UNIX based machines a Windows EPICS Client has been set up on the PC in order to have a completely control of a ID during the field integral measurements. The EPICS PC configuration allows the computer to issue directives to EPICS over the command line through Process Variables (PV). The channel access communication between LabVIEW and EPICS is created using the CaLab interface [3].

Flip coil system are commonly used to perform field integral measurements of insertion devices used in synchrotron light sources, where very strict tolerances on the magnetic field quality are required.

The first integrals of the transverse field components Bx and By along the longitudinal axis Z, defined by:

$$Ix = \int Bx\,dz\,; \quad Iy = \int By\,dz \qquad (1)$$

are obtained from the induced voltage ε in the coil in acccording to the Faraday's law: $\varepsilon = -\mathrm{N}\frac{d\Phi}{dt}$. Where Φ is the variation of magnetic flux linkage through the surface defined by the coil and N is the number of turns.

In addition to the usual point by point measurements, an important feature in this field integral bench is the capacity to perform "on the fly" measurements. This measurement technique consists to measure Iy and Ix by a continuously rotating coil from 0° to 360° around the z-axis at the starting and ending point followed by a translation movement at constant speed along the x-axis over the whole scanned range, with horizontal orientation to measure the variation of Iy and with vertical orientation to measure the variation of Ix. The field integral variations at the end of the translation movements are given by:

$$\Delta Iy = -\frac{\int Vy\,dt}{ND}\,; \quad \Delta Ix = -\frac{\int Vx\,dt}{ND} \qquad (2)$$

where the voltage readings Vx and Vy are recorded by digital multimeter at constant steps and subsequently transferred to PC for processing. ΔIx equation is valid only if the variation of Ix over a vertical distance equal to the coil's width *D* is small enough. During the measurement the coil is rotated forward about the longitudinal axis through the zero reference. At this point the measurement is triggered initially. The rotation continues and the measurement proceeds through 360° where the acquisition ends. At regular angular intervals the DMM is triggered electronically to collect the induced voltages and angular intervals. Once the forward measurement is completed, the coil is then rotated backwards so that data can be collected from the two different rotational directions and averaged. At the completion of the measurement cycle, the multimeter outputs the voltage at each encoder location. Assuming that variation of the magnetic field within the width of the coil is small enough, the voltage integrated over the measurement time t_2 - t_1 is given by:

$$\int_{t1}^{t2} \varepsilon\,dt \approx ND\left(Iy\int_{\theta 1}^{\theta 2} Sin\theta\,d\theta + Ix\int_{\theta 1}^{\theta 2} Cos\theta\,d\theta\right) \quad (3)$$

Therefore Iy is obtained by a rotation from 0° to 180° and Ix from -90° to 90°.

The full control of the measurement system is carried out by the main GUI illustrated in Fig. 1. This panel allows the user to initialize Delta Tau, enable and disable the servor motors and to set up various system parameters such as the width of the coil, number of turns, linear and

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angular speed. It also performs homing, positioning and movement in master-slave mode for each axis.

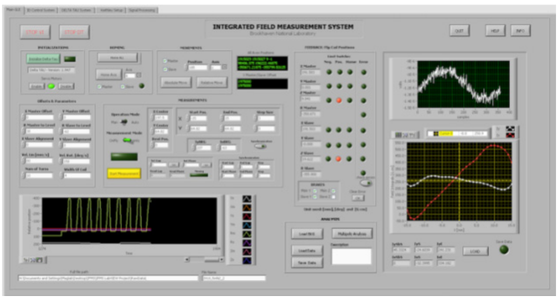

Figure 1: Main GUI interface.

Multiple scans can be taken at different locations in X or Y and the method of measurement (point by point or on the fly) can be selected. The GUI also allows access to offsets to align the slave to the master and the master to the beam line. The user can enter measurement information for data acquisitions such as measurement range and step, mechanical centers of the coil, background field integrals and the filename destination. The operation mode button allows the user to select measurements synchronized with gap and/or phase movements of an insertion device. After a measurement is completed, the data are analysed and graphed on the screen. The new software has been developed using a modular programming approach. This consists to separate the functionality of the software into independent and interchangeable modules, known as subVIs, each of which accomplishes everything necessary to execute only one specific aspect of the desired process. Figure 2 showns three subVIs, the "Integral RotCoil" (Fig. 2A) and "Integral MovCoil" (Fig. 2A) to calculate respectively the field integrals by rotation and translation movements of the coil and "OnFly Measurements" (Fig. 2C) to perform automatic measurements and data acquisition. It embeds a set of other SubVIs which are employed to control and synchronize the various hardware components in the measurement system.

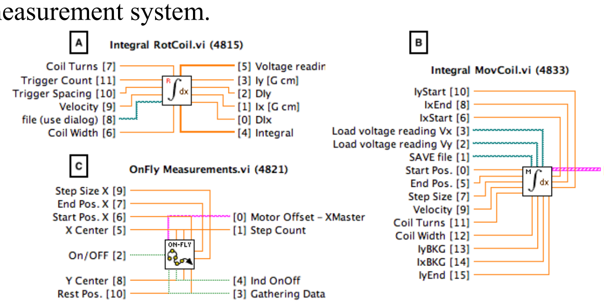

Figure 2: Main SubVIs.

The SubVIs in Fig. 3 provides a real-time monitoring of the global status of all motors on the system. Conditions on each axis such as position, home and limit switch, following error and amplifier fault error are checked and made visible on the main panel during the measurement process.

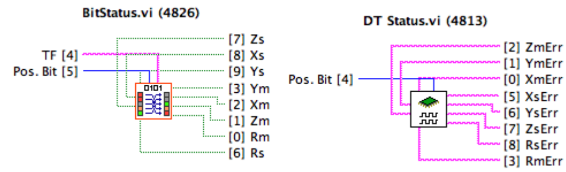

Figure 3: SubVIs for Delta Tau status.

Further control panels are available on other secondary tabs for testing, configuration and debugging of the motion controller, data acquisition system and IDs control system.

Figure 4 (left) shows the horizontal (red line) and the vertical (blue line) point by point field integral measurements versus the transverse position of a 1.5m IVU at 8 mm gap.

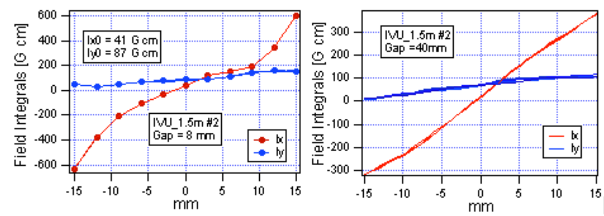

Figure 4: Field integrals of a 1.5m IVU.

In order to verify the accuracy and repeatability of the on-the-fly measurements 5 scans have been taken at 40 mm gap (Fig. 4 right). The standard deviation is 5 G cm for the on-the-fly measurements and 3 G cm for the point by point.

CONCLUSION

Although the insertion devices are very different, we strived to find a common design to make them look similar to the operator and to hide the different levels of complexity behind a common user-friendly interface.

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