MOPC12

# A NEW MAGNETIC MEASUREMENT SYSTEM FOR THE FUTURE LOW EMITTANCE NSLS-II STORAGE RING

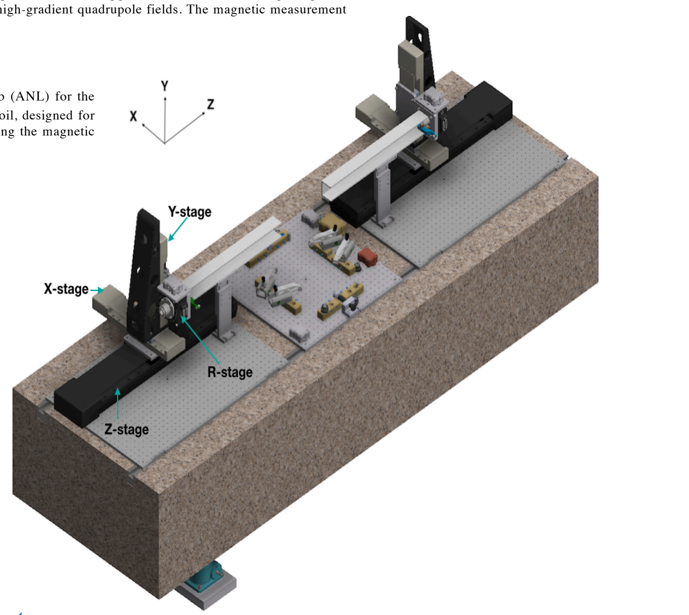
MEDSI CHICAGO 2020


M. Musardo, T. Corwin, F. DePaola, L. Doom, R. Faussete, D. Harder, S. Sharma, T. Tanabe, **Brookhaven National Laboratory, Upton, New York**
C. L. Doose, A. K. Jain, **Argonne National Laboratory, Lemont, Illinois**
D. Assell, J. DiMarco**, Fermilab, Batavia, Illinois**

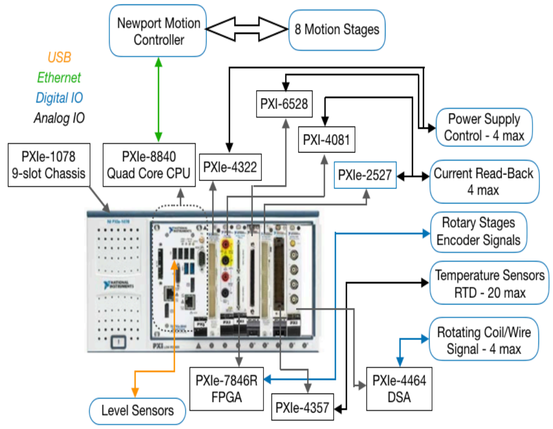


A new magnetic measurement system is under construction at BNL for accurate field harmonic measurements and fiducialization of magnets for a future upgrade of the NSLS- II storage ring. The entire storage ring is envisioned to be replaced with a new lattice concept, known as Complex Bend, which superimposes dipole and high-gradient quadrupole fields. The magnetic measurement system will use rotating wire and a PCB rotating coil specifically designed for small-aperture (< 15 mm) high gradient magnets.


The magnetic measurement system configured at NSLS-II is based on the measuring bench developed at Argonne National Lab (ANL) for the Advanced Photon Source (APS) upgrade project. The new measuring bench consists of a Printed Circuit Board (PCB) rotating coil, designed for measuring field strength and field quality to a level of 0.1 units up to the 15$^{th}$ harmonic and a rotating wire system for determining the magnetic center and for fiducializing multipole magnets with an accuracy better than 10 µm using a Laser Tracker




## PXI modules and the DAQ system diagram




A National Instrument (NI) PXI system is employed for trigger generation and data acquisition (DAQ). The NI-PXI (PCI eXtensions for Instrumentation) is composed of three main hardware subsystems: a PXIe-1078 9-slot chassis, a PXIe-8840 embedded controller and seven plug-in modules.

## *Rotating Wire System*

The measurement bench is assembled on a 2.75 m long granite block supported on 3 leveling jacks. The leveling jacks are JOYCE WJ123 with a 3 Ton capacity, 1 inch of screw travel and 12:1 ratio gearset. The granite block has machined T-slots and Survey & Alignment holes. Both the magnets and the stages are supported on three anodized aluminum plates affixed to the granite surface. Stop blocks on the center plate provide banking surfaces to align the magnet to the rotating wire. Other banking alignment features, such as magnet pushers and support assemblies, help to align the rotating wire and rotating coil to any type of magnet. Aluminum shims between the stop-blocks and the magnet reference surfaces are used depending on the geometry and dimensions of the magnet to be measured. The two outer aluminum plates are populated with Newport X,Y,Z and R stage assemblies as shown in Fig. 1. Thus, there is independent X, Y, Z and R positioning at each end of the bench which can operate in tandem.

## *Rotating Wire Signal Acquisition*

The voltage induced, as the wire rotates about the longitudinal magnet axis, is picked up by a Mercotac two conductor slip-ring and sent to the PXIe-4464 Dynamic Signal Analyzer module. The DSA module is set to 200 kS/s and acquires 10 revolutions of rotating wire signal. The acquired signal is 10 seconds long and contains 2 Msamples, as the rotary stages are set to spin at 1 rev/s. The 2 Msamples of data are integrated and interpolated at 1000 rotary positions per revolution and then averaged to obtain a flux vs rotary position signal.

The rotary data acquisition is trigged by a signal from the FPGA module after an index pulse from the downstream rotary stage is detected. The FPGA code counts the level-shifted and squared sin/cos rotary encoder signals generated by a comparator circuit and fed into the NI SCB-68A terminal box. Upon detection of the index pulse the DSA module promptly begins acquiring the rotating-wire signal. After acquisition, the voltage waveform is numerically integrated to obtain flux as a function of time. The rotary stage has 60k encoder counts per revolution and the time is captured for each 1/1000th of a revolution, therefore, 60 encoder counts is equivalent to 0.36 degrees. The FPGA code runs in a timed loop at 40 MHz; thus, the time resolution is 25 ns. The loop index value is saved to memory every 60 encoder counts and the time for each position is equal to the loop index times 25 ns. The time values are used to interpolate the flux values at each 0.36-degree increment yielding a flux signal as a function of angular position.

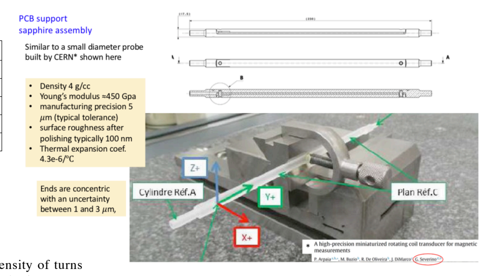
## *PCB Rotating Coil*

A 12 mm diameter PCB-based rotating coil is being developed under a BNL contract in which Fermilab will provide the conceptual design, prepare the engineering drawings, procure components, fabricate, and perform testing, assembly and commissioning.

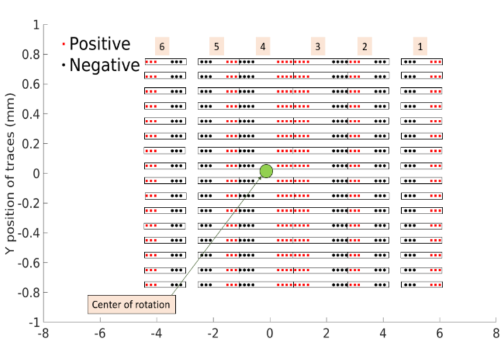
The PCB coil design calls for a cylindrical sapphire support to ensure sufficient stiffness, thereby minimizing unwanted vibration and sag. The **sapphire** also curtails thermal expansion, with a coefficient of 4.3x10$^{-6}$units/°C. The PCB structure outer diameter will be 12 mm and the ends will have 6 mm outer/ 3 mm inner diameter in order to accommodate the 1.8 mm thick printed circuit board, wiring, and ABEC 5 all-ceramic bearings. The active coil length is 270 mm, and the overall probe length is 390 mm.

Table 1: PCB Coil parameters

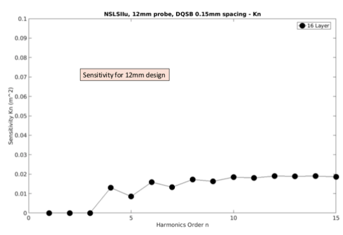
| | |
|---|---|
| Total PCB thickness | < 2 mm |
| Active coil length | 270 mm |
| Length of each end stem | 25 mm |
| Total probe length | 390 mm |
| Reference radius | 5 mm |
| Diameter | 12 mm |




## PCB design cross-section




In order to boost the signal amplitude, the probe is designed with a high density of turns and multiple layers (75 µm wide traces with 75 µm space between them). The layers are very thin -- about 100 µm -- and the connection 'vias' between the layers is small - 350 µm diameter. The PCB coil has the capability of providing un-bucked (UB), dipole bucked (DB), dipole-quad bucked (DQB) and dipole-quad-sextupole bucked (DQSB) signals, in order to ensure minimal spurious harmonics in measurements of both quadrupole and sextupole magnets.




***The coil will be suitable for measuring field quality to a level of 10 ppm of the main field (0.1 "units") up to the 15$^{th}$ harmonic with a sensitivity between 0.01 $m^2$ and 0.02 $m^2$ at the reference radius of 5 mm. The bucking factors are expected to be about 1000, therefore the DBuck signal should have a typical absolute measurement of the quadrupole field with an accuracy of about 0.15% (with no calibration).***