Dipole Survey and Alignment of NSLS-II

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Introduction
The survey group at Brookhaven National Laboratory (BNL) undertakes the entire alignment task across the lab which includes NSLS-II, AGS, RHIC and etc. NSLS-II is an on-going project which will be a new state-of-the-art, medium-energy electron storage ring (1 GeV), 30 GeV, 3 GeV, the gantry structure world-leading immunity and brightness with a 0.1 nm, annual maximum horizontal-constant when it's fully built out. It will provide: 1 nm spatial resolution and 0.1 MeV energy resolution to facilitate the study of nanomaterials. Its circumference is 792 meter with the potential of at least 50 bending magnets. The construction of the NSLS-II's ring building began in March 2009 and it's scheduled to be in full operation in June 2015. There are 60 dipole girders and 90 multipole girders totally. NSLS-II project requires ±100 micron alignment accuracy between girders. The work associated with dipole can be categorized as pre-survey portion and alignment portion. The pre-survey of dipole includes mechanical frame establishment, manufacturing dimension and vacuum clearance verification. The alignment portion includes the positioning of dipole relative to magnetic measurement system and tunnel positioning relative to control network.

Instrument and Software
The major instruments used in NSLS-II project are laser trackers, articulated arms and total stations. In the early stage, meterometer and digital level were used to establish the primary and elevation control network, but they were phased out. SitePREP is used to analyze the control network data initially and double check the data obtained from SA occasionally. The major software in use is SA. We have 12 SA keys to ensure the seamless transfer of data among the group members. The uniform interface and versatile function of the software is very helpful in the project. Essentially, the data analysis for dipole measurements can be annotated with the help of the Measurement Plan (MP). It has been proven to be very effective. Although the writing and debugging MP used some time, the result can be provided in a timely manner once the raw data is obtained.

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Questions? Ask me …
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The Characteristic of Dipole

Dipole Pre-survey
When a dipole is ready to be inspected, there are 3–4 laser tracker setups in order to capture all the information needed. The measurement elements include:
- Common targets are measured during each setup to orient instruments. Unified Spatial Metrology Network (USMN) of Spatial Analyzer (SA) is used to get the optimal coordinates.
- Pole surfaces points are measured to define the horizontal plane and can be used to compute the aperture of the dipole.
- Points are measured on the upstream and downstream end of the top and bottom poles to control the beam longitudinal position.
- Inboard and outboard circle points can determine the bending radius. The bisected circle defines the beam orbit.
- The magnet frame can be established and the information is ready for further alignment.
- Some measurements are dedicated for Interface Control Drawing (ICD) check purpose, such as the end and bottom of coil position, mounting holes in the base etc. Inspection report will be generated for each dipole. Discrepancy report will be submitted if the dimension is out of tolerance.

Dipole Alignment Relative to Hall Probe
Dipole needs to be aligned to the Hall probe (HP) bench for magnetic measurements. In order to enhance magnetic measurement precision, the alignment goal of dipole relative to topigngrity of HP is better than ±100 micron and the residuals of roll, pitch and yaw should be minimized.

The main steps are listed in the following:
- HP frame was built at the beginning according to the movement of the probe and the supporting gantry. The coordinates system (CS) can be represented by the monuments pasted on the frame of HP.
- Laser tracker will be used to measure the monuments to retrieve the HP frame and direct the alignment of specific dipole.
- Use the watch window to get all the top fiducials moved in elevation direction. The small raw residual is achieved by keeping the X reading of upstream and downstream fiducials almost the same.
- The alignment residuals will be reported to magnet group for further analysis.

Dipole Installation in Storage Ring
Dipole girders installation in storage ring (SR) will be a 3-step process:
- Dipole girders will be aligned relative to control network with about ±200 micron precision. Similar with the alignment of multiple girders, two-trackers will be employed at the same time to streamline the alignment process.
- There has been about 1/5 of the dipole girders had been aligned this way by the end of August, 2012.
- Next year, when the settlement of tunnel stabilizes and the environmental control are fully in action, multiple girders will be gone through a very precise girders profile reproduction process as reported in this workshop. Along with this kind of activity, dipole girders will be re-aligned relative to the adjacent multiple girders and the girders alignment specification will be pursued and achieved.

Alignment Error Estimate
Dipole alignment error can be calculated based on the following error sources:
- Pre-survey precision: ±30 micron
- Tunnel control network: ±30 micron
- Alignment residual: ±50 micron
- The final alignment precision is about ±100 micron.