A Novel Undulator Magnet Gap Separation Mechanism

J. Skaritka, E. Haas, G. Rakowsky, C. Stelmach, L-H. Yu

National Synchrotron Light Source, Brookhaven National Laboratory,
Upton, New York 11973, U.S.A.
Phone: (631) 344-7411; Fax: (631) 344-3238
E-mail: skaritka@bnl.gov

Abstract

A novel gap-separation mechanism has been designed for a permanent magnet undulator that is applicable for both FEL and synchrotron radiation sources.

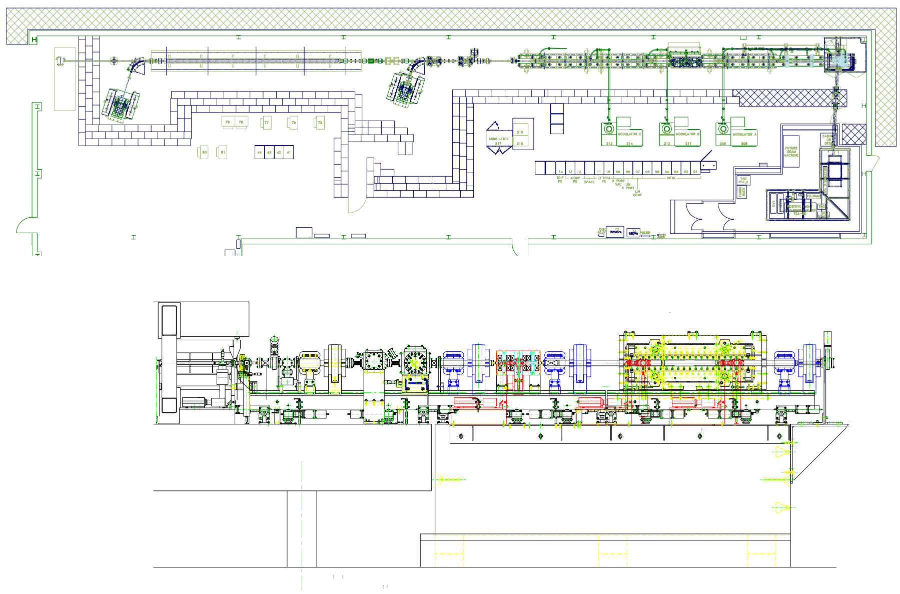
An upgrade to the SASE FEL currently in operation at BNL's Source Development Laboratory (SDL) is anticipated. Seeding with a 266 nm Ti Sapphire laser to produce 1 micro Joule of deep ultra violet coherent radiation at 88 nm is being incorporated. Further improvement will be to incorporate high gain harmonic generation (HGHG) to produce 200 micro-Joules at 200 nm and a third harmonic of 1 micro-Joule at 66 nm. This will require an introduction of a modulating pre-bunch undulator magnet. Presented is a novel, relatively low cost, method to control the gap of the modulator magnet. A gap separation mechanism and corresponding magnet support structure have been designed. The rail-mountable undulator magnet support structure is to be incorporated with a precision rail and motorized strut-driven beam-based alignment system that is already in place on the beam line. A single motor is used to drive the separation mechanism. This novel approach can provide gap control and parallelism to within 20 microns, while allowing easy access to the gap for magnetic measurements, vacuum chamber installation and beam diagnostics. The paper presents the detailed design of the system, and describes assembly, testing and installation procedures.

Keywords: SDL, HGHG, SASE FEL, undulator, gap separation

1. Introduction

The SASE FEL in operation at BNL's Source Development Laboratory (SDL) is anticipated to be upgraded to Seeded High Gain Harmonic Generator operation. To accomplish this the magnetic optics of the matching section between the SDL's Linac Beam Line and the NISUS undulator must be altered to accommodate a modulating undulator and a dispersion magnet. Figure 1 depicts the SDL beam line. It is composed of a 1.5-cell photocathode gun/focusing solenoid assembly, four sections of SLAC-style linac delivering 50 MeV/section, 4-magnet chicane, a beam dump, and an on axis laser seeding system. Down beam of the SDL source is the NISUS undulator magnet, its matching section with its magnetic optics and associated diagnostics, FEL in-vacuum beam transport, and the final electron beam dump.

To facilitate high gain harmonic (HGHG) operation the beam must be modulated prior to entry into the NISUS undulator. Previously reported [1] work to establish a HGHG FEL utilized the NSLS mini undulator magnet to perform appropriate beam modulation. It was determined the same modulator could be used in SDL's HGHG FEL upgrade. Previous mechanical operation showed significant problems occurred with the >20 year old mechanical lead screw gap separation mechanism of the mini-undulator.



View of modulator as installed into matching section of SDL beam line

Fig. 1: SDL beam line.

The lead screws and drive motors for the old mechanism were worn and exhibited significant backlash and resulted in non-parallelism of the undulator's magnet poles. The pole assemblies of the HGHG modulator must be parallel to ± 20 microns. The matching section between the NISUS undulator presented space constraints that disallows the use of the previous gap separation mechanism. In addition to these issues the drive columns surround the magnet assemblies and limit access to the magnet gap for magnetic measurements as well as vacuum vessel and beam diagnostic installation.

All these above factors lead to the conclusion that a new gap separation had to be redesigned for the mini-undulator that would address each of the above issues while integrating efficiently into the current beam line.

An additional consideration was given to the application of beam line insertion devices that may be used in future upgrades of the NSLS. The desire was to mount an undulator along with other beam line optics and diagnostics onto a rail system. The rail itself is adjustable by remotely operated struts and incorporated into a beam based alignment system. If successful this may have applications in other synchrotron radiation facilities.

2. Detailed Design of the Gap Separation Mechanism

It is highly desirable to provide a single motor drive to control the vertical location of the undulator's magnet assemblies. A vertical position control was built for the Prototype Small-Gap Undulator (PSGU); it used an inclined plane to control vertical position of the magnets and vacuum chamber [1]. A system was devised to utilize a double-inverted incline plane to control the gap position of the undulator [2]. Figure 2 shows an assembly drawing the mini undulator. An aluminum box is mounted via slide

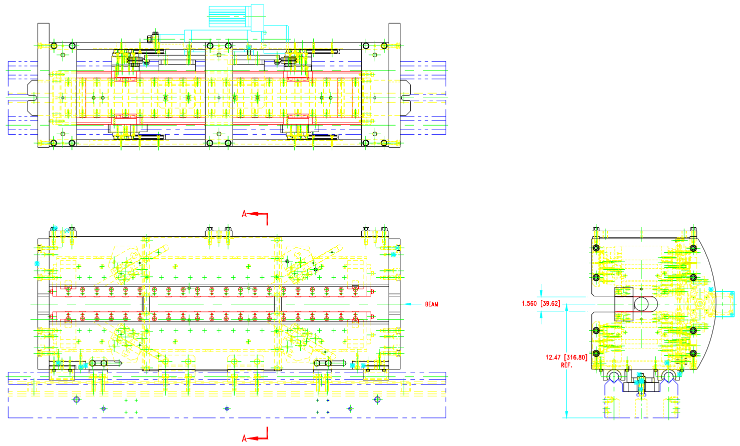


Fig. 2: Gap separation mechanism assembly.

bearings onto the strut activated rail assembly. The box is designed with massive end plates. These plates have a central horizontal gap to accommodation the use of a hall probe mapper to measure the entire magnetic field including end fields, as well as the installation of the vacuum chamber and beam diagnostics. The end plates are designed to minimize the side to side flexure of less than 5 microns across the magnet's gap. Figure 3 depicts a cross section of the mechanism. Four precision preloaded linear ball slides are affixed to the quarter point locations of each of the magnet assemblies. These ball slides roll along rails that are inclined at 30 degrees and secured onto the inside of the box assembly. There are eight slides in all; four each on the top, four each on the bottom. A set of non-magnetic stainless steel DULA-VEE cam followers mounted on each of the magnet jaws prevent axial motion of the undulator magnet, keeping top and bottom poles aligned. A single linear drive cylinder powered by a stepping motor applies a linear thrust between the vertically fixed plate and the box assembly. As the box assembly moves axially along the rail, this action drives the two jaws apart about the beam line axis. Once the desired gap is reached a shaft brake is engaged to prevent shifting should power to the stepper motor driven actuator be interrupted. A further safeguard is made by tightening fixture bolts at the base of the box assembly. These bolts would have to be loosened to allow the gap to be changed.

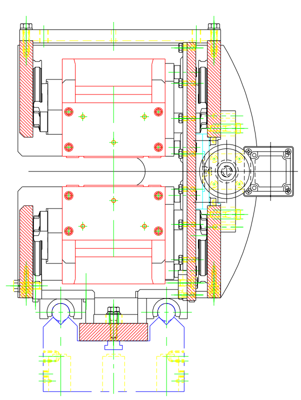


Photo of Modulator on magnet test stand.

Fig. 3: Cross section of gap separation mechanism.

Two sets of "Z" brackets are used to affix the gap position relative to the rail. This is done with the use of a back plane bar, which is fixed to the rail. The aluminum bar resists the axial thrust load that results from the attractive forces between the two magnet jaws of the undulator. This is done for two reasons. First, if the drive motor needed servicing, it could be removed or replaced without affecting gap position. Second, after magnetic measurements, it may be desirable to set the gap prior to magnet installation. The "Z" brackets and the back plane bar allows this to happen. The entire magnet assembly may be taken off the magnetic test stand, moved, and installed onto the beam line rail without affecting the initial gap setting.

3. Survey and Alignment

The magnetic field across the poles of the mini undulator is very flat so therefore the need for precision side to side adjustment is not critical. Average horizontal location of ±0.5 mm with respect to the beam line axis. Therefore, no horizontal advisement is offered other than shimming of the slide bearings. In practice, vertical axis positioning reproducibility of ±0.1 mm will be achieved.

Yaw control is accomplished by shimming of the slide bearings as well. Adjustment of role, pitch, and yaw is accomplished by first establishing a line parallel to and centered over the alignment rails. On top of the magnet assembly that define the magnet centerline as well as roll and pitch. Survey targets can be used for the adjustment process. A presurvey is performed to conform gap center deviation relative to the fiducial plane. Jacking screws on top of each of the slide bearings allow for gap center elevation adjustment. A design shim thickness of 2.0 mm is used to give nominal centering. Precise vertical position is achieved by adjusting the jacking screws until the fiducial targets indicate the desired height above the rails. Shim packs on top of the slide bearings are adjusted, inserted between the box frame and the bearing, then bolted securely.

4. Testing

A series of magnet measurements were performed using the stretched wire device [3], a hall probe mapping system, and a vibrating wire system. The stretched wire is located over the rail assembly, leveled and centered with respect to the beam line axis. A plot of the electrons path through the undulator is obtained using a stretched wire system, any gross deviations from the desired trajectory are corrected. The elevation, roll, pitch, and yaw is finally adjusted and the drive system is tested to check reproducibility. The assembly is transferred to the hall probe mapping bench. Here the field is precisely mapped and any magnetic shimming is performed. A plot of the test results from the stretched wire measurements is presented below.

After this, precise magnetic center shall be achieved using a stretched wire system. The elevation/roll pitch and yaw is finally adjusted and locked into place and the relative gap axis is fixed by way of the back plane bar and Z brackets. The assembly is transferred to the hall probe mapping bench. Here the field is precisely mapped and any magnetic shimming is performed.

The assembly's motor is adjusted so the gap may be changed. The magnet gap will be repeatedly altered to check for reproducibility or magnet pole parallelism and vertical gap center. Once the magnet measurements are completed the Z brackets are bolted to the box frame.

5. Installation

The beam line shall be prepared for the wiggler installation. Beam line magnetic optics shall be disassembled. Survey will check the elevation of the quad centers above the beam line and then transfer the quadrupoles to the testing rail for final gap center alignment.

The shielding around the beam line is removed and the area made ready for modulator installation. Lifting eyes are affixed to the magnet box frame to allow the rigging of the magnet assembly from the magnetic measurements lab to the beam line.

Surveyors shall locate the assembly along the beam line rail and secure it into place by bolting the ends of the back plane plate onto the rail. Once fixed to the rail, final in situ survey shall be performed and any adjustments made.

The vacuum beam tube is installed in the magnet gap and the beam based alignment drive system is actuated. Magnet beam tube diagnostic pop-ins are located in the undulator center on the beam line axis and secured onto the end "C" plates of the box frame. Gap measurement sensors are installed and tested. Precision linear potentiometers are used to confirm pole parallelism and magnet gap.

6. In situ Testing

By using the front of the box frame a portable hall probe mapper may be devised so that transport back to the magnetic measurement laboratory may be unnecessary. The vacuum tube would be removed, the portable hall probe mapper installed and magnetic measurements performed while the magnet assembly is on the beam line. After in situ testing and or assembly is complete the shielding is reinstalled around the beam line.

7. Conclusion

In this paper we have presented a novel approach to control the gap of an undulator magnet. The design has implications where rail systems are used to locate components onto and along a beam line and modular design allows for beam based alignment.

The design has implications for use with insertion devices in other facilities where compactness, modularity and magnet gap drive simplification is desirable. The mechanical design, assembly, and test procedures were described. The design adapts an undulator assembly to a rail alignment system while eliminating the need for two or more independent drives on the magnet jaws.

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