The NISUS Magnet Diagnostic

J. Skaritka, A. Doyuran,
E. Johnson, T. Kim, T. Shaftan, 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
Email: skaritka@bnl.gov

Abstract

This paper presents the detailed design of the diagnostic "pop-ins," a description of their use for FEL operation, examples of data obtained, results of reproducibility studies, and a description of associated external diagnostic components.

The Near Infra-Red Scalable Undulator System,(NISUS) is a ten-meter long undulator magnet that serves as the radiator section of the Deep Ultraviolet Free Electron Laser (DUVFEL) currently in operation at BNL's, Source Development Laboratory (SDL), of the NSLS department. The NISUS undulator requires extensive diagnostic capability to assure generation of SASE light for non-seeded or seeded operation with the anticipated upgrade to High Gain Harmonic Generation (HGHG). The design of the e-beam and laser in vacuum diagnostics was challenging due to the fact that all of the sensing components resided in the undulators gap and had to be compatible with an existing vacuum chamber. Budget constraints and the required quantity (18) made a highly reliable, multifunctional, economic design paramount. The pop-in monitors are novel, low cost in vacuum diagnostic devices that perform the following functions: Laser alignment, e-beam trajectory, e-beam position and e-beam profile monitoring using visible YAG and optical transmission radiation (OTR) emission, emittance measurement, and FEL light sampling. The reproducibility of ± 1 CCD pixel with a resolution of 9 microns has been achieved. Using these devices, operators were able to achieve SASE operation in record time.

Keywords: SDL, NISUS, SASE, diagnostic, pop-in monitors

1. Introduction

The NISUS undulator is an integral part of the Deep Ultraviolet Free Electron Laser (DUVFEL) that is currently in operation at the Source Development Laboratory of the Brookhaven National Laboratory.

The Nisus undulator forms the radiator section for a self amplified spontaneous emission (SASE) coherent Light Source. An upgrade to high gain harmonic generation (HGHG) is anticipated. To perform appropriate steering of the electron beam trajectory through the undulator to achieve lazing, the DUVFEL employs a variety of diagnostic devices and systems. This paper presents an overview of the mechanical components and systems involved in beam diagnostic and alignment systems of the SDL's DUVFEL.

---

2. The In-Vacuum Iris on Axis Diagnostic/System Alignment

A variety of criteria must be achieved to assure SASE and HGHG operation at the DUVFEL. One criterion is extreme alignment accuracy of the electron beam and an in-coupled seeded laser beam with respect to the magnetic axis of the 10-meter long NISUS undulator. Unlike many wiggler magnets where flat magnet poles are used giving uniform horizontal fields, the poles of NISUS are canted and an exact center is defined so that alignment tolerances tend to be more stringent than other wigglers. Electron/Photon trajectory to magnet axial alignment must be coaxial to within 50 microns to achieve adequate coupling for SASE and HGHG lazing. In an earlier work [1-4] optical alignment was achieved by use of coaxial iris's that defined the beam line axis that aligned with the magnetic field center of the wiggler magnet and the Seed Laser Beam. With the use of dipole magnets on either end of the experiment these iris's are placed on monuments outside of the vacuum chamber making alignment readily achievable.

Figure 1 depicts the DUVFEL beam line. Due to the size of the NISUS undulator there is no convenient line of sight that disallows on axis survey alignment. It was necessary to locate the laser beam/electron beam axis defined by the aperture of the iris inside the vacuum system, on either end of the NISUS undulator.

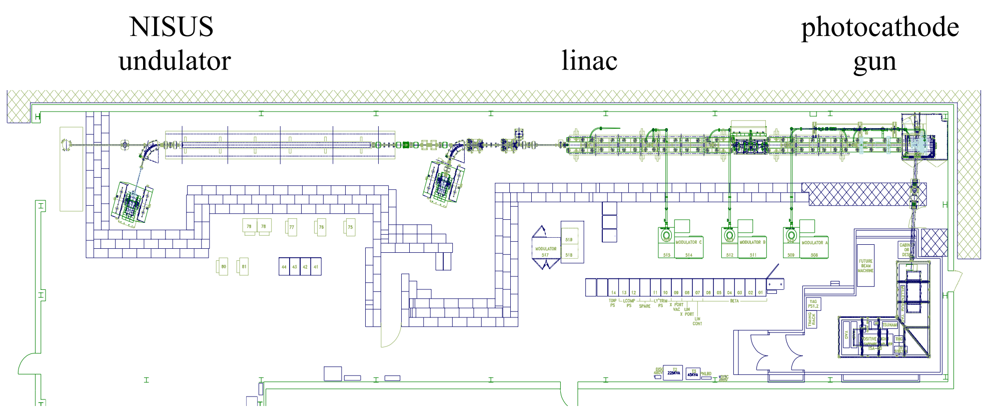


Fig. 1: DUV-FEL on SDL beamline.

Figure 2 shows a photograph of the iris cube. A linear actuator controls the iris. Ports on either end of the cube allow for observation of the on axis alignment laser impinging on the iris. A pre-survey is performed and the cubes are positioned onto the beam line. On the down beam side of the iris in each cube is a fiducialized YAG crystal beam position monitor that is used to assure that the electron and photon beams are coaxial through each iris.

Fig. 2: In-vacuum iris cube.

This precision alignment step is necessary to locate the main beam diagnosis in the NISUS undulator. Knowing the alignment laser is on axis thereby defines the beam line axis on each of the in NISUS beam diagnostic monitors. As long as the alignment laser spot as produced by the BDM is reproducible, a frame grabber can be used to define the beam spot as it appears on the monitor as the electron beam axis. In this way the individual BDM monitors do not need to have long term absolute alignment accuracy of 10 microns which is impossible given the constraints of the system at hand. This greatly simplifies NISUS operation, since each monitor only has to be reproductable to within 10 microns for relatively brief periods between alignments.

3. Alignment Laser System

Early in is the design of the DUVFEL it became apparent that an on axis laser alignment system would be necessary to define the electron beam axis.

The critical requirement for this laser system is alignment with a required angular reproducibility of ± 1 micro radiation.

It was necessary for this reproducibility to be achieved by an in vacuum injectable, stepper motor activated mirror assembly. The incoupling mirror slides on a set of ultra precision parallel cylinders. The laser beam is steered out side of the vacuum chamber by remote actuators until the laser beam is on axis through the Nisus undulator and coaxial with the in-vacuum iris's.

4. NISUS Beam Diagnostic Monitor (BDM Pop-in) Capabilities

The NISUS wiggler is a ten-meter long device with 17 monitoring positions. Each monitor provides a number of functions.

- Alignment Laser

The units are used to monitor the relative position of the on axis alignment laser that is described above. It is used in conjunction with a computerized frame grabber and energized steering element in the nisus beam tube and to steer the e-beam through the NISUS undulator.

- Beam Position / Profile

The unit is used to monitor the position, profile, and focus, of the electron beam at multiple locations along the NISUS undulator.

- Spontaneous Radiation Monitor

The unit is used observe and sample the spontaneous synchrotron and SASE emission as they develop along the length of the undulator.

- OTR and Beam Energy Monitors

Optical transmission radiation (OTR) is produced any time an electron pulse passes through conductive surface. It is an excellent diagnostic to observe fine detail in the profile of the electron beam as it undulates through NISUS. Beam energy sampling as well as transmissibility measurements, at each of the diagnostic ports were desirable. All these requirements had to be incorporated into a package that would fit into a prefabricated vacuum chamber, cost constraints and the large number of BDM monitors required a unique yet simple design.

5. BDM Operation

Figure 3 depicts the detailed design of what is commonly called the "pop-in assembly." A three position linear actuator drives a periscope assembly in and out of the NISUS vacuum chamber. A triangular mirror is used so as to allow light to exit the chamber in either direction. The cost of the purchased items for each of the pop-in assemblies is less than $2000.

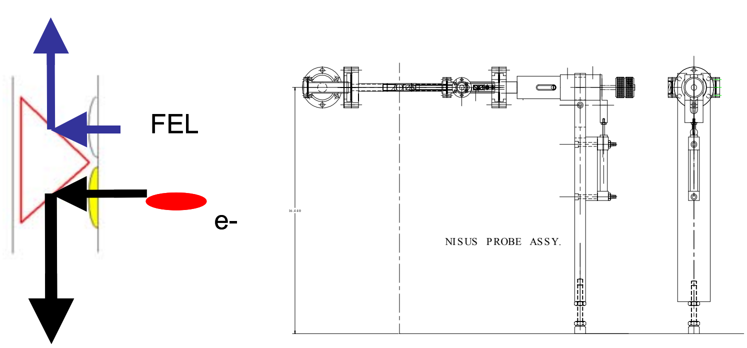
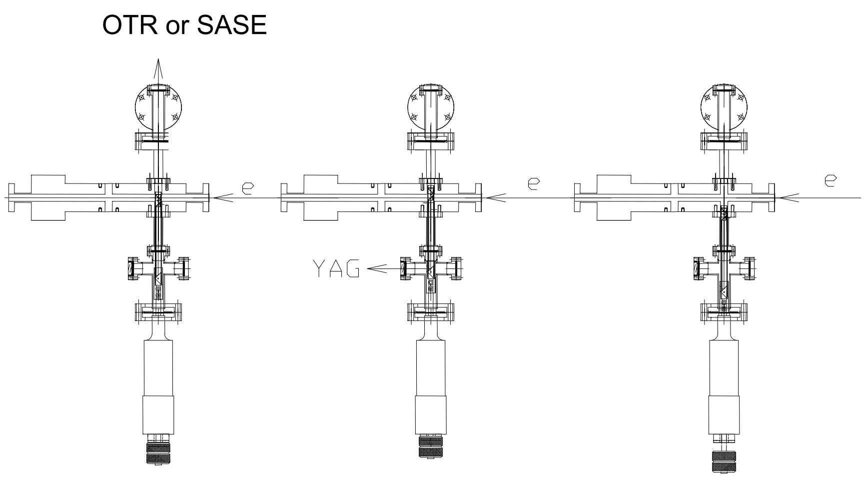


Fig. 3: BDM pop-in design.

Figure 4 depicts the various positions of operation. In Figure 4B the monitor is in its maximum injected position. A disk of YAG crystal is used to observe the electron beam profile. A precision fiducialization plate is used to support the YAG crystal and is used to check to reproducibility of the pop-in relative to the alignment laser. In Figure 4C the monitor is out of the beam. In Figure 4A the forward mirror is positioned in the beam to sample synchrotron radiation or to sample SASE emissions. About one quarter of the monitors in NISUS have a thin titanium foil to block out any propagating beams spontaneous radiation yet allowing the electron beam through to the mirror. These devices are called shadow-shields. This is necessary due to the fact that it is very difficult to separate out the two signals. Generally, the intensity of the OTR signal may be only 0.1% of the spontaneous emission. Spontaneous radiation and FEL light exit the BPM along with OTR in the unshadow-shielded BDMs. The BDMs with the shadow shield allow only OTR light to exit the forward (north) window, which is detected by a high-resolution CCD camera. The image of the alignment laser and light emitted from the e-beam's interaction with a YAG crystal is extracted via the south window. Figure 5 depicts the image as seen on the fiducialized YAG crystal.

A variety of monitor assemblies are used on either side of the NISUS undulator. On the south side of NISUS at each of the diagnostic output ports an in-vacuum periscope and two external mirrors are used to reflect the light produced by the YAG



A B C

Fig. 4: BDM operating positions.

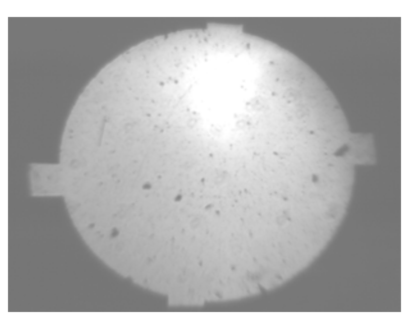


Fig. 5: View of YAG crystal and fiducialization plate.

screen into a "CCD" camera. The pop-in assemblies and south side cameras are primarily used to determine the e-beam position relative to the on axis alignment HeNe laser. This diagnostic has proven itself essential for "e" beam steering through NISUS. On the north side of NISUS several different detectors are used. Diode detector are used to measure the total energy of light exiting the beam chamber at each diagnostic output port. These small detectors are used in conjunction with "CCD" cameras to detect and resolve the SASE emission beam profile and energy. The light from the forward in-vacuum mirror is measured by the detector. A commercially available flipper mechanism has been automated and can be used to reflect the light signal into a high resolution CCD camera which can be focused onto the in vacuum mirror surface. Radiation emitted from the mirror surface may be imaged. On several of the pop-in assemblies very fine wires (10 microns thick) have been attached to a special insert just above the surface of the mirror. The camera is manually focused until these fine wires are resolved visually. In this manor changes in the CCD image can be resolved. By digitizing the image with a frame grabber, a check can be made of the shot to shot reproducibility of the subject pop-ins. Reproducibility studies have demonstrated that pop-in and laser spot position reproducibility of less then 10 microns can be achieved over hundreds of cycles.

To focus light emitted either from the south side YAG crystal or the north side mirror into the respective detectors a focusing lens was needed. The lens holder need to have greater than ± 3 mm X,Y and ~10 mm Z travel. This used to provide the user with local steering correction and longitudinal focusing adjustment. No commercially available unit could be found to supply the desired adjustability in the restricted space of the undulators magnet gap. An alloy aluminum flex element was designed and prototyped that gave the desired adjustment. Figure 6 is a photograph of the device. This design has been applied to many applications throughout the SDL.

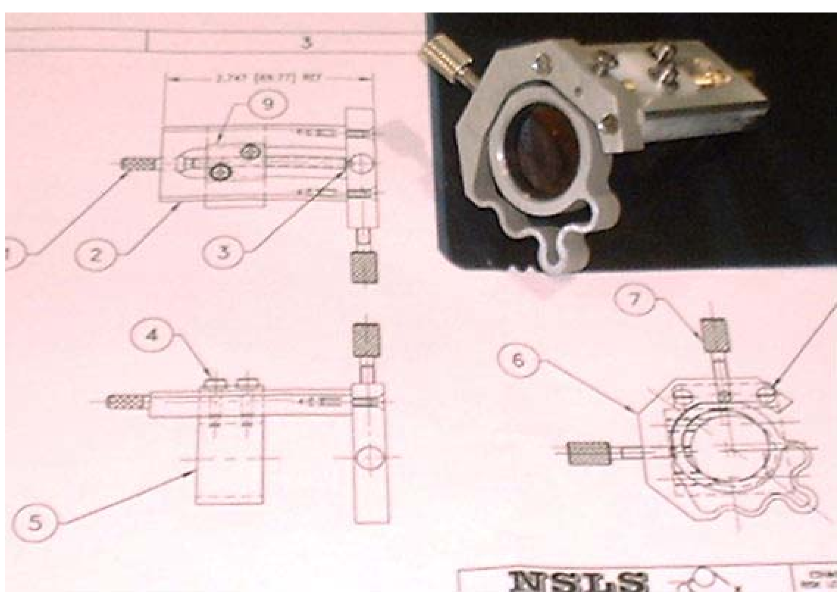


Fig. 6: NISUS adjustable diagnostic/lens holder.

6. Flange Mounted Detectors

Two versions of flange mounted detectors were developed. This was done for the simple reason that there was a serious lack of space in the NISUS magnet gap area so photo detectors were designed to mount directly to the output windows of the NISUS vacuum chamber extensions. Each mount incorporates the aluminum flex element for alignment. Remote filtering was also desired so a Geneva mechanism and a custom filter wheel were employed in the design.

Figures 7 and 8 shows these two devices in place mounted to the output ports of the NISUS vacuum chamber.

Fig. 7: Flange mounted detector.

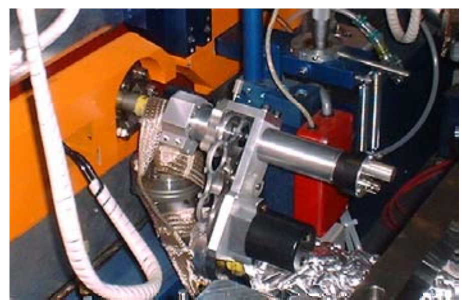


Fig. 8: Flange mounted detector with a remote filter wheel.

7. Conclusion

In this paper we have briefly described the design and operation of a number of mechanical devices including the NISUS Magnet Diagnostic monitor or BDM's used for the electron beam and photon beam diagnostics of the DUV-FEL at Brookhaven's Source Development Laboratory. We have described the on Axis laser alignment system and how the BDM's are used to measure beam position as well as sample both spontaneous emissions, SASE energy, and SASE beam profile as a function or position along the NISUS undulator. The BDM can also be configured to produce an OTR signal for a high-resolution image of the electron beam profile. We have shown that a simple relatively inexpensive device can provide a wealth of information. These devices have been proven essential for beam steering through the 10-meter long NISUS undulator, and this design may find uses in other applications where long small gap undulators are in use.

8. Acknowledgements

Special thanks goes to the technical staff of the SDL Group, Phil Marino, Joe Greco and the NSLS Mechanical staff, Rodger Hubbard, Bill Bambina, Sorin Pop, and Don Shea. For the assembly and trouble shooting of these devices as well as the vacuum group personnel, Walter DeBoer, Mike Caruso, Malry Tardd, and Pete DeToll for installation.

9. References

[1] T. V. Shaftan, A. Doyuran, H. Loos, L. H. Yu, S. Mikhailov, J. Skaritka, S. Krinsky, W. Graves, B. Sheehy, E. D. Johnson, J. Wu, J. Rose, Z. Yu, J. Rakowsky, "Beam-based Trajectory Alignment in the NISUS Undulator," Proc. of EPAC2002, 837-839 (2002).

[2] A. Doyuran, W. Graves, E. D. Johnson, S. Krinsky, H. Loos, J. Rose, J. Skaritka, T. V. Shaftan, B. Sheehy, J. Wu, L. H. Yu, G. Rakowsky, "Diagnostic System for the NISUS Wiggler and FEL Observations at the BNL Source Development Lab," Proc. of EPAC2002, 802-804 (2002).

[3] A. Doyuran, M. Babzien, T. Shaftan, S. G. Biedron, L. H. Yu, I. Ben-Zvi, L. F. DiMauro, W. Graves, E. Johnson, S. Krinsky, R. Malone, I. Pogorelsky, J. Skaritka, G. Rakowsky, X. J. Wang, M. Woodle, V. Yakimenko, J. Jagger, V. Sajaev, I. Vasserman, "Characterization of a High-Gain Harmonic Generation Free-Electron Laser at Saturation," Phys. Rev. Lett. 86, 5902 (2001).

[4] L.-H. Yu, M. Babzien, I. Ben-Zvi, L. F. DiMauro, A. Doyuran, W. Graves, E. Johnson, S. Krinsky, R. Malone, I. Pogorelsky, J. Skaritka, G. Rakowsky, L. Solomon, X. J. Wang, M. Woodle, V. Yakimenko, S. G. Biedron, J. N. Galayda, E. Gluskin, J. Jagger, V. Sajaev, I. Vasserman, "High-Gain Harmonic Generation Free-Electron Laser," Science 289 (2000) 932.