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Alignment of the VISA Undulator ♦

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Abstract

As part of the R&D program towards a fourth generation light source, a Self-Amplified Spontaneous Emission (SASE) demonstration is being prepared. The Visible-Infrared SASE Amplifier (VISA) undulator is being installed at Brookhaven National Laboratory. The VISA undulator is an in-vacuum, 4-meter long, 1.8 cm period, pure-permanent magnet device, with a novel, strong focusing, permanent magnet FODO array included within the fixed, 6 mm undulator gap. The undulator is constructed of 99 cm long segments. To attain maximum SASE gain requires establishing overlap of electron and photon beams to within 50 μm rms. This imposes challenging tolerances on mechanical fabrication and magnetic field quality, and necessitates use of laser straightness interferometry for calibration and alignment of the magnetic axes of the undulator segments. This paper describes the magnetic centerline determination, and the fiducialization and alignment processes, which were performed to meet the tolerance goal.

Zusammenfassung

Als Teil eines Forschungs- und Entwicklungsprogrammes mit dem Ziel des Baus einer Synchrotron-Lichtquelle der vierten Generation wird eine Demonstration des "Self-Amplified Spontaneous Emission (SASE)" Effektes vorbereitet. Hierzu wird zur Zeit am Brookhaven National Laboratory im Bundesstaat New York der "Visible-Infrared SASE Amplifier (VISA)" Undulator aufgebaut. Der VISA Undulator besteht aus 4 je 99 cm langen Segmenten, die von einem Vakuum Container umschlossen sind. Der Undulator hat eine Periode von 1,8 cm, die von Permanentmagneten erzeugt wird. Desweiteren ist ein neuartiges, stark fokussierendes FODO Magnetfeld, das auch ausschließlich von Permanentmagneten angeregt wird, in das nur 6 mm weite Magnetgap integriert. Um eine maximale SASE Verstärkung zu erzielen, müssen die Elektronen- und Photonenstrahlen sich innerhalb eines Bereiches von 50 μm überlagern. Diese Anforderung bedingt herausfordernde Toleranzen für die Herstellung und die Magnetfeldqualität. Diese können nur eingehalten werden unter Verwendung von Geradheitsinterferometrie für die Kalibrierung und Vermessung der magnetischen Achsen der Undulatorelemente. Dieser Bericht beschreibt die Bestimmung der magnetischen Achse, und die Verfahren zur Bestimmung der Referenzmarken und der Einrichtung.

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1 Introduction

The four-meter long undulator consisting of four 99 cm long segments is supported on a strongback and mounted inside a vacuum vessel.[1] The undulator segments need to be aligned to 50 μm with respect to each other so that maximum **S**elf-**A**mplified **S**pontaneous **E**mission (SASE) gain can be attained.[2] To accomplish successful alignment[3] three major tasks need to be completed: firstly, the undulator segments need to be fiducialized, secondly, the segments need to be aligned, at first conventionally with respect to the global beam line coordinate system and then interferometrically with respect to their common axis, and lastly, the beam of a laser (**R**eference **L**aser **B**eam - RLB), which will provide the reference for the diagnostic pop-in monitors[4], has to be pointed such that it becomes collinear to the undulator axis.

2 Error Budget

The fiducialization and alignment residuals have to be kept to less than 50 μm. The first two entries in the total budget come from the fiducialization process, positioning and RLB alignment being the remaining contributions. Their associated projected errors are shown in the Table 1 and, added in quadrature, come very close to the desired final residual of 50 μm.

Alignment Error Budget	*projected*	*achieved*
	/μm/	/μm/
Magnetic Centerline Determination	20	10
Transfer onto Fiducials	23	8
Positioning	28	20
Setup RLB with respect to Undulators	29	
Total (added in quadrature)	51	

Table 1: Tolerance Budget

3 General Approaches

3.1 Fiducials

Fiducials are measured independently and are considered as such for both horizontal and vertical coordinates. To obtain micron type results, great care must be taken to avoid any kind of first order errors. Hence, in high precision industrial metrology, measurements are always taken in the principal plane, i.e. horizontal measurements are carried out

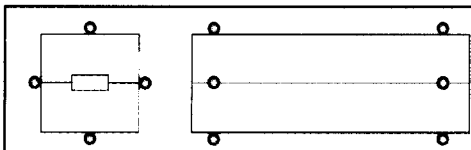


Fig. 2 Undulator fiducials

in the horizontal plane and vertical measurements in the vertical plane, respectively. Consequently, the undulator is designed to have the horizontal fiducials on the side and the vertical fiducials on the top. For redundancy reasons tooling balls are also placed on the other sides (see fig. 2).

3.2 Determining the Magnetic Centerline

The high tolerances preclude the traditional mechanical approach to locate the centerline. Instead, it is necessary to determine the true centerline based on magnetic properties. Because of the limited aperture, a pulsed wire system was chosen as the primary measurement tool[5]. Since wire sag would affect measurements in the vertical plane, vertical plane measurements are transformed into horizontal plane measurements by rotating the segments by 90°. It should also be noted that earth's field effects need to be compensated for by enclosing the setup in a Helmholtz coil.

3.3 Straightness Measurements

The extremely tight alignment tolerance precludes the application of traditional high precision optical alignment methods. Instead, a standard HP straightness interferometer in "long distance" mode (0.5m - 30m) will provide a straightness resolution of 0.8 μm with 5 μm accuracy over the length of the undulator, and a straightness measurement range of ±1.5 mm. This method is one dimensional, i.e. horizontal and vertical positioning is accomplished using two independent straightness interferometer systems.

4 Instrumentation

4.1 Pulsed Wire System

To measure and correct trajectory errors, and to determine the magnetic centerline, a pulsed wire system[6] was chosen as the primary measurement tool. Two undulator segments are set up on a granite table for stability. The segments are supported the same way as in their final installation. Smaller granite blocks sit atop the ends of the table, supporting the 4 m long wire, the oil bath damper, one Wire Finder each at both ends of an undulator segment pair, and the wire pulse detector. The setup is shown in Figure 3. The wire is threaded through the undulator segments, fixed at one end, and then tensioned by a weight at the other end after being deflected over a pulley. A High Voltage

Fig. 3 Pulsed Wire Bench Setup

Pulser sends a current pulse through the wire. The Lorentz force of the transverse field of the undulator segment's quadrupoles induces a mechanical transverse impulse, which causes a displacement wave to propagate down the wire. The wire pulse detector sees the signal as a displacement of the wire. The pulse's timing resolution provides the longitudinal parameter. The distorted pulses are displayed on an oscilloscope (see fig. 4) and provide an instant image of the trajectory thus becoming an excellent null-finding indicator for locating the magnetic axis.

4.2 Measuring Straightness Offsets

Straightness Interferometer

To measure straightness in contrast to distance measurement interferometry the reflector is held fixed, and the Wollaston prism moves along the object being measured. Since the interferometer counts fringes, the beam signal must never be interrupted, e.g. due to a deviation of the Wollaston prism from the beam or by blocking off the beam transport, since this would cause the interferometer to lose count. A guide rail moves the Wollaston prism parallel to the measurement object, and an interface between the prism and the fiducials is needed. A constant distance rod can realize such an interface. Whenever the prism is in the longitudinal vicinity of a fiducial, the rod is inserted between the Wollaston prism and the fiducial. To facilitate the insertion of the rod and to provide constant measurement conditions, the Wollaston prism is mounted on a cross slide. In addition, to ease the placement of the rod, both ends have a sleeve, which fits loosely over the tooling ball on the undulator as well as the one on the prism (see fig. 5, sleeves are not shown). However, this implementation does not provide any indication of when the rod is truly perpendicular to the interferometer beam. Fortunately, this is not a new and unique problem, being also a condition typical to optical tooling measurements.

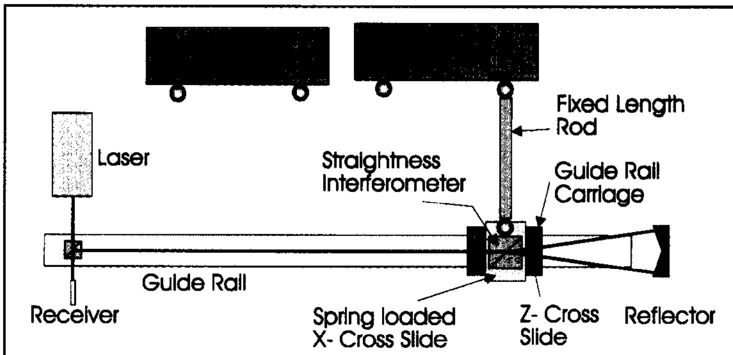


Fig. 5 Interferometer implementation

Arcing

When arcing the smallest scale value is read when the scale is perpendicular to the line of sight. The arcing can be implemented in this set-up by slowly moving the Wollaston prism in Z direction while watching the straightness interferometer read-out (see fig. 6). An additional motor driven stage was added between the carriage and the X cross slide. In this configuration, the carriage is moved by hand to a position of about an inch before a measurement point (see fig. 7). Then the Z stage drive is engaged, which moves the Wollaston prism across the unknown measurement point (see fig. 8). A computer interfaced to the drive read-out and the interferometer readout records coordinate pairs (z, x) over this distance. Subsequently, a simple circle fit not only solves for the true measurement point and thus for the shortest distance, but also improves the significance of the solution by fitting many readings[7].

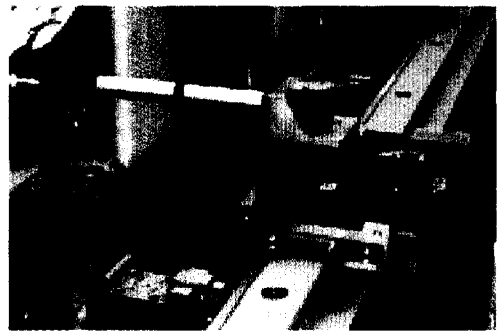


Fig. 8 Arcing rod attached to cross slide

4.3 Locating the Wire Position

As described above, a "pulsed-wire" bench is used to determine the magnetic centerline. The wire position on either side of an undulator pair will be detected with Wire Finders (see fig. 9). The position measurement is carried out in one plane at a time with one device on either side of the undulator. Each wire finder is mounted on a frame, which sits perpendicular to beam direction on the undulator support plate during magnetic measurements. Each frame carries two tooling balls in the measurement plane in the same geometry as the tooling balls

Fig. 9 Laser based Wire Finder

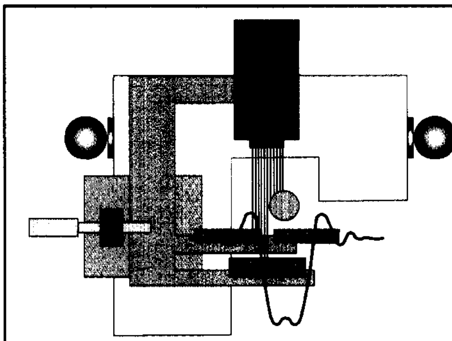


Fig. 10 Wire Finder Schematic

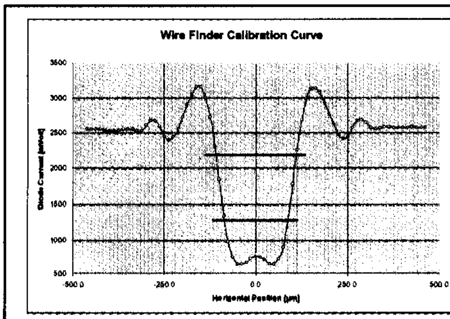


Fig. 11 Wire Position Determination

on the undulator. A laser-based design allows detecting the wire position without touching it (see fig. 10). The device consists of a laser emitter mounted so that the emerging beam will pass through a slit across the wire to a receiver on the other side. After measuring the intensity of the signal received, a computation based on the signal profile will provide an accurate determination of the wire position (see fig. 11).[8]

4.4 RLB Laser Finder

A laser beam cannot be picked up accurately by standard mechanical alignment instrumentation. Therefore, a tool was needed that would reference an optical beam to mechanical fiducials[9].

The Laser Finder (LF) (see fig. 14) consists of a frame, which carries four tooling balls in the same geometry and dimensions as they are when mounted to the end of an undulator. A quadrant detector is mounted to the center of the frame within a few hundred µm. The quadrant detector will give a read-out of the beam position in the quadrant detector's coordinate system.

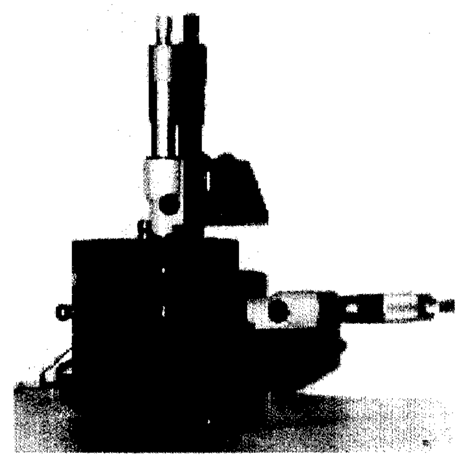


Fig. 14 Laser Finder Implementation

The Laser Finder is built as a nulling device. The quadrant detector is mounted on a two-dimensional cross slide. The position of the quadrant detector can be adjusted by micrometers horizontally and vertically. The quadrant detector sums the laser intensity readings on each of the two halves of the sensitive surface and then compares the two. This arrangement is subsequently electronically rotated 90° to measure the other dimension. The detector's coordinate system needs to be related to the tooling ball coordinate system through calibration measurements.

5 Alignment Process

First, conventional alignment methods will be used to support mechanical installation. This step will align the undulator with respect to the global beam line coordinate system and with respect to the common axis with an accuracy of about 150 – 200 µm.

A dual straightness interferometer setup is used to measure the position of the undulator tooling balls relative to the arbitrary straightness interferometer reference line. A special alignment jig was designed to facilitate the setup and alignment of the two straightness interferometers, one vertical and one horizontal (see fig.).

Fig. 23 VISA test installation with jig

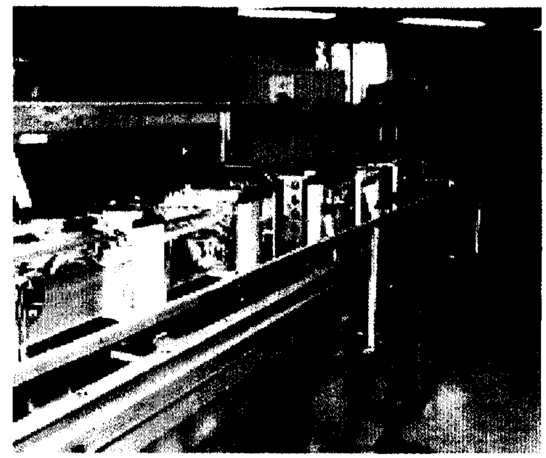
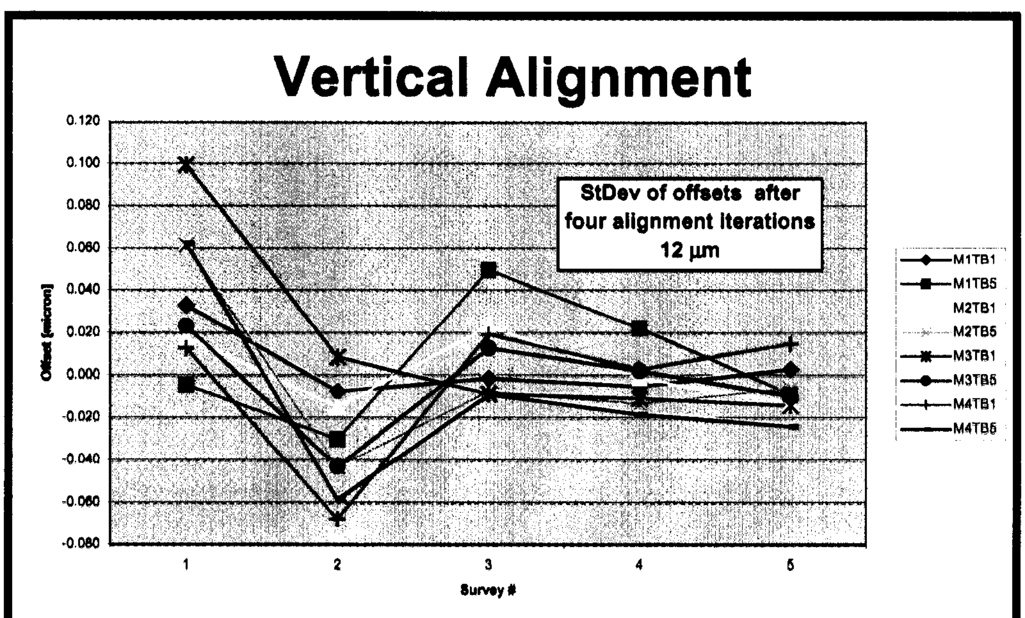


Fig. 26 Alignment jig with SI lasers

To create an accurate snap shot of an undulator segment's position, the horizontal and vertical straightness interferometer readings are taken simultaneously. It should be stressed again that the straightness interferometer is only a relative measurement tool. The capability to align the undulators to an absolute position is only provided through conventional alignment.

8 Conclusion

Actual fiducialization measurements have confirmed that the "Magnetic Centerline Determination" and "Transfer onto Fiducials" tolerances cannot only be met, but at least cut in half. The alignment jig has been assembled and successfully tested. A first alignment run demonstrated that the alignment system works as designed and that the alignment iterations converge. A final alignment will proceed in February.



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Anschriften

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