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AN INSTRUMENT DESIGN FOR THE ACCURATE DETERMINATION OF THE ELECTRON BEAM LOCATION IN THE LINAC COHERENT LIGHT SOURCE UNDULATOR*

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Abstract

The Linac Coherent Light Source (LCLS), currently under design, requires accurate alignment between the electron beam and each undulator's magnetic centerline. A beam finder wire (BFW) instrument has been developed to provide beam location information that is used to move the undulators to their appropriate positions. A BFW instrument is mounted at each of the 33 magnets in the undulator section. Beam detection is achieved by electrons impacting two carbon fiber wires and then sensing the downstream radiation. The wires are mounted vertically and horizontally on a wire card similar to that of a traditional wire scanner instrument. The development of the BFW presents several design challenges due to the need for high accuracy of the wires' locations and the need for removal of the wires during actual operation of the LCLS (30 microns repeatability is required for the wire locations). In this paper, we present the technical specification, design criteria, mechanical design, and results from prototype tests for the BFW.

INTRODUCTION

The Linac Coherent Light Source (LCLS), currently under design, requires accurate alignment between the electron beam and each undulator's magnetic centerline. A beam finder wire (BFW) instrument has been developed to provide beam location information that is used to move the undulators to their appropriate positions.

The primary function of the BFW system is to provide a high-resolution beam location reference signal that can be input into the positioning mechanism system for each magnet in the beam undulator system. The sensing signal will be generated either by indirect radiation monitoring downstream of the BFW or by measuring the charge on the wires due to the direct impact of the electron beam on the wires.

The design described herein is for reduced power operation where the free-electron laser (FEL) intensity is not strong enough to damage the wires. The development of practical and reliable beam locating instruments that meet the required positioning accuracy, survivability under severe beam conditions, and operation in an ultrahigh-vacuum environment present several engineering design challenges.

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SPECIFICATIONS

We derived the engineering specifications of the BFW from the electron beam parameters for LCLS undulators [1] and the physics requirements [2]. Table 1 gives the relevant parameters and requirements.

Table 1: Summary of Physics Requirements [2].

Parameter	Value	Unit
Number of wires per BFW device	2	
Wire perpendicularity	10	mrad
Wire diameter	0.040	mm
Wire material	C	
Vertical position of Y-Wire from the BA	0.20	mm
Horizontal position of X-Wire from the BA	0.40	mm
Vacuum hardware clearance radius at target	>2	mm
Number of independent signal detection methods	2	
Y-Wire horizontal insertion reproducibility	30	µm
X-Wire vertical insertion reproducibility	80	µm
Roll, pitch, and yaw tolerance	10	mrad

Note: the X-Wire is vertically oriented and measures the X position, while the Y-Wire is horizontally oriented and measures the Y Position.

General Requirements

The BFW operates in two modes, active and inactive. In the active mode a pair of wires will be inserted into the vacuum chamber close to the beam axis. In the inactive mode the wires are removed from the beam path.

Wire Requirements

Each BFW has two wires that can interact with the electron beam when in active operation mode. The wires are oriented in the vertical and horizontal directions, within a roll-angle accuracy of 6 mrad (= 0.02 mm / 3.5 mm). The cross-sectional diameter of the wires is 40 µm. A smaller wire diameter would be fragile and its position would be difficult to detect for fiducialization. A larger wire diameter would result in generation of radiation damaging to the undulator magnets.

The horizontally oriented wire (Y-Wire) is used for the vertical alignment of the undulator segment, while the

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vertically oriented wire (X-Wire) provides horizontal alignment. The wire material is carbon.

Wire Locations

The Y-Wire shall be located 0.20 +/- 0.02 mm vertically off the beam axis as shown in Figure 1. The X-Wire shall be located 1.00+/-0.05 mm horizontally off the beam axis as shown in Figure 1. Any vacuum hardware needs to clear a radius of at least 2 mm around the beam target location during the beam detection process.

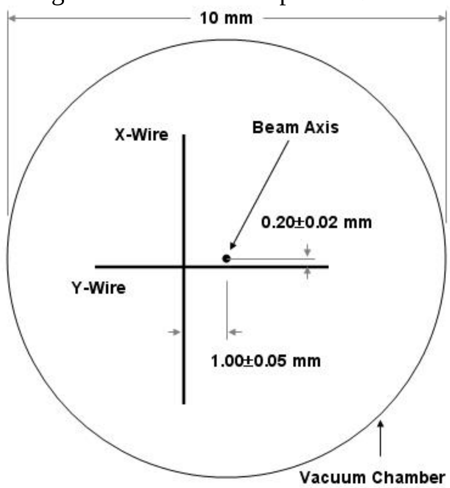

Figure 1: Schematic diagram of the positions of the X- and Y-Wires with respect to the girder axis when the system is fully aligned.

Beam Detection Requirements

For each plane there are two independent methods used to measure the beam intensity at the wire location: (1) beam-induced wire current and (2) scattered particles. In order to allow independent intensity measurements on either wire, both wires are electrically isolated and independently equipped with readout electronics.

Wire In/Out Motion Requirements

The reproducibility of the vertical position of the Y-Wire, which has been extracted and reinserted, must be better than 30 µm. The reproducibility of the horizontal position of the X-Wire, which has been extracted and reinserted, must be better than 80 µm.

MECHANICAL DESIGN

General Layout

A beam finder wire (BFW) device, as specified in this document, close to the upstream end of the undulator segment and a quadrupole close to the downstream end will allow for beam-based undulator segment alignment, which can be accomplished from the control room without the need for tunnel access.

The function of the BFW can be summarized as follows: The BFW will be mounted upstream of each undulator segment and fiducialized so that its horizontal and vertical wires will have a fixed and known position with respect to the beam axis. The beam axis is parallel to and coincides with the undulator axis when the undulator segment is in its neutral position. The BFW position will be remotely controllable through the motion of the undulator support base, but is not affected by the horizontal slide motion of the undulator segment. When the BFW is to be used for undulator segment alignment, the electron beam will be brought into collision with the two wires, one at a time, by moving the BFW-undulator segment arrangement. The amount of beam hitting the wire will be measured either via the beam-induced current on the wire or by detecting scattered particles downstream of the wire. After the relative position of the beam with respect to the wire has been set in this way, the wires will be extracted. As a result, the undulator segment will then be aligned to the electron beam. The layout of the break between two undulator sections is shown in Figure 2.

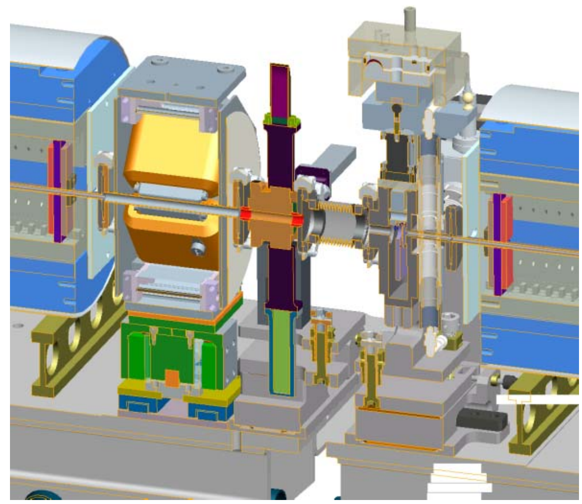

Figure 2: General layout of break between undulators.

BFW Design Description

The nature of the required functioning of the BFW lends itself to a two-position mechanism, i.e. wire in beam and wire out of beam. A simple approach to this design is the use of classic three-point kinematic stops for accurate positioning of the wires.

The BFW assembly is shown in Figure 3. A top frame assembly is mounted to the vacuum chamber that contains the wire card. A pneumatic cylinder pushes up on the bottom kinematic plate, which then engages into the upper kinematic plate that is attached to the fixed frame. The bottom kinematic plate is attached to rods that run down through the bellows and is attached to the wire card holder. Therefore, an upward actuation of the pneumatic cylinder raises the wires into the beam. The wires are accurately located with respect to the beam centerline as a result of the engagement of the kinematic plates. When the cylinder is deactivated the wires move down out of the beam path.

Alignment of the wires to the undulator centerline is accomplished by precision adjustment screws that locate the upper kinematic plate relative to the fixed frame. Fiducials mounted on the wire card, external slide, and undulators are used for alignment references both on bench and in-field adjustments.

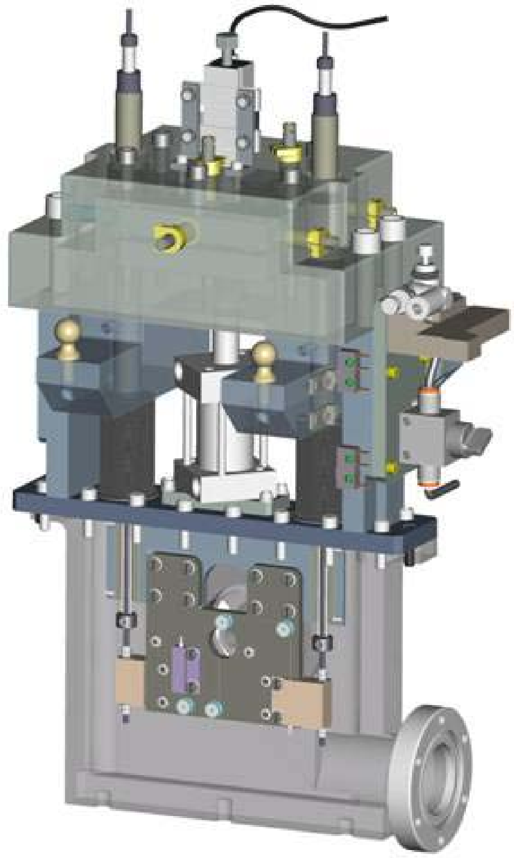

Figure 3: BFW assembly.

Electrical connections run from the beam detection wires up to feedthrough connectors mounted at the top of the hollow lifting rods. A pneumatic solenoid is mounted to the of the unit for control of the cylinder. A linear potentiometer is mounted at the top of the unit and is used to detect that the kinematic plates are properly engaged when in the up position.

PROTOTYPE TESTS

Prototype Description

A prototype unit was constructed as shown in Figure 4. The primary purpose of the prototype testing was to determine that the wires can be accurately located under repeated up-down operation. Laser displacement sensors accurate to +/- 0.5 µm were used to measure the movement of the kinematic plates in order to determine the required repeatability of the wires. A vacuum chamber was installed at the bottom of the assembly to simulate operation under forces resulting from the vacuum condition.

Figure 4: Prototype assembly.

Prototype Results

The results of the testing indicated that the horizontal wire placement could be repeated to within +/- 7 µm and that the vertical wire could be repeatedly located to within +/- 14 µm. Also, the tests showed that the wires could be adjusted to within +/- 2 µm. The overall performance of the prototype was very satisfactory and showed that the design was durable and robust.

STATUS AND CONCLUSION

Thirty-seven production BFWs are currently being fabricated. Mounting of the carbon wires on the wire card still poses some challenges. Detailed assembly and alignment procedures need to be completed.

Completion of the first three units is scheduled for September 2007. To date, part fabrication has gone well, and we expect to start assembly this August.

REFERENCES

[1] LCLS online parameter database, http://www-ssrl.slac.stanford.edu/htbin/rdbweb/LCLS_params_DB_public/

[2] H. Nuhn, “LCLS Physics Requirement Document # 1.4-004, Undulator Beam Finder Wire” Stanford Linear Accelerator Center, September 2005.