LCLS Physics Requirements Document	1.4-002	Undulator	Revision 0

Magnetic Measurements Facility Requirements

Robert Ruland Author	Signature	7/19/05 Date
Zachary Wolf Author	Zach Wolf Signature	7/19/05 Date
Steve Milton Undulator WBS Manager	Signature	19 July 05 Date
Heinz-Dieter Nuhn System Physicist	Heinz-Dieter Nuhn Signature	7/19/05 Date
James Welch System Physicist	Signature	7/25/05 Date
David Schultz E-Beam Systems Manager	DCSchultz Signature	7/26/05 Date
Paul Emma Accelerator Physics Team Leader	Paul Emma Signature	7/21/05 Date
Darren Marsh Quality Assurance Manager	Signature	7/19/05 Date
John Galayda Project Director	John Galayda Signature	7/26/05 Date

Brief Summary

This specification summarizes the physics requirements for the LCLS Magnetic Measurement Facility. These include requirements for undulator measurements and fiducialization and also quadrupole strength measurements and fiducialization.

Change History Log

Rev Number	Revision Date	Sections Affected	Description of Change
000	7-12-05	All	Initial Version

Introduction

A new facility will be built to perform the LCLS magnetic measurements. The measurements which will be performed in the facility are specified. Because of the accuracy required, specialized equipment must be used. Requirements for these instruments are also included.

Magnetic Measurement Facility

The LCLS will require very demanding magnetic measurements. At present, SLAC does not have a magnetic measurement facility capable of performing the LCLS measurements. Therefore, a new magnetic measurement facility will be built at SLAC. Final tuning of the undulators and all fiducializations will be done right before installation. Having the facility at SLAC also allows rapid checks of any components which are not operating properly. Periodic checks of components can be made to look for ageing.

In addition to the undulators, the LCLS quadrupoles also require demanding magnetic measurements. Because of the very tight alignment requirements, very accurate fiducialization measurements must be made.

Detailed requirements for the magnetic measurement facility have been given in technical note LCLS-TN-04-1. This note emphasizes, in particular, the temperature stability requirements of the facility. In order to set the K value of the undulators, the temperature of the laboratory must stay at the desired set point to 0.1 degrees C. Because the undulators will be measured over many months, we require 0.1 degree C long term temperature stability. A sophisticated climate control system is necessary to meet these requirements. A number of other requirements for the facility are given in the technical note.

Undulator Tuning

The LCLS will consist of 33 undulator magnets plus spares. These magnets must be tuned in the magnetic measurement facility. The process of undulator tuning is fully described in technical note LCLS- TN-04-7 “Introduction to LCLS Undulator Tuning”. The note includes an extensive discussion of errors in undulators and the tools used to correct them.

The primary measurement device used in tuning will be a precision Hall probe. The Hall probe must be contained in a small package to fit in the undulator gap. It must measure at least two components of the magnetic field. It must also maintain its calibration for at least several days at a time.

Hall probe calibration is extremely important at the magnetic measurement facility. In order for all undulator segments to emit radiation at the same wavelength, they must all be set to the same K value to 1.5 parts in 10^4. This means the magnetic field in the undulators must be measured with at least this accuracy. This is near the state of the art

in Hall probe measurements. In order to meet this requirement, an automated NMR calibration system must be set up near the Hall probe measurement system. The calibration system must be fast and easy to use so that the measurement schedule is not impacted.

The device used to transport the Hall probe through the undulator has very special requirements. The undulators have an axis and the field varies as one moves vertically and horizontally from the axis. Because of the field variations in the undulators, the measurement probes must travel in a straight line through the undulator to within 20 μm in order to accurately measure the undulator parameters. This requires high precision motion of the Hall probes. In addition, the travel range must be at least 6 meters in order to fully characterize the phase advance going into and out of the undulator. The Hall probe must be on a carriage which allows both x and y motion which is accurate at the micron level. The x and y motions are used to determine the axis of the undulator. The carriage must also allow the probe to be pitched and rolled so the probe is aligned with the field direction in the undulator. The field in the undulator varies very rapidly in the z direction. This means the position of each measurement must be known with great accuracy. A precision scale with micron accuracy giving the probe position over the whole measurement range is required. These requirements for the measurements force the use of a high precision motion system. The only solution available requires the use of a massive granite test bench with precision air bearings on the carriage. A set of x and y stages with micron accuracy scales is mounted on the carriage. On the stages a pitch, roll stage is mounted which holds the Hall probe. The z position is given with a long precision optical scale.

The primary tuning tasks are as follows. They are driven by the required undulator parameters in the parameter database. The K-value must be set to 3.5 with a precision of 0.015%. The electron trajectory must be straightened to remain within 2 μm of the undulator axis. The rms phase deviation must be reduced to be below 10 degrees. Phase measurements into and out of the undulator must be made to determine the break lengths. The first and second magnetic field integrals must be reduced below 20 Gcm and 2500 Gcm^2, respectively.

Undulator Fiducialization

Once the undulator axis is determined during the tuning process as the line along which the K-value is set and the tuning is performed, the axis must be related to external fiducials so the undulator magnet can be placed in the machine. In order to transfer coordinates from the measurement probe to fiducials on the body of the undulator, a large coordinate measurement machine is required. The machine must be accurate to 15 μm throughout a volume which includes the undulator and other tooling fixtures.

The horizontal position of the axis must be related to fiducials to 100 μm. The vertical position of the axis must be related to fiducials to 40 μm. The yaw must be kept below 15 μrad. The pitch must be kept below 12 μrad. The roll must be kept below 500 μrad.

Quadrupole Fiducialization

A quadrupole will be paired with each undulator segment to make a FODO lattice for the electron beam. The quadrupole must only focus the beam. It must not give the beam significant transverse deflections; otherwise the beam will not follow the axis of the undulator. In order for this to happen, the beam must travel through the quadrupole in such a way that the integrated field strength along the path is zero. Such a path must be established in the magnetic measurement facility.

A vibrating wire system will be used to establish the line along which the integrated magnetic field is zero in the LCLS quadrupoles. At the center of the quadrupole, the x and y position of the line must be determined to 25 μm with respect to fiducials. The quadrupole will be positioned on the wire within a few microns. The wire position will be determined with special "Wire Finders" capable of locating wires at the micron level. The entire assembly is then placed in the large coordinate measurement machine to reference the wire position relative to tooling balls on the quadrupole.

After the quadrupole and undulator are fiducialized, they must be joined together so the beam can travel both through the center of the quadrupole and along the undulator axis. The step will also be done on the large coordinate measurement machine.

Quadrupole Strength

The quadrupole strength and its integrated corrector strength must be measured. The nominal absolute value of the integrated gradient of each quadrupole is 3.000±0.009 T, with a maximum value of 4.0 T. Additionally, each Quadrupole will have corrector windings integrated into its design that will add an on-axis dipole field with independently adjustable amplitudes of its horizontal and vertical components. The integrated corrector field of each component will be adjustable within the range of $\pm 3 \times 10^{-4}$ Tm.
The aperture in the quadrupole is small. This necessitates a small device to measure its strength. A wire will be stretched through the quadrupole and moved with precision stages. The flux change will be measured during the wire motion. The flux change allows the quadrupole strength to be determined.

Cradle Assembly

Each undulator segment, and its quadrupole, BPM, and associated vacuum components are mounted to a Cradle. The quadrupole and the BPM are aligned to the undulator axis under the control of the CMM. The vacuum chamber is aligned and straightened to 100 μm using height gauges on the Vacuum Chamber Alignment Bench

Summary

A summary of the measurement requirements for the magnetic measurement facility is given in the following table:

Undulator Tuning Upper Limits	**Value**	**Units**
K value accuracy	0.015	%
Trajectory straightness	2	microns
RMS phase error	10	degrees
First field integral	20	G cm
Second field integral	2500	G cm^2
Undulator Fiducialization Accuracies	**Value**	**Units**
X position of axis wrt fiducials	100	microns
Y position of axis wrt fiducials	40	microns
Axis yaw	15	micro-radians
Axis pitch	12	micro-radians
Undulator roll	500	micro-radians
Quadrupole Fiducialization Accuracies	**Value**	**Units**
X position of magnet center wrt fiducials	25	microns
Y position of magnet center wrt fiducials	25	microns
Quadrupole Strength Measurement	**Value**	**Units**
Integrated strength accuracy	1	%