DEVELOPMENT OF INSERTION DEVICES MEASUREMENT SYSTEM AT IHEP*

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Abstrac

In the cooperation between IHEP and EXFEL, the first undulator prototype (U48) for EXFEL was developed by IHEP. In order to meet, maintain and verify the magnetic performance of U48, a 6.5 meters long magnetic measurement bench has been built in IHEP. The measurements are done with the probes moved through the gap of U48 by the measurement bench. The measurement system consists of an accurate bench, motion control cabinet and data acquisition devices. The development status of the system is described in this paper. The characteristics and performances of the magnetic field measurement system are presented.

INTRODUCTION

The European X-ray Free Electron Laser project (XFEL) has the objective to reach lasing in the hard x-ray regime at 0.1nm. It will generate ultra short X-ray flashes – 27, 000 times per second and with a brilliance that is a billion times higher than that of the best conventional X-ray radiation sources. Starting in 2015, it will open up completely new research opportunities for scientists and industrial users [1]. To generate the X-ray flashes such that the undulators must have severe requirements. This in turn requires very high accuracy of the measurement bench. Errors in the bench construction cause the measurement errors. IHEP undertook the development of the first undulator prototype of EXFEL called U48. In order to measure and tune magnetic field of U48 to be within the specifications, a high precise measurement system was developed in IHEP. The new bench was modelled after the bench of EXFEL. The proposed critical design parameters for the measurement system were reviewed by Dr. Joachim Pflüger of EXFEL.

The magnetic field of U48 was measured with the magnetic sensors moved through the gap at constant speed by the measurement bench. The measurement system is able to measure vertical (By) and horizontal (Bx) components. During the magnetic sensors moving, the data of By and Bx are taken simultaneously. The measurements are performed with a programmable trigger.

THE MEASUREMENT SYSTEM

The measurement system consists of bench, magnetic sensors, data acquisition devices, motion control cabinet, host computer and measurement program.

A view of magnetic measurement system with U48 is shown in figure 1.

The bench is based on a granite support. The upper granite surface is accurately machined. A carriage which is mounted x-y transverse stages can move along the granite. In order to assure the stiffness of the stages, the stages are also based on granites. Three stacked stages which are used to adjust the pitch, yaw and roll of the measurement sensors are fixed on y stage because the magnetic sensors are direction sensitive. The carriage riding on air bearings uses the precision surfaces as a guide to move the sensors. The carriage is driven by linear motor. Linear motor is directly mounted on the granite support. The type of linear motor has been selected to ensure negligible magnetic perturbations during field measurement.

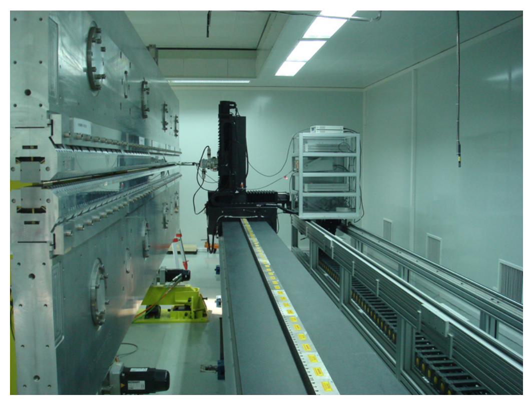

Figure 1 : The undulator measurement bench with U48 of EXFEL under test

The data acquisition devices are settled in an aluminous rack. In addition, the electric cables, pneumatic hoses and vacuum hoses of the bench are fixed under the rack. The rack is mounted on the guide rail which is parallel to the bench but has no connection with the bench. The rack moves following the carriage synchronously. The purpose is to decrease the signal cables between the sensors and the data acquisition devices as short as possible. The electromagnetic interference from surrounding to the measurement signals will be reduced. At the same time, the forces from the cables and the hoses to the carriage don't affect the position accuracy when the carriage is moving.

Specifications

The specifications of the bench are following the accuracy requirements for measuring and tuning of U48. The tolerances of the bench can be derived from the specifications and physical requirements of U48. The

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parameters and the physical requirements of U48 are shown in table 1.

Table 1: Undulator U48 Parameters and Physical Requirements.

Parameter(units)	**Value**
Length(mm)	5000
Period length(mm)	48
Peak field(T)	1.37(@gap=10mm) 0.63(@gap=19mm)
First magnetic field integral(Tmm)	≤±0.2 (horizontal, vertical)
Second magnetic field integral RMS(Tmm^2)	≤50 (horizontal, vertical)
Electron phase deviation RMS (°)	< 6

The length of U48 is 5 meters. Concerning the position for the zero gauss chambers, the whole effective travel range is designed to 6.5 meters. Plus the length of the carriage, the total length of the granite is 7.5 meters.

The specifications of the bench are shown in table 2.

Table 2: The Specification of The Bench

Parameter(units)	**X**	**Y**	**Z**
Travel length(mm)	300	400	6500
Straightness deviation	≤±5	≤±5	≤±15
Position accuracy at sensors tip(μm)	≤±10	≤±10	≤±5
Repeatability(μm)	±1	±1	±1.5
Perpendicular(mrad)	≤0.02		

Ideally, the carriage has only one degree freedom that moves along longitudinal axis. But in fact, the motion of the carriage has the deformation in x, y, roll, pitch and yaw. These errors will affect the position accuracy of the magnetic sensors. That is why the position accuracy at sensors tip is required in the specifications.

Motion Control

The motors are controlled in closed loop using the linear encoders. The resolution of the linear encoders for longitudinal axis and transverse axes is 0.1μm. The x,y axes are driven by servo motor. The z axis is driven by linear motor. The angles adjustment axes for magnetic sensors are driven by step motors. The motions of all axes are controlled by UMAC controller. The controller communicates with the host computer via Ethernet. The controller can produce TTL triggers for data collection. The repetition frequency of the triggers can be programmed by the user.

Data Acquisition

The data acquisition devices are settled in the rack. They are flux-meter, gauss-meter and two digital multimeters (Agilent 3458A). The flux-meter is connected with the small coil to measure the horizontal field of U48. The gauss-meter is connected with the Hall Probe to measure the vertical field of U48. Because the measurement is performed "on the fly", the speed of the measurement data acquisition is fairly fast. The analog signals from the flux-meter and the gauss-meter are collected directly by the multimeters. The measurement data are stored in the internal buffers of multimerers at the triggering frequency. The devices communicate to the host computer via GPIB. The data are transferred to the computer after finishing a measurement.

Measurement Program

The measurement program performs the motion control, data acquisition devices setup, undulator alignment by magnetic field measurement, the scan of Bx and By field. The program is implemented in Labwindows/CVI of National Instrument. The measurement data can be processed by a program also developed in Labwindows/CVI. The block diagram of the program is shown in figure 2. The interface of the magnetic field scan is shown in figure 3.

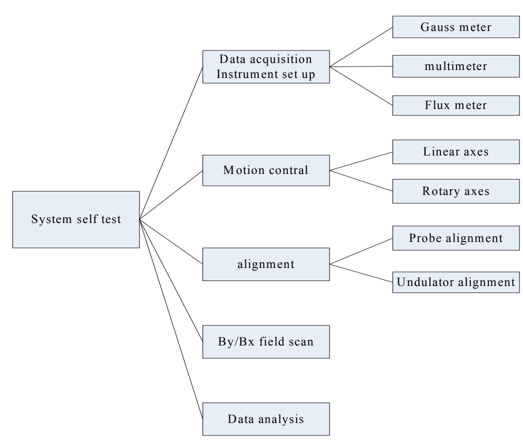

Figure 2:Measurement program block diagram

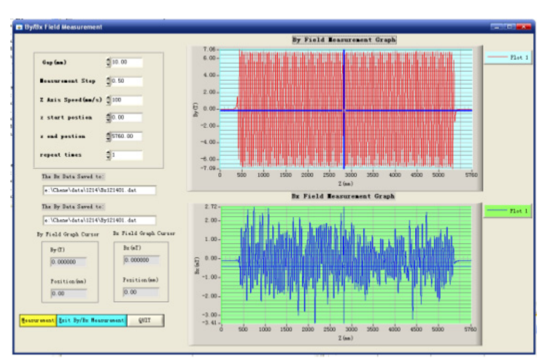

Figure 3: The interface of the magnetic field scan

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Magnetic Sensors and Calibration

The magnetic sensors consist of a transverse Hall probe (FW-Bell) and a small rectangle coil. The diameter of the Hall probe active area is about 1mm.The effective area of the coil is 2692cm^2. The holder is made of fiberglass. At the tip of the holder, it has special design to make the coil and the Hall probe orthogonal.

To calibrate a Hall probe to sufficient accuracy requires a sophisticated and expensive laboratory setup. For U48 measurements, we want to the calibration accuracy of Hall probe agree with EXFEL. Therefore the Hall probe was calibrated in DESY undulator measurement Lab. The calibration accuracy is 0.05%.We rely upon the calibration data supplied by DESY. Calibration curves were calculated by a least squares fit of the 11th order polynomial. The effective area of the small coil is calibrated in a solenoid by the authority department of China. The accuracy is 0.2%. The structure of the holder is shown in figure 4.

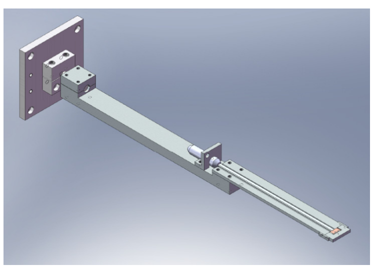

Figure 4:The structure of the magnetic sensors holder

U48 MAGNETIC FIELD MEASUREMENT

The U48 and the measurement system are in the dedicated lab that the temperature is fairly good controlled. The temperature vibration is less than ±0.1°C.

Alignment the Undulator to the Bench

Before the tuning measurement of U48, the undulator has to be precisely aligned to the measurement bench. Firstly, by means of optical telescope the rough alignment is done. Secondly, the alignment is according to the magnetic field measurement. From the property of the undulator magnetic field the procedure for searching the magnetic axis is exploited. This is more precise way for alignment. By scanning the By field of each pole along the x axis and y axis separately, the magnetic center of y axis and x axis along z axis can be figured out. The curves fit to a straight line. The slopes of the straight line define the yaw and pitch of the undulator. According to the results of magnetic axes measurement, the undulator can be adjusted to the right position. These procedures are iterated until position errors between the undulator and the bench are acceptable.

Searching the Correct Direction of the Sensors

The Hall probe and the small coil are direction sensitive to the magnetic field. To search the correct angle of the probe sensors, the sensors should be covered in the field of undulator and adjusted in pitch, yaw and roll by the stacked stages.

Magnetic Center Measurement

The undulator field is measured at the magnetic center. The magnetic center measurement procedure is the same as undulator alignment.

Magnetic Field Measurement

The magnetic field scan range for U48 is about 6 meters. The measurement interval is 0.5mm.Therefore, there are 12000 samples in total. The measurements are performed at constant speed. The typical measurement speed is 100mm/s. It is about one minute for a scan.

The zero-field offsets of By and Bx components are measured before and after executing field scans. These offsets are used to correct for the zero-field errors in the calibration and drifts of the data acquisition devices.

SYSTEM PRECISION

The system characterization tests were performed on U48 magnetic field measurement. During the tests the status of the undulator and the environment were kept stable. The magnetic field of undulator was scanned several times every day. The same measurement was done for several days continuously. From these data the reproducibility of the measurement system can be calculated.

The system repeatability of U48 measurement in 5 days is reported in the table 3.

Table 3: The System Repeatability of U48 Measurement (RMS)

	Vertical field	Horizontal field
B(T)	$<2\times10^{-4}$	$<4\times10^{-5}$
∫B(Tmm)	<0.02	<0.0082
∫∫B(Tmm^2)	<50.3	<20.5

The uncertainty of the field measurement is a function of the uncertainty of individual samples. Sources of discrete sample uncertainty are background electronic noise, sensors position uncertainty and the temperature vibration during a scan.

The U48 measurement lab has fairly good temperature stability. The sample uncertainty comes from temperature vibration can be ignored.

The good repeatability of horizontal field measurement is not easy to achieve. The horizontal field is very weak compared with the vertical field. The effect of the background electronic noise to the signal of the coil is bigger than to the signal of Hall probe. The digital low pass filter by using the program can solve this problem very well.

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In addition to the uncertainty in individual discrete measurements, the effect of the uncertainty in the zero field measurement should be considered. The zero field measurement uncertainty contributes directly to the integral errors. The 1st integration error is proportional to the product of the zero field measurement uncertainty and the integral length. The 2nd integration error is proportional to the product of the zero field measurement uncertainty and the square of the integral length. The measurement length of U48 is about 6 meters. Therefore, the error of the 2nd field integration that results from the error of zero field measurement is quite big. The zero gauss chamber is used to correct the zero field uncertainty.

CONCLUSION

The undulator magnetic field measurement system has been developed at IHEP and successfully tested. The travel range in the longitudinal of the bench is the longest in China currently and up to 6.5 meters. The position accuracy was calibrated by the interferometer and the mechanical accuracy was measured by autocollimator. The position accuracy and mechanical accuracy are better than the specifications. The performance of the measurement system meets the U48 measurement requirements.

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