

SwissFEL MAGNET TEST SETUP AND ITS CONTROLS AT PSI

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Abstract

High brightness electron bunches will be guided in the future Free Electron Laser (SwissFEL) at the Paul Scherrer Institute (PSI) by several hundred magnets. The SwissFEL machine imposes very strict requirements not only at the field quality but also at the mechanical and magnetic alignments of these magnets. To ensure that the magnet specifications are met, and to develop reliable procedures for aligning magnets in the SwissFEL and correcting their field errors during machine operations, the PSI magnet test system was upgraded. The upgraded system is a high precision measurement setup based on Hall probe, rotating coil, vibrating wire and moving wire techniques. It is fully automated and integrated in the PSI controls. The paper describes the main controls components of the new magnet test setup and their performance.

INTRODUCTION

The Free Electron Laser Facility (SwissFEL) is under construction at Paul Scherrer Institute (PSI) [1]. About 740 m long, the facility is going to be a highly precise source of extremely short X-ray pulses. The electron beam steering magnets will be installed in 2015-2016, and user operations are expected to begin shortly after that.

SwissFEL magnets are designed by PSI specialists and will be produced by industry. Upon delivery, to make sure that field quality specifications are met, all magnets will be systematically measured at PSI. The parameters that have to be measured include the integral field strength and the magnetic length, the field uniformity and harmonics, the quadrupole axis position with respect to magnet fiducials and the hysteresis effect. The measurement results will be included in the SwissFEL magnet measurement database, which can be used, for example, to align magnets in the SwissFEL and correct their field errors during machine operations.

In order to provide a modern, user friendly environment for SwissFEL magnet measurements, the PSI magnet test system was upgraded to become a fully automated, high precision measurement setup based on Hall probe, rotating coil, vibrating wire and moving wire techniques.

HALL PROBE MEASUREMENTS

Main magnetic field measurements and field mapping in dipoles are performed using Hall probes. A computerized Magnet Measuring Machine (MMM) for automatic fast magnetic field measurements has been in operations at PSI for more than 40 years. It was upgraded

several times. The last upgrade was finished just few months ago (see Fig. 1).

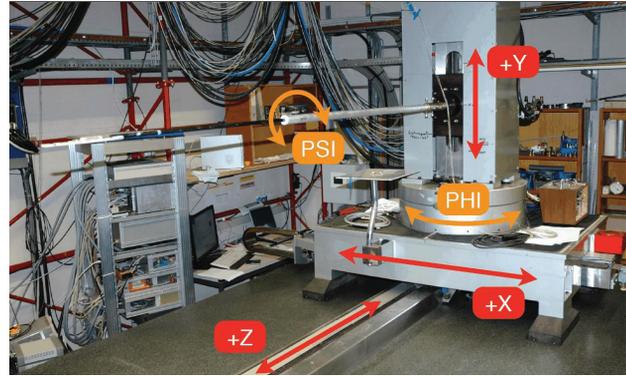


Figure 1: MMM setup at Paul Scherrer Institute.

Basically, the MMM is an extremely precise positioning device sliding on compressed air pads over a flat, carefully machined granite block. The position is determined by an Inductosyn detector unit providing one half micron accuracy. The Hall probes are attached to a titanium measuring arm, which can move with five degrees of freedom (three translation directions plus two rotations in the horizontal plane and around the arm). Each movement is done by a dedicated stepping motor. The magnet current is set by PSI digital power supply controllers. Probe potentials are recorded by the Agilent 3458A digital multimeter (DVM device). Periodic Hall probe calibrations are done with the use of the Metrolab PT2025 NMR teslameter (NMR device).

All measurements are performed in a continuous scan on the fly mode, i.e. the machine doesn't stop to make a particular measurement. With the maximum speed of the machine along the longest axis (which is a longitudinal axis Z) the longest drive takes less than one minute per line and is totally independent of the number of measurement points. We note that the measurement axis can be any of three translation directions while two rotation directions are used only for probe positioning. Therefore, a measured field map corresponds to a line, a plane, or a volume in a Cartesian coordinate system.

The MMM controls are built in the frames of the PSI control environment, which is based on EPICS [2]. The main controls hardware is implemented in the VME-64x standard. The VME controls computer (IOC) is a single board CPU MVME-5100 running the VxWorks real time OS. This IOC (we call it mmmIOC) also runs the real time EPICS database handling all MMM components and containing the information about the state of these components and all measurement data.

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The stepping motors and their encoders (which are based on Inductsyn units mentioned above) are interfaced through the MAXv-8000 card and its transition module. The access to PSI digital power supply controllers is provided by in-house developed Industry Pack (IP) control modules PSC-IP2 sitting on Hytec VME carrier boards. Several digital IO signals are handled by Hytec IP modules. Such signals are used for external digital voltmeter triggering and providing a MMM manual mode when the machine is positioned by pressing buttons on a remote control unit, which looks similar to old fashioned TV remote controls. The DVM and NMR devices are interfaced over an Agilent E5810A LAN/GPIB gateway. The corresponding controls software runs on a Linux box connected to a local computer network.

The MMM measurements are done with the use of a specially designed graphical user interface (GUI) tool called mmmgui (see Fig. 2). The mmmgui is based on a very popular Qt toolkit [3], which automatically makes it computer platform independent. At PSI, the tool usually runs on a Linux console PC installed in the Hall probe measurement lab. We note that the lab is temperature controlled ($\pm 0.1^\circ \text{C}$), which is very important for this kind of magnet measurements.

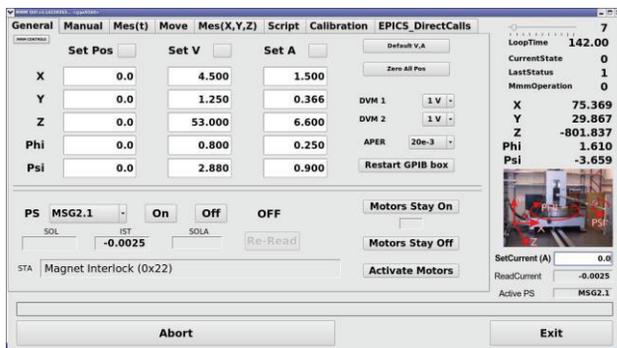


Figure 2: MMM controls GUI tool (mmmgui).

The mmmgui software is multi-threaded. Threads are responsible for various MMM operation modes, which are implemented as standard Qt tabs and called MMM panels (Fig. 2). Threads communicate to each other based on a shared memory, which is synchronized with the MMM EPICS database. This way, a mmmgui user gets an easy access to all MMM components.

In particular, the Mes(X,Y,Z) MMM panel is provided to drive a Hall probe along a measurement axis. The user has to define the start and end positions of the probe, the motor acceleration and maximum speed, the number of measurement points, and the magnet power supply current. Based on these data, the mmmgui software calculates time intervals between measurement points to make them quasi-equidistant. These intervals immediately become a part of the EPICS database and are used by the mmmIOC software to trigger the DVM device when the probe is moving. Each time the DVM device gets an external trigger, it stores the actual probe potential into

the internal memory buffer. When the motion is completed, all recorded data are transferred by the mmmgui to the computer disk, and the memory buffer is emptied. Simultaneously, the probe potentials are written into the EPICS database, which already contains time stamps and probe coordinates corresponding to those potentials. The time stamps are obtained directly from the mmmIOC OS and the probe coordinates are DMA transferred from the VME memory associated with motor encoder data at the moments when the trigger signals are generated. The mmmIOC software assures all necessary real time constraints on the whole data acquisition process. We note that normally the same line is measured again in the reverse direction before moving MMM to another line. Measuring in both directions helps to cancel positional errors and any voltages induced in the probe connections moving in magnetic field gradients.

The mmmgui also automates the Hall probe calibration process, which makes it an especially valuable tool for magnet measurement applications. All calibration steps are directed by the software. The user has to only define the number of the DVM device readings to average (which helps to reduce measurement noise) and the set of magnet power supply currents, at which the probe potentials are compared with the NMR device data. All calibration process status information is provided on the MMM Calibration panel. At any time, based on physics measurement criteria also provided on the panel, the user can interrupt/stop the calibration or skip/repeat a measurement point. As soon as the calibration is finished, the measurements data become available in EPICS and are written on the computer disk (in a file with a specified name and predefined data format), which can be used for any post processing analysis.

VIBRATING WIRE TEST BENCH

A single stretched vibrating wire method is known to be the most accurate technique to define the magnetic axes of multipole magnets [4]. The idea of the method is following. A stretched wire excited by an alternating current (AC) starts oscillating in the magnetic field. The AC frequencies corresponding to natural wire resonances cause particularly large vibrations, which makes such a system very sensitive to the existence of the magnetic field along the wire. Essentially, when the wire stretched in a multipole magnet stops vibrating, the effective magnetic axis and the wire are aligned. So, to locate the magnet axis, the wire should move until its oscillations vanish.

The PSI vibrating wire measurement bench is installed in a separate small room, which is not air-conditioned in order to minimize the airflow. All electronics is kept outside of this room to make sure that temperature changes during measurements are low and slow. The main bench monitor/control components are two pairs of linear motorized stages, a vibration detector, and temperature sensors. The linear motorized stages Newport M-ILS150CCL move in horizontal and vertical directions. One stage pair is static on a measurement table and the

other can be relocated, which allows for measurements with different wire lengths. The magnets are placed on the table on a distance of the quarter wire length next to the static linear stage pair. At the other wire end the vibration detector is positioned with the equal distance next to the movable stage pair. The reference point positions on the wire supports and the magnets are found with a FaroArm Quantum device. The position accuracy is better than 10 μm . The detection of wire vibrations is done by a novel PSI detector consisting of four pick-up coils, which form two orthogonally positioned pairs allowing one to detect the complete wire vibrations in space. The measurement signal from the pick-up coil pair contains the information about the wire position relative to the center of the coils and about the wire vibration. At that, the position of the wire in the detector doesn't influence the vibration reading and the vibration-induced voltage is virtually independent of the wire current frequency. The PSI vibrating wire test bench setup is shown in Fig. 3.

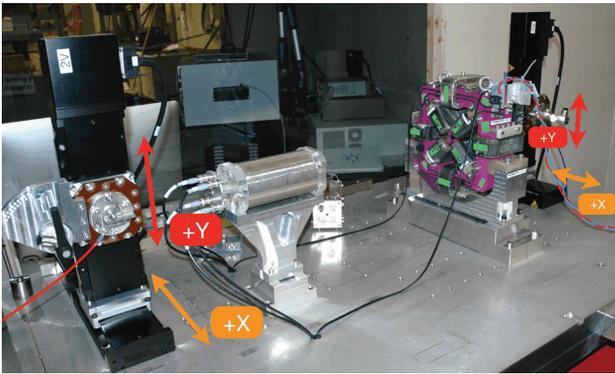


Figure 3: Vibrating wire test bench at PSI.

The central instrument of the measurement system is a digital lock-in amplifier HF2LI from Zurich Instruments (ZI) [5]. Two lock-in demodulators are used for the vibration detection and two for the wire position detection. One internal oscillator generates a constant voltage output powering the wire, another one is used for the reference signal.

The magnet and air temperature in the room is monitored with Sensirion SHT75 sensors connected to an ETHMS (Embedded Temperature and Humidity Measurement System) module designed at PSI, which is based on LPC1768 controller with ARM Cortex M3 processor. The temperature resolution of the system is 0.01° C.

The linear stages are handled individually with Newport SMC100 motion controllers. Although each stage has its own controller, the movements of two horizontal and two vertical stages are made to occur simultaneously.

The vibrating wire measurement control software runs on two IOCs. One of them is a Linux PC communicating with Newport SMC100 stage controllers over a standard serial (RS232) port and with ETHMS modules via direct

network connections. The software is built on top of the Stream Device support package, which makes it easy to setup any device configuration and monitor its parameters in real time. The second IOC is Windows PC talking to the ZI lock-in amplifier over a local USB port. The control software monitors the amplifier state with the use of the API library provided by Zurich Instruments. It also handles the EPICS records associated with the amplifier settings and status. Being a part of the PSI EPICS controls, all vibrating wire setup parameters are available for real time monitoring and control functions on any computer connected to a local network.

The main application controlling the whole measurement process is written in Python, which is supported by EPICS. The application significantly simplifies the work on the measurement setup tuning, tests, and operations.

MOVING WIRE SYSTEM

Single stretched moving wire and rotating coil techniques are the most suitable for harmonics measurements in multipole magnets. Both techniques have pretty much the same concept: to move a wire or a coil along a circle in the magnet aperture and to measure the magnetic flux change as a function of the rotation angle.

A moving wire system created at PSI is based on a high performance multi-axes Newport XPS motion controller/driver, which implements advanced trajectory and synchronization features to precisely control complex motion sequences. The EPICS community provides a software package allowing one to efficiently setup XPS and control its operations [6]. This package is a part of a new moving wire measurement control tool developed at PSI. The tool is implemented as a Moving Measurements Control (MMC) application, which runs on a Linux box, and a set of MEDM GUI panels that are very easy to use for handling measurements. The MMC application communicates with the XPS controller over the computer network. Two pairs of linear motorized stages connected to the XPS controller are configured (as XY groups) to synchronously move both ends of a stretched wire along a specified line or arc, which makes it easy to perform any required circular motion. The MMC application must be provided with a wire trajectory definition file containing a set of reference points through which the system has to move the wire and a number of trajectory points (including start and end ones and assuming that they are equidistant) in which the XPS controller will generate triggering signals for external electronics. Simultaneously with generating an external triggering signal, the XPS controller writes the corresponding wire coordinate into its local memory buffer.

The XPS triggering signals are caught by another (already familiar from previous sections) DVM device used for magnets measurements. This device writes the information about the electric currents flowing through the moving wire at those moments into its internal memory buffer. The MMC application assures that the

DVM device configuration follows the XPS controller settings.

When the specified trajectory is finished, the MMC application transfers XPS and DVM device local memory buffers into the EPICS waveform records associated with a 2D trajectory representation and corresponding wire currents, which immediately makes measurement data available for archiving, post processing, modeling, etc.

We note that the SwissFEL rotating coil measurement system is under development in collaboration with CERN.

CONCLUSIONS

A new PSI magnet measurement setup is ready for testing SwissFEL magnets. Each subsystem is associated with the measurement technique used. All subsystems are automated following PSI controls standards. The automation software is implemented as a set of tools supporting magnet measurement subsystems. Each tool consists of a main control application handling the measurement process and few GUI panels, which are used to run that application and monitor its state.

Being a part of the EPICS based control environment, the magnet measurement data are very easy to work with. For instance, the data archiving is done with the use of a standard EPICS Archiver. Applications written in

MATLAB and popular scripting languages (e.g. Python, Bourne shell) allow users to efficiently handle magnet measurement processes remotely, perform online and offline data analysis, and generate measurement data reports.

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