MAGNET MEASUREMENT SYSTEM UPGRADE AT PSI

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Abstract

The magnet measurement system at the Paul Scherrer Institute (PSI) was significantly upgraded in the last few years. At the moment, it consists of automated Hall probe, moving wire, and vibrating wire setups, which form a very efficient magnet measurement facility. The paper concentrates on the automation hardware and software implementation, which has made it possible not only to significantly increase the performance of the magnet measurement facility at PSI, but also to simplify magnet measurement data handling and processing.

INTRODUCTION

The majority of magnets for PSI accelerators and experiments are designed in house and produced by industry. Upon delivery, these magnets are systematically measured to assure that all field quality specifications are met. The measurements are done with the use of the PSI magnet measurement system the technical and operational capabilities of which have significantly advanced in the last months. As a result, it is a modern, automated, user friendly system, which consists of high precision measurement setups based on Hall probe, moving wire, and vibrating wire techniques. The setups are arranged in separate rooms of the PSI magnet measurement laboratory, which are equipped with all necessary measurement tools, control computers, and operational consoles. The magnet measurement system is integrated into the PSI controls, which is based on EPICS [1]. This fact combined with the cutting-edge data acquisition and control software developed for magnet measurement applications at PSI makes the system easy to run not only from local operational consoles but also remotely, eventually from any PC connected to the PSI network.

HALL PROBE SETUP

Basic magnetic field mapping is performed using Hall probes. Fast automated Hall probe measurements are provided by a computerized Magnet Measurement Machine (MMM) created at PSI.

The MMM is a very precise positioning device sliding on compressed air pads over a flat, carefully machined granite block. Hall probes are attached to a titanium arm with carbon fibre extensions that can move in three translation directions (X, Y, Z) and rotate in the horizontal plane (a yaw angle) and around the arm (a roll angle). Each move is performed by a dedicated stepping motor. Positions are determined by Inductosyn® linear encoders with one half-micron accuracy. We note that the MMM measurements are performed in any translation direction while two rotations are used only for the proper probe positioning. Therefore, a measured field map corresponds to a line, a plane, or a volume in a Cartesian coordinate system.

The Hall probe setup is installed in a temperature controlled (± 0.1° C) room, which is important for accuracy of this kind of measurements.

Hall probe potentials are recorded by an Agilent 3458A digital multimeter (DMM device). Periodic probe calibrations are done with the use of a Nuclear Magnetic Resonance based Metrolab PT2025 teslameter (NMR device). Both devices can be remotely controlled via the GPIB bus. Magnet current values are set by PSI digital power supply controllers.

The main Hall probe setup control hardware is implemented in a VME-64x standard. The control computer (IOC) is a MVME-5100 single board CPU running the VxWorks real time kernel. The IOC also runs the EPICS database and control software (MMM server), which handle all Hall probe setup components and provide the information about the state of these components and all measurement data. The stepping motors and their encoders, which are based on Inductosyn® sensors, are interfaced via a MAXv-8000 card and its transition module. In-house developed Industry Pack (IP) control modules PSC-IP2 sitting on a Hytec 8002 carrier board provide the access to magnet digital power supply controllers. A variety of digital (DIO) signals are required for MMM operations. They are handled by Hytec 8505 IP modules. DIO signals are used, for example, to trigger DMM devices and to support a special manual mode (as opposed to its normal mode that is automatic), in which the MMM is positioned by the magnet measurement personnel pressing buttons on a remote control unit that looks similar to a conventional TV remote control. We note that the manual mode is especially valuable for initial MMM positioning with respect to any magnet to measure.

MMM measurements are performed in a “continuous scan on the fly” mode, which means that the machine doesn’t stop to make a particular measurement. This allows one to finish a complex field mapping process for each magnet in a relatively short time frame, which is typically one day or less.

The MMM control is done with the use of a specially designed graphical user interface (GUI) tool, which is called mmmgui. The tool is based on a well-known Qt framework [2], which automatically makes it computer platform independent. At PSI, the tool can run on any 32 or 64 bit Scientific Linux PC console. The mmmgui control software (MMM client) is multi-threaded. Each thread deals with a particular MMM operational mode, which is supported by a dedicated mmmgui panel implemented as a standard Qt tab. Threads communicate to each other over a shared memory synchronized with the MMM EPICS database.

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The most frequently used MMM operation, which is driving a Hall probe along a measurement axis, is supported by the Mes(X,Y,Z) mmmgui panel. The operator has to define the start and end positions of the measurement, the motor acceleration and maximum speed, data acquisition time, the number of measurement points, and the magnet power supply current value. Based on this information, the mmmgui control software performs a series of calculations and system parameter settings. In particular, assuming that the measurement points are equidistant, their coordinates are defined and immediately become a part of the EPICS database. This makes the MMM server software ready to trigger the DMM device exactly when the probe reaches such measurement points. Each time the DMM device is triggered, the actual probe potential is written into its internal memory buffer. When the motion is completed, all recorded data are transferred by the mmmgui software to the computer disk. Simultaneously, the measured 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 VxWorks operating system 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 MMM server 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.

Another mmmgui panel, which is called Script, supports user programs written in a simple scripting language Lua [3], which is popular in computer games. In this way, field mapping procedures developed by magnet experts and implemented as Lua scripts fully automate the magnet measurement process at PSI. Operator's interventions are required only in case of possible MMM component failures, which is monitored and reported by the control software.

Because of its operational nature, the mmmgui is implemented as a single-user application. When the mmmgui starts, it tries to connect to the MMM server. If the server is already busy with another MMM client, the connection is refused and the mmmgui exits displaying a corresponding error message. Otherwise, the requested connection is established, which gives a user an exclusive access to all MMM resources and assures that the measurement process could never be influenced by anybody else.

VIBRATING WIRE METHOD SUPPORT

A stretched wire excited by an alternating current (AC) starts oscillating in the static 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. This idea is the fundamental basis of a single stretched vibrating wire method [4], which is the most accurate technique to define the magnetic axes of multipole magnets.

A vibrating wire measurement test stand at PSI is arranged in a room, which is not air-conditioned in order to minimize the air flow. Electronics is kept outside of this room to make sure that temperature changes during the measurements are low and slow. Main 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. The other pair can be relocated, which allows for measurements with different wire lengths. The magnets are placed on the table at the distance of a quarter wire length next to the static 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 core instrument of the measurement system is a digital lock-in amplifier HF2LI produced by 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 and serving as a reference signal.

At the time being, magnet and air temperatures in the room are monitored by Sensirion SHT75 sensors connected to the in-house developed embedded temperature and humidity measurement controller (ETHMC), which is fully integrated in the EPICS environment. This solution provides a good (0.01° C) temperature resolution. It is easy to configure and run. Unfortunately, the ETHMC loses the network connection (which is the only interface to the PSI controls) from time to time and must be rebooted to fix it. In order to improve the reliability of the temperature measurement system, we are planning to switch to WAGO [6] commercial controllers in the next few months.

The linear stages are individually handled with Newport SMC100 motion controllers. Although each stage has its

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own controller, the motions 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 box communicating with Newport SMC100 stage controllers over a standard serial (RS232) port and with the ETHMC via the computer network. The software is built on top of a standard EPICS Stream Device support package, which makes it easy to handle any device configuration and monitor its parameters on-line. The second IOC is a 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. We note that EPICS doesn't provide a standard solution for handling USB devices, and this software is a good example of how to integrate such a device into the control system. In particular, only event driven API functions are used by the amplifier EPICS driver/device support modules, which notably increases the overall system efficiency.

Being a part of the PSI EPICS controls, all vibrating wire setup parameters are available for on-line 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 SETUP

A single stretched moving wire method is suitable for harmonics measurements in multipole magnets. The idea of this technique is relatively simple: move a stretched wire along a cylindrical surface in the magnet aperture and measure the magnetic flux change as a function of the rotation angle.

A moving wire setup 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. A standard EPICS XPS support software package is a part of a special moving wire measurement control tool developed at PSI. The tool consists of a Moving Measurement Control (MMC) application, which runs on a Linux PC, 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 plane or cylindrical 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 trigger signals for external electronics. Simultaneously with generating a particular external trigger signal, the XPS controller writes the corresponding wire coordinate into its local memory buffer. The XPS trigger signals are caught by a DMM device dedicated to the moving wire setup. This device writes the information about the flux change induced voltage of the moving wire at those moments into its internal memory buffer. The MMC application assures that the DMM device configuration follows the XPS controller settings. When the wire motion along the specified trajectory is finished, the MMC application transfers XPS and DMM device local memory buffers into the EPICS waveform records associated with a 2D trajectory representation and corresponding wire current values, which immediately makes measurement data available for archiving, post processing, modeling, etc.

CONCLUSIONS

A new magnet measurement system has been in successful operations at PSI for the last few months. The system is automated following PSI controls standards. The automation software is implemented as a set of tools supporting Hall probe, moving wire, and vibrating wire magnet measurement setups. Each tool consists of a main control application handling the measurement process and a set of GUI panels, which are used to run that application and monitor its state. Being a part of the EPICS 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. The applications written in popular scripting languages (Python, Lua, Bourne shell, etc.) allow users to efficiently handle magnet measurement processes remotely, perform on-line and off-line data analysis, and generate measurement data reports. Further system developments are going to be concentrated on the design and implementation of EPICS 4 data services [7], which should organically combine the measurement data, the data processing models, and the data processing results for each particular magnet into a transparently structured data object associated with this magnet.

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