PAUL SCHERRER INSTITUT

ADVANCED PROCESS CONTROL TOOL FOR MAGNET MEASUREMENTS AT PSI

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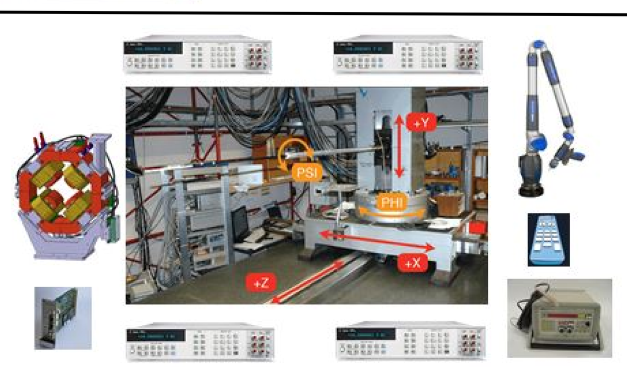
Introduction

Charged particle accelerators and their experimental stations at PSI contain a number of various magnetic field generating components: dipoles, quadrupoles, solenoids, etc. The quality of these components, which are usually referenced as magnets, strongly affects the accelerator and experiment capabilities. To assure that all magnetic field quality specifications are met, such components are systematically measured at the PSI magnet measurement laboratory (MML). The equipment of this laboratory was significantly upgraded few years ago. In parallel with this upgrade, an advanced magnet measurement data acquisition and control system (MMDACS) was created. The system was implemented as a part of the PSI controls environment, which is based on EPICS.

Major features of this system were presented at the ICALEPCS'13 conference. Since then, the system was consistently showing its high efficiency and reliability in all magnet measurements at the MML. It was also successfully adapted to an advanced 3D Hall probe setup and a new 64 bit Linux PC platform at PSI. The main activities around MMDACS, though, were concentrated on the development and enhancement of user friendly control applications that can efficiently assist operators in routine magnet measurement procedures. The result of such activities is a magnet measurement process control tool (PCT), which is a set of applications specialized in particular magnet measurement techniques supported at PSI, which include Hall probe, vibrating wire, and moving wire methods. The core of each application is the state machine software designed by magnet measurement and control system experts.

Hall Probe Measurement Components and Process Control Application

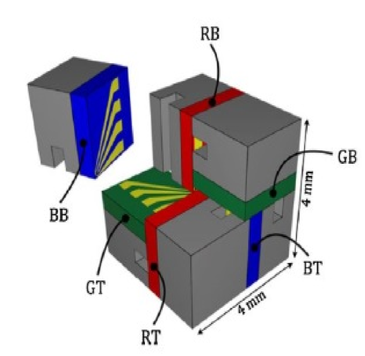
Magnetic field mapping at PSI is performed by Hall probes. Measurements are done with the use of a Magnet Measurement Machine (MMM). To provide stable long-term measurement conditions, the machine is located in a temperature controlled (±0.1° C) room. A magnet is positioned on the measurement bench to be aligned with the main driving direction of the measurement machine. Five MMM stepper-motors can move a Hall probe, which is mounted on a carbon-fiber arm, in three translational directions or axes (X, Y, Z) as well as rotate it in the horizontal plane and around the arm. Since rotations are used only for proper probe positioning in space, any particular measured field map at PSI corresponds to a line, a plane, or a volume in the Cartesian coordinate system (X, Y, Z). The measurements are performed in a "continuous scan on the fly" mode (the MMM doesn't stop to make a particular measurement).



MMM setup and control components

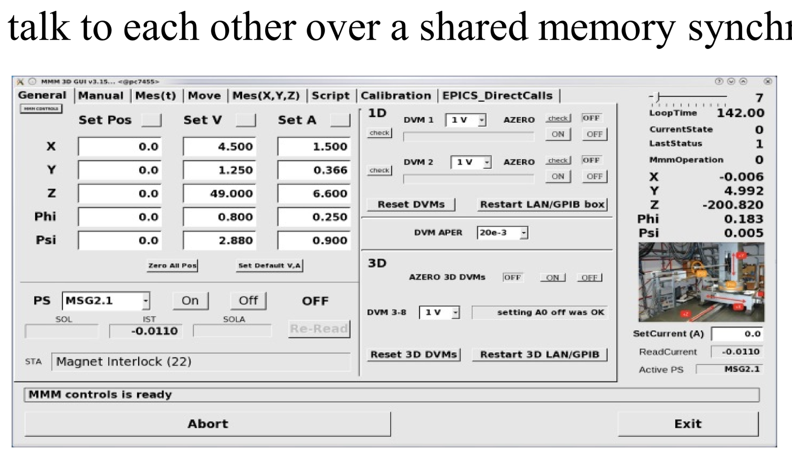
- The magnet current is set by PSI digital power supply (PS) controllers, which are handled by dedicated IPAC (PSC-IP2, VME) modules.
- Hall probe potentials are recorded by the Keysight 3458A digital multimeters or DMM (GPIB). Data triggering is done by an IPAC DIO (Newwoodsolutions 8505, VME) module.
- Probe calibrations are done based on the NMR Metrolab PT2025 teslameter (GPIB).
- Hall probe motion in any of five possible directions is provided by a dedicated stepping motor vis a standard PSI control interface (MAXv-8000, VME).

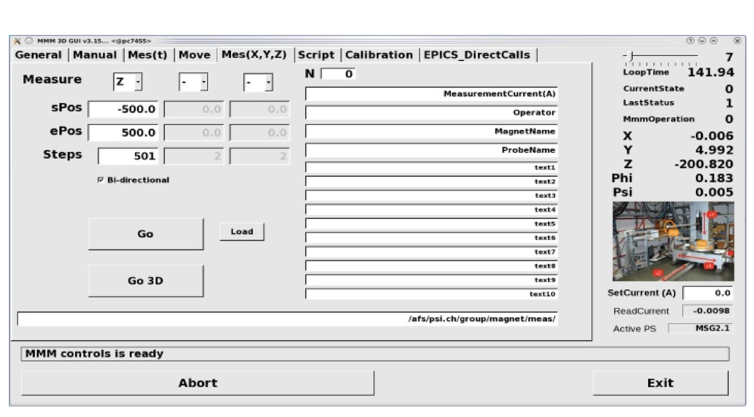
The magnet measurement lab possesses a set of classical one-dimensional (1D) Hall probes, which are can measure only one magnetic field component. Recently, this set was enhanced by an innovative, in-house developed, high accuracy 3D Hall probe ("Hallcube"). This probe consists of three pairs of 1D Hall probes forming a sub-millimeter cubic active volume and, therefore, is sensitive to all three magnetic field components.



The MMM measurement equipment control software is a part of the MMM server program. This program is executed on a VME-64x process control computer (also referenced as an Input Output Controller or IOC), which is a MVME-5100 single board CPU (VxWorks OS + a memory resident EPICS database to handle MMM measurement equipment components and measurement data).

A specially designed control screen mmmgui, is a graphical user interface (GUI) representation of the MMM client program. The screen is based on a Qt framework, which automatically makes it computer platform independent. The MMM client program runs on one of the MML Linux PC consoles. It is multi-threaded. Each thread deals with a particular MMM operational mode, which is handled by the state machine software associated with this mode and available from a dedicated standard Qt tab panel on the mmmgui screen. Threads talk to each other over a shared memory synchronized with the MMM EPICS database.





The MMM state machine software is developed by magnet measurement and control system experts, which makes it highly optimized and extremely efficient for all MMM operations. The MMM client and server programs communicate via EPICS. They both are combined into the Hall probe process control application, which can handle a variety of basic operational modes.

Vibrating Wire Method Support

The vibrating wire process control application implements the fundamental idea of the vibrating wire method. If a stretched wire is excited by an alternating current (AC), then it starts oscillating in a static magnetic field. The AC frequencies corresponding to natural wire resonances cause especially large vibrations, which makes such a system extremely sensitive to the existence of the magnetic field along the wire. Essentially, the fact that the wire stretched in a multipole magnet stops vibrating means that the effective magnet axis and the wire are aligned. So, to locate this axis one should move the wire until its oscillations vanish. The vibrating wire method is one of the most accurate techniques to determine the magnetic axes of multipole magnets.

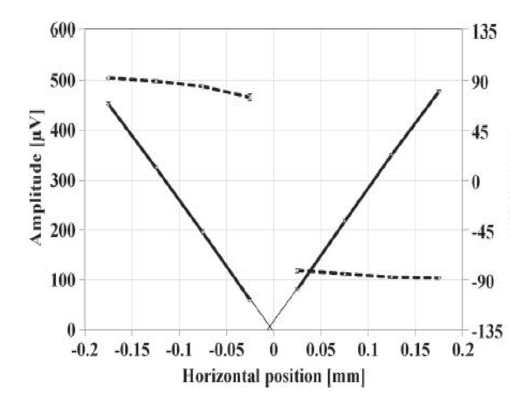
The vibrating wire test bench is installed in a separate room, which is not air conditioned, to minimize the air flow. The magnet and air temperature are monitored by the control module developed at PSI (the resolution is 0.01º C). Electronics is kept outside of this room to make sure that temperature changes during measurements are low and slow.

Basic setup elements

- Two pairs of linear motorized stages Newport M-ILS150CCL with their controller units SMC100 having RS232 external interface.
- A lock-in amplifier HF2LI (Zurich Instruments).

The HF2LI control software was significantly modified in the last two years to allow one to reliably communicate with such amplifiers on any Windows and Linux computer over a local USB port. Based on the used magnet measurement setup and its characteristics, the implemented vibrating wire state machine software performs the next basic functions.

- Power the wire by the HF2LI amplifier with a specified AC.
- Move the wire to a specified horizontal and vertical position inside the magnet aperture.
- Activate phase lock loop of the HF2LI to the constant filed component along a pre-calculated path.
- Measure and record the horizontal and vertical wire coordinates on that path as well as demodulated amplitudes of pickup coil signals in some predefined time interval.
- Calculate the average values of the recorded amplitudes.
- Plot the average amplitudes against the position of the wire in the magnet.
- Define the magnetic axes of the magnet. As the amplitude is always a positive number, there are two linear fits, one with a negative and one with a positive slope. The intersection point of these two fits is taken for the magnetic axis. In particular, for quadrupoles such a plot looks like one shown here, which is the result of a horizontal scan through a quadrupole magnet.



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.

Main setup components

- Newport XPS motion controller with advanced trajectory and synchronization features (external triggering).
- Two pairs of linear motorized stages Newport M-ILS150CC.
- Keysight 3458A digital multimeter.

The wire is stretched between two holders mounted on vertical stages. The stages are configured (as XY groups) to synchronously move both ends the wire along a specified arc. As a result, the system gets ready to execute any cylindrical wire motion. The measurements are handled by the moving wire process control (MWPC) application that communicates with the XPS unit and DMM device over the computer network. The application is based on the EPICS synApp software package. The XPS support part of this package was modified to fit PSI data acquisition and measurement requirements and run reliably on any (32 or 64 bit) Linux PC. The application is accompanied by a set of MEDM and caqtdm GUI panels, which are very easy to use. They guide a user through a sequence of required measurement and data acquisition steps, which are controlled by the state machine software. These steps can be described as follows.

-A desired wire trajectory is defined. The trajectory is a set of reference points through which the wire has to be moved as well as a number of equidistant points in which the XPS unit will generate trigger signals for the DMM device and write corresponding wire coordinates into its local memory buffer.

-The wire trajectory information is saved into a wire trajectory definition file. Based on this file, the MWPC application configures the XPS unit to execute the specified trajectory.

-The MWPC application sends the command to the XPS unit to execute that trajectory.

-The XPS unit executes the specified wire trajectory. The XPS external trigger signals are caught by the DMM device, which saves the information about the flux change induced voltage of the moving wire at trigger moments into its internal buffer. The MWPC application assures that the DMM device configuration follows the XPS unit settings.

-When the wire motion is finished, the MWMC application transfers the XPS and DMM device internal memory buffers to the EPICS waveform records associated with a two-dimensional (2D) wire trajectory representation and corresponding wire voltages, which immediately makes all measurement data available for archiving, processing, modeling, etc.

CONCLUSIONS

The presented in this paper PCT has been in use for magnet measurements at PSI for about one year. Developed by magnet measurement and control system experts and implemented as user friendly GUI panels and powerful state machine software behind them, the PCT consistently shows its high reliability. It acts as a very efficient assistant that guides magnet measurement operators through the most optimized steps for each measurement method.