An instrument for precision magnetic measurements of large magnetic structures.

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A high precision system for measuring the three-dimensional distribution of magnetic fields over large volumes, such as those produced by accelerator magnets, has been designed and is working at the LLS facilities in Barcelona. This instrument can be calibrated to a precision of ±1 Gauss for magnetic fields of up to 1.5 T by means of an NMR system. After appropriate identification of the various sources of error, and the optimisation of the various parts of the instrument where they are generated, an overall precision of ±2 Gauss has been achieved, i.e. a relative precision of $\pm 2\cdot 10^{-4}$ for a nominal field of 1 T.

The principal elements are: i) an anti-vibration floor mount; ii) a moving arm containing a 3D Hall probe scans the volume (up to $500 \times 250 \times 3000$ mm^3) with a precision of ±50 μm in any direction; iii) a magnet/NMR system for routine calibration of the Hall probes; iv) a stabilised current converter for the magnets which supplies a maximum current of 1500 A; v) a cooling system, and vi) an instrument control and data acquisition system.

The goal of the measuring bench is to produce an as accurate and fast as possible field map of the device being measured. In order to achieve this, several critical aspects of the system have to be optimized; these aspects are independent of the "intrinsic" precision of the system and define the measurement protocol. Although this strictly can vary depending on the particular device under measurement, some common items can be drawn. These are:

- Discretization of the 3D space. A choice has to be made on the grid density and zone definitions. This strongly depends on the magnetic field intensity variation with position.
- Moving path choice. Since the motor system is not symmetric for the three axis (e.g. different speeds), a good choice for the path that connects the grid nodes is essential.
- Temperature stabilization. The measurement cannot start until the required thermal equilibrium is reached. This applies to both the magnet (cooling water) and Hall probe.
- Magnet current stabilization. The measurement cannot start until the DC current is stable within the accuracy of the power supply.
- Magnet hysteresis control. It is vital to cycle the power of an electro-magnet several time to reach saturation and achieve a common reference point. Without this, the measurements might not be reproducible.
- Mechanical alignment. Since the movements of the mechanical arm are referred to its coordinate system, it is necessary, prior to execute the measurement, to reference the mechanical centre of the magnet relative to the arm coordinate system, to which is referred the path.
- Calibration procedure. The measurement protocol includes a calibration just after every grid measurement, in order to correctly take into account any possible system and

environmental parameter drifts. From the calibration procedure we obtain two sets of data pairs $\{(V_i, B_i)\}$ for both the x and y axes.

Once all these procedures have been accomplished, the field measurement begins. The data acquisition and system monitoring is done following a finite state machine algorithm. At any time, the measurement can be aborted, stopped and restarted with new relevant parameters. Once all the instruments have been initialised, there is an option to concatenate measurements with different grids. During measurement, all relevant parameters (temperatures, current supply, position, measured Hall voltages, etc) are monitored in real time in the GUI. The control of the whole system can be done from any terminal connected to the main workstation via an X server.

Once the measurement or calibration has finished, all the measured and monitored values are downloaded in an ASCII tabulated file. Data reduction consists in the calculation of magnetic field values from measured Hall voltages. First, the calibration coefficients are extracted from calibration data file, and then they are applied to actual measured voltages. Other relevant parameters, as field gradients, field integrals, virtual field boundaries, fringe fields, etc. are then extracted from measured grid. All the results are written to an output ASCII tabulated file. The data reduction and analysis program has been written in LabView.

This system has been used for the evaluation of the storage ring bending magnets of ANKA synchrotron and is currently being used in the evaluation of the Canadian Light Source combined magnets, as well as the bending magnet prototype for the future Spanish synchrotron.