A VME-BASED LABVIEW SYSTEM FOR THE MAGNETIC MEASUREMENTS OF THE LHC PROTOTYPE DIPOLES

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ABSTRACT

A magnetic measurement system based on a set of rotating harmonic coils has been integrated together with the coil positioning and rotation control, the associated data acquisition and the power supply control using a PC. This PC is a mono-board VME module with its networking connection, local hard disk and serial interfaces. The PC communicates with its peripheral devices (the controller embedded in the power converter, the coil positioning PLC and the coil rotation hardware) via RS-232C lines and acquires data using VME modules: in-house designed voltage integrators for the magnetic measurement and a commercial ADC for real-time measurements. The software is a LabVIEW application: it handles and synchronizes the peripheral devices of the measurement system and the real-time tasks related to the data acquisition; it constitutes a man-machine interface for the operator and also directly stores field maps onto a file server. The system is operational on the test benches and has proved reliable, user-friendly and performed as expected.

1 INTRODUCTION

CERN has started a vigorous R&D program for its next accelerator, the Large Hadron Collider. This collider will have 1200 of double aperture superconducting dipole magnets to produce the very high magnetic field (8.35 T) necessary to guide the accelerated particles. These magnets will be produced by industry, but will need extensive testing at CERN to verify their performance. One of the main tests is the magnetic field quality test, for which a rotating coil measurement system based on VME and LabVIEW has been developed at CERN. This system will be described in this paper.

2 THE ROTATING COIL MAGNETIC MEASUREMENT SYSTEM

2.1 The measurement principle

A coil rotating in a static magnetic field measures the value and the geometrical quality of this field. During the coil's rotation a voltage (V) is induced which is proportional to the rate of change of magnetic flux (ϕ). Integrating this voltage between two angular positions (θ) gives the magnetic flux according to

$$\int V\,dt = K_{coil}\,(\phi(\theta) - \phi(0)) \qquad (1)$$

and is independent on the rotation speed[1]. The size of the magnetic flux depends on the size of the magnetic field and on the coil characteristics (dimension, number of turns, etc.). The main task of the measurement system is to determine the coefficients of the harmonic expansion for the field B in the aperture of a magnet[1], as defined by:

$$\mathbf{B}(z) = \mathbf{B}_y + i\mathbf{B}_x = \sum_{n=1}^{\infty} C_n \left(\frac{z}{R_{ref}}\right)^{n-1} \qquad (2)$$

where z is the complex variable $x+iy$, R_{ref} is the reference radius (10 mm for LHC) and C_n are the harmonic coefficients. This task is accomplished by a set of rotating coils driven by the acquisition system. Following standard techniques, the fluxes are Fourier analysed, obtaining the transforms $\tilde{\phi}(\omega)$. Finally the harmonic coefficients C_n are calculated from the frequency decomposition of the fluxes as

$$C_n = \frac{\tilde{\phi}(\omega)}{K_n}. \qquad (3)$$

Here K_n are geometry dependent coefficients computed from magnetic measurements of the coil geometry in a reference magnetic field. The K_n are collected in calibration tables for each coil set.

2.2 The system architecture

The measurement system consists of a rigid shaft with one or more coils on it (fig.1).

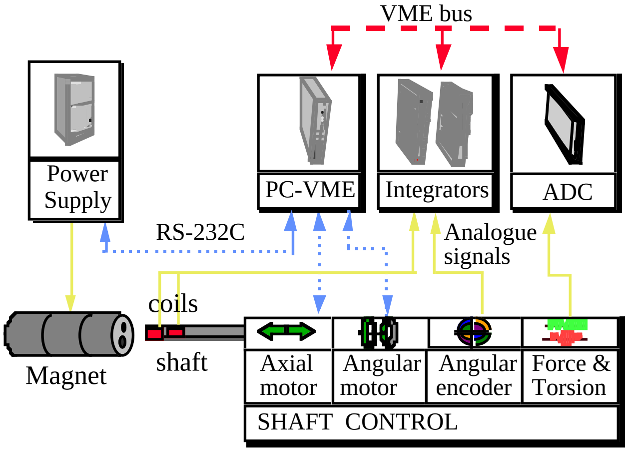

Fig.1. Schematic of the Magnetic Measurement System

This shaft can be rotated and moved axially by stepping motors. An angular encoder is used to synchronize the integrators with the rotational motion, while an ADC is used to check the bending force and torsion on the shaft. A PC (IBM compatible) in VME controls the entire system, using the VME access for the integrators and the ADC, and RS-232C for the motors as well as for a high current power supply, which generates the current for the magnet under test.

3 SYSTEM INTEGRATION USING LABVIEW

The LabVIEW system has two main benefits over previously used systems[2]: the user-friendly graphical interface and the integrated software environment. All sub-systems, the power supply, the motors, the integrators and the ADC, are programmed using LabVIEW.

3.1 LabVIEW on a PC in VME

The advantage of the PC in VME is the direct access to VME available through library calls from within LabVIEW in the form of Code Interface Nodes[3]. This library has been developed at CERN in the ECP division, and is available for several computer platforms which support LabVIEW (PC (IBM compatible and Macintosh) and SUN workstation). Other convenient features are the availability of 4 serial ports to connect to the coil motors and magnet power supply, and the on-board Ethernet interface and hard disk. It is the most compact solution for combining the LabVIEW software with the control and measurement hardware.

3.2 Instrument synchronization

To enable a fully integrated measurement solution requires careful hardware and software synchronization, because the same software application is used as man-machine interface, as an instrument controller and for real-time data acquisition.

During a measurement the axial position of the coil inside the magnet is not changed, but the coil is being rotated. The integrator is therefore synchronized by a hardware trigger from the axial encoder. The read-out of the integrator by the PC is synchronized by software polling on the integrator's status bit. The integrator read-out is the most critical real-time task for the PC. A new library function has been written to allow the read-out of at least 14 integrators simultaneously within the minimum time (4 ms) between angular encoder triggers. This time is calculated by $t_{min} = 1 / (n \cdot s)$, where n is the number of readings per rotation and s the speed in turns per second. For our system n = 250, and s = 1.

The power supply is synchronized to the magnetic measurement to within 1 second by software. This limit is determined by the relatively slow RS-232C serial communication between the PC and the power supply. To have the best precision of the current value during ramping, the current is read just before and just after each measurement.

4 SYSTEM OPERATION AND DATA HANDLING

The user configures a measurement through pre-defined, user-friendly panels which contain fields with default values, menus and loadable configurations. Before each measurement the physical properties of the coils should be known, how many coils are mounted on the shaft and which type of integrator is being used. A data-base has been made containing a complete description and parameter set (K_{coil}) for each coil configuration, which is a powerful tool for the operator to easily configure a measurement. Furthermore the user can choose between an absolute (1 coil) or a compensated measurement (2 coils, to compensate the main harmonics in the signal). Other information needed by the measurement application are at which positions inside the magnet should be measured and at which current (fixed or cycled). A current profile can be given which will be executed during the measurement. A combination of fixed and cyclic current measurements is possible. A full set of measurement definitions can be saved on the local disk. A measurement will be executed with the following steps:

- Axial positioning of the coil inside the magnet
- Current cycling by the power supply
- At a chosen current level the coil will rotate one turn forward and one turn backward while the integrators read the coil voltage.

The ADC is used to read the shaft bending force and torsion sensors. When these forces go over a certain threshold the angular position of the coil will be different from that given by the encoder and the measurement will be less accurate. In such a case the operator is warned.

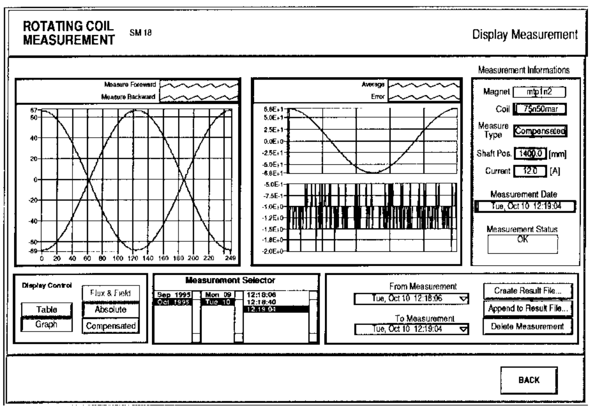

Fig.2. Result display in magnetic measurement program.

Raw data of the measurement are displayed (Fig.2) and automatically stored on the local disk and can be transferred to a file server. Each measurement is indexed by the date and time and contains also the measurement definitions used for that particular measurement. Inside the measurement application an on-line analysis sub-program allows to compute the magnetic field on retrieval of the stored voltage data. This standard analysis of the fluxes takes the average of forward and standard rotation measurements, thus allowing during ramps of the field a first-order correction of the field drift (equivalent to a linear interpolation between the measured points). This feature is used to measure field and field errors *on-the-fly* and has been proven to lead accurate results for dynamic effects[4].

The analysis being a sub-program allows the user to change the analysis algorithm and to re-do the field calculation if necessary. The resulting field data is displayed and can be exported in text format for analysis with other software packages on different computer platforms.

5 CONCLUSIONS

The presented VME-based LabVIEW system for the magnetic measurements of the LHC prototype dipoles is a compact system where one software application provides the integration. The hardware for the magnetic measurement (integrators, ADC, axial and rotating movement of the coils) had been developed prior to the integration with LabVIEW. The LabVIEW application has been developed to have a user-friendly graphical interface to define and execute a measurement. Another advantage is to have the same software at all levels of the system, from the user interface to the equipment drivers.

The system is operational on two test benches at CERN and has proven its user-friendliness and performs adequately for the present use.

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