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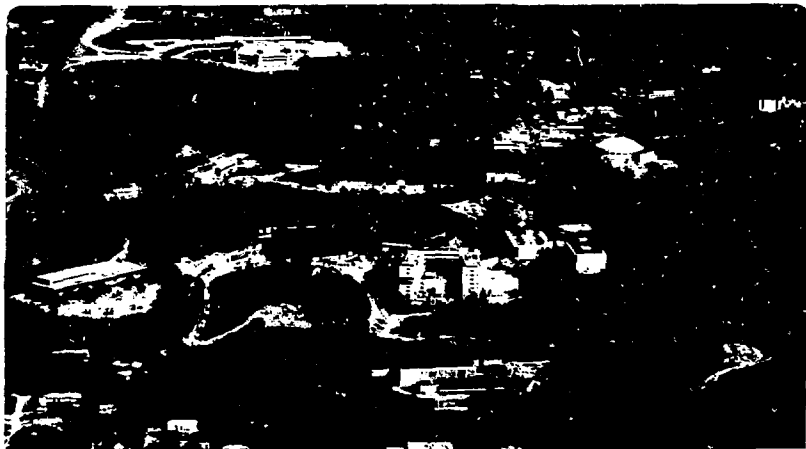
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THE LBL MAGNETIC-MEASUREMENTS
DATA-ACQUISITION SYSTEM

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Summary

The LBL Magnetic Measurements Engineering (MME) Group has developed a Real-Time Data-Acquisition System (DAS) for magnetic measurements. The design objective was for a system that was versatile, "portable," modular, expandable, quickly and easily reconfigurable both in hardware and software, and inexpensive. All objectives except the last were attained. An LSI 11/23 microcomputer is interfaced to a clock-calendar, printer, CRT control terminal, plotter with hard copy, floppy and hard disks, GPIB, and CAMAC buses. Off-the-shelf hardware and software have been used where possible. Operational capabilities include: (1) measurement of high permeability materials, (2) harmonic error analysis of (a) superconducting dipoles and (b) rare earth cobalt (REC) and conventional quadrupole magnets, and (3) 0.1% accuracy x-y mapping with Hall probes. Results are typically presented in both tabular and graphical form during measurements. Only minutes are required to switch from one measurement capability to another. Brief descriptions of the DAS capabilities, some of the special instrumentation developed to implement these capabilities, and planned developments are given below.

Introduction

The MME DAS was developed to meet LBL requirements for magnetic measurements, requirements which are both varied and unpredictable. Often, our two-man group is not informed of the specifications for a measurement until shortly before the results are needed. We have been asked to make a harmonic analysis of a quadrupole on the same day we were scheduled to make permeability measurements. Although it would be more convenient for us to make magnetic measurements in one of our three limited-purpose MME laboratories, the power structure at LBL has discouraged us from moving the Bevatron accelerator! Therefore, our measurements are made in assembly shops, existing beam lines, or interiors of existing accelerators. Accuracy requirements vary from 100% to 1 part in 10^6. A wide variety of measurement techniques and instrumentation is needed to meet customer requirements. Although the MME DAS general design was defined in our minds several years ago, its evolution has been determined by the immediate needs of projects and the realities of available funds.

The System

Figure 1 is a block diagram of a mapping system representative of the present state of our hardware.

Computer

Primary interfacing of the LSI 11/23 microcomputer is accomplished on the DEC Q-BUS. Attached to the Q-BUS are 128 kwords of RAM, a Digital Pathways Clock Calendar, a DSD 440 dual double-density floppy disk system, a DEC RL02 10-Mbyte hard disk, a Standard Engineering Co. CAMAC interface, a National Instruments GPIB interface, and a DEC DLV11-J 4-channel RS 232 interface. Connected to the DLV11-J are a DEC LA-120 printing terminal (used primarily as a printer), a Tektronix 4051 graphics minicomputer (for plotting) with a Tektronix 4631 Hard Copy Unit, and two Zenith Z-19 CRT terminals. During a measurement, a single CRT terminal, used as a control terminal, also presents status information to the operator. The second

CRT terminal is used under the TSX PLUS time-share operating system for system development.

CAMAC Digital Bus

The CAMAC bus is typically used for digital I/O. Shown interfaced in Figure 1 are two stepping motor controllers, two 4-channel up-down counters, and a MME optical encoder interface. Mechanical stage position is recorded by up-down counters monitoring optical encoders mounted on lead screws. By this means, stage positions are determined independently from the position command. This independent determination has been extremely helpful in debugging our mechanical stages.

Other implementations of the measurement system use CAMAC modules that control power supplies, monitor the LBL/CERN MME magnetometer, monitor/control the MME Precision Programmable Bipolar V/I converter[1,2] and the MME very low noise Programmable Search Coil Switching Module.

Analog GPIB Bus

Interfaced to the GPIB Bus is a Hewlett Packard Model 3455A 6-1/2 digit DVM, which is multiplexed by means of a Hewlett Packard Model 3495A Scanner. This combination monitors the outputs of power supply shunts, Hall effect gaussmeters, and analog integrators. (Not shown is an ICS Model 4880 Instrument Coupler, used to interface the logic bins used in harmonic error analysis of magnets, and a Hewlett Packard Model 3437A High Speed 3-1/2 digit DVM.) To date, all high precision/resolution analog data has been acquired on the GPIB Bus.

Software

The RT-11 operating system was designed by DEC for real-time applications. Programming is done in FORTRAN IV. Software libraries utilized include: Tektronix PLOT 10 (TCS) for plotting, DEC Laboratory Subroutines, DEC Scientific Subroutines, OHNEX Sub-Device Package to partition the RL02 hard disk to floppy-disk-size sections, S&H Computer TSX PLUS time-sharing system for program development, Standard Engineering Co. CAMAC library, and the National Instruments GPIB library.

A major reduction in system costs occurred when we switched from flow charting to structured programming[4] and structure diagrams. Short structured programs are written that are primarily only calls to subroutines or groups of short subroutines. Short subroutines are easier to debug and often have wide utility. Structured programming has significantly reduced the effort necessary to design, maintain, and modify complex data acquisition systems.

Applications

Mapping

Figure 1 is the block diagram of the system used to tune and map the LBL/SSRL/EXXON wiggler.[5,6] SC 2 and SC 3 are long search coils which are positioned by hand to measure field integrals needed to tune the wiggler. The computer is programmed to prompt the operators in a sequence of actions that move the coils and acquire and process the raw data. SC 1 (one wiggler period long) and three orthogonally mounted Hall probes are on a moving stage. A map with a grid of 3 X-positions and 2201 Z-positions consists of a collection of 50,000 numbers and requires 4 1/2 hours. The

Figure 1. Block diagram of the LBL MME DAS configuration for tuning
and mapping the LBL/SSRL/EXXON wiggler magnet.

raw data is plotted in real time. Post-processing
programs curve fit in the vicinity of the peaks deter-
mining peak magnitude and positions for the 57-pole
wiggler. Other post-processing programs make expanded
scale plots of the fields measured. The wiggler mag-
net is reported in Reference 5; some of our measure-
ments are included in this report.

Harmonic Error Analysis of Dipole and Quadrupole Magnets

Error harmonics and the fundamental signal are
measured using search-coil arrays rotating slowly on
a symmetry axis of the magnet. A single search coil
detects the fundamental signal during the first cycle
of rotation. The search-coil arrays are reconfigured
to buck the fundamental and lower harmonics during
the second rotational cycle, allowing the measurement
of higher harmonics with excellent resolution. Data
is first drift corrected, then harmonic analysis is
done using the Fast Fourier Transform Technique.

We plot the drift-corrected raw data and a semilog
bar graph of the error harmonic ratios. A table of
the error harmonic ratios and their phases relative
to the fundamental is printed. For a quadrupole mag-
net, the measurements, data processing, and output
described above require about 90 seconds.

We have developed a post-processing program for
"fixing" permanent magnet rare earth cobalt (REC)

quadrupoles.[7-9] The shims required to "zero" selec-
ted harmonics are calculated. An REC quad can be
measured, shimmed, and remeasured within a half hour.

Several specialized electronic modules have been
developed for harmonic analysis systems. The MME
very low noise Programmable Search Coil Switching
Module feeds signals to the MME Precision Programmable
Bipolar V/f converter, which in turn feeds a latchable
up-down counter in an LBL logic bin. The combination
of the V/f converter and up-down counter functions as
a digital integrator. While the "digital integrator"
continues to count, the contents of the counter are
periodically latched and sent to the computer by pul-
ses from an optical encoder mounted on the shafts of
the search-coil arrays, i.e., data is collected "on
the fly."

Permeability Measurements

Because the conceptual design for a permeameter
suggested by Dr. Klaus Halbach in 1978 used a tech-
nique for determining magnetic intensity that is
unique among permeameters described in the literature,
we have suggested that the measurement technique and
the D.C. permeameter be named after Halbach.[10]

A cylindrical sample is "sandwiched" between the
pole tips of an electromagnet. The "B-coil" surrounds
the central portion of the sample in the usual manner.
Magnetic intensity, H, is determined from a separate

measurement of magnetic induction, B, using the following unique technique. A 0.080-inch diameter axial Hall probe measures B in a small (0.100-inch diameter) hole located on the symmetry axis of the sample. $H_{air} = B_{air}/\mu_o$ and, because the tangential component of H is continuous at any boundary, H_{sample} is determined. The magnetomotive force is provided by a bipolar power supply. The DAS controls the sequencing of the magnetomotive force and the measurements of quantities for determining B and H.

One advantage of the Halbach permeameter over permeameters described in the literature is that the B-coil may be removed from the sample and placed in a "zero" field reference. This makes it possible to measure flux linkage absolutely, rather than measuring only changes in flux linkage. A second advantage is ease of measuring magnetic properties at very high magnetizing intensities. Whereas permeameters without iron return paths may be limited to magnetizing intensities up to 1000 Oe, our first implementation, using a 30-year-old convection-cooled magnet, enabled us to measure up to 8000 Oe.

The time table for automating the Halbach permeameter illustrates the versatility of the DAS. We were preparing to measure the harmonic content of a superconducting dipole in September 1981 when E. Hoyer asked us to make permeability measurements of vanadium permendur at higher magnetizing intensities than were available on commercial charts. In less than two months, the system was operational and preliminary results had been obtained.

Discussion

In November 1979, we envisioned a data acquisition system that encompassed a major portion of anticipated measurements. We have implemented many of the capabilities we originally anticipated. In May 1980, our initial DAS configuration was a quadrupole harmonic analysis system.[11] In October 1981, we automated a permeammeter for measuring permeability at magnetic intensities above those reported in the literature. In October 1981, we made harmonic analysis measurements of a superconducting dipole magnet.[12] In July 1982, we implemented a 2-dimensional mapping system with a position precision of 0.01 mm.[13] In January 1983, we reconfigured the mapping capability to measure three orthogonal components of magnetic induction on the 2-m length of the LBL/SSRL/EXXON 57-pole REC/vanadium permendur wiggler.

Although none of the implementations of the DAS discussed above were inexpensive for its first application, subsequent applications of implementations have been very competitive. Software, a major cost, is being reduced as we create a larger library of transportable subroutines. The mechanical hardware for the two mapping systems was very expensive, about $30,000 each. The conceptual design for a versatile and reconfigurable 3-axis, 3-component mapping system has been started. Position determination by laser interferometry should allow the use of inexpensive mechanical positioning hardware. We also intend to automate NME floating-wire analog measurement techniques and to interface and update other magnetic measurement instruments developed at LBL.

The versatility and reconfigurability of the LBL Magnetic Measurements Data Acquisition System have

brought demands for its services that have exceeded expectations.

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