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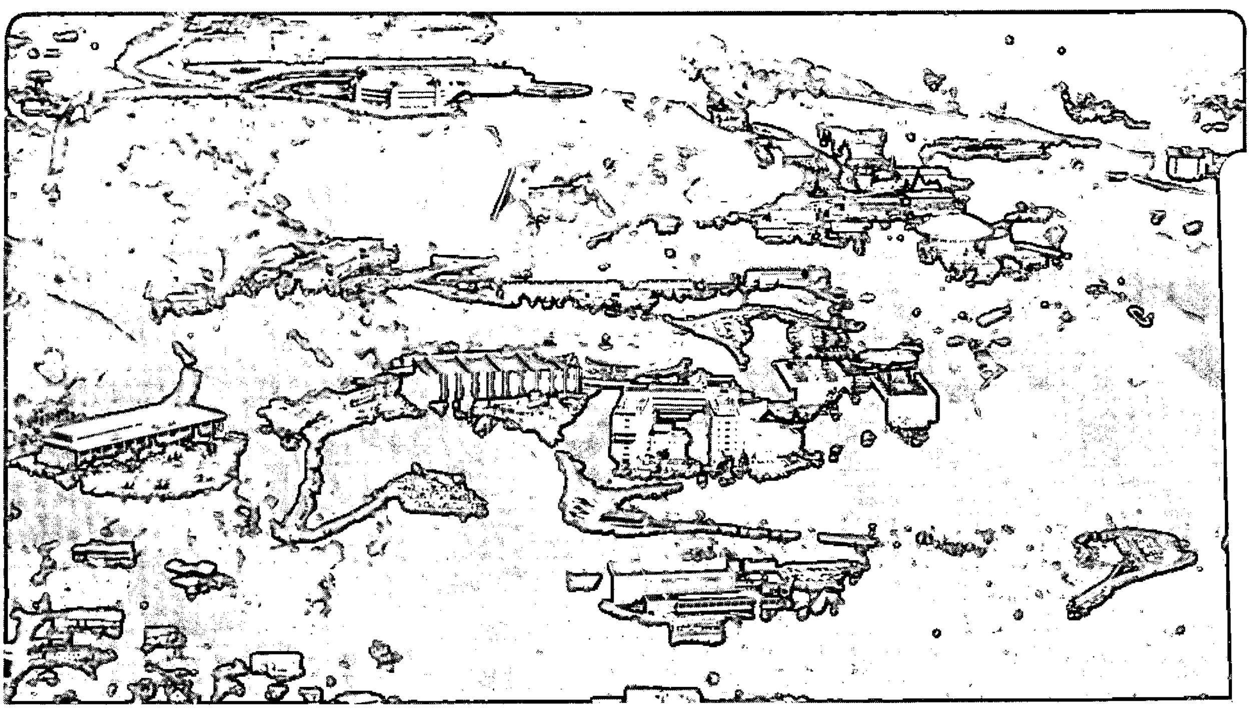

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Magnetic Measurements at Lawrence Berkeley Laboratory*

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Abstract—Recent magnetic measurement activities at LBL have been concentrated in two separate areas, electro-magnets and permanent magnets for the Advanced Light Source (ALS), and superconducting magnets for the Superconducting Super Collider Laboratory (SSCL). A survey of the many different measurement systems is presented. These include: AC magnetic measurements of an ALS booster dipole engineering model magnet, dipole moment measurements of permanent magnet blocks for ALS wigglers and undulators, permeability measurements of samples destined for wiggler and undulator poles, harmonic error analysis of SSC one meter model dipoles and quadrupoles and five meter long SSC prototype quadrupoles, harmonic error analysis of ALS dipoles, quadrupoles, and sextupoles, precision Hall probe mapping of ALS storage ring combined function magnets, and the design of the ALS insertion device magnetic mapping system. We also describe a new UNIX based data acquisition system that is being developed for the SSC. Probes used for magnetic measurements include Helmholtz coils, integral coils, point coils, and bucking harmonic analysis coils, several different types of Hall probes, and nuclear magnetic resonance magnetometers. Both analog and digital integrators are used with the coils. Some problems that occurred and their rectification is described. The mechanisms used include rotating systems with optical encoders, X-Y mapping systems with optical encoders and a laser position measuring device.

SSC MEASUREMENTS

SSCL 5- meter Quadrupole Prototypes

The Superconducting Magnet Group at LBL is developing prototype 5-meter long quadrupoles for the SSCL. The DAS (data acquisition system) used for measuring 1-m model dipoles and quadrupoles is being "upgraded" for the Supercon Group[1]. There are several reasons for the upgrade.

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Both the microprocessor, a DEC LSI 11/73 and the RT-11 operating system are obsolete. Although the real-time data acquisition code is well structured and results of a single measurement are printed within seconds of completing a data acquisition cycle, reporting results of a test series is involved and time consuming. The raw data saved for a test series is first post processed to create ASCII files. The ASCII files are transmitted by means of modems over phone lines to an IBM AT and imported into a Lotus 123 spreadsheet template. Graphs created by Lotus Graphwriter along with tables created by 123 are imported into a report generated by the word processor Lotus Manuscript. The data is really not available for computer manipulation or perusal by magnet scientists.

In coordination with the MTL (Magnet Test Laboratory) of the SSCL, we are developing a two cpu networked system. It makes use of a Unix Sun Sparc workstation as the measurement and analysis platform, with the actual real time data acquisition occurring in a VME crate running VxWorks, a real time Unix-like kernel[2]. These two sub-systems are connected via an ethernet network.

Fig. 1 is a block diagram of the real time data acquisition hardware. The VME crate has both CAMAC and IEEE-488 interfaces. Except for the VME Interrupt module and the search coil with its associated drive system, the instrumentation is the same as reported earlier. The tangential coil and its drive system was fabricated by Brookhaven National Laboratory for us. It is a continuously rotating type with a 42 cm long search coil array utilizing slip rings.

Application code is written in ANSI standard C, compiled using the Free Software Foundation C compiler, gcc. During measurements, the VME controller is slaved to a Sun workstation and cannot be accessed by other computers. Operator interaction, data analysis and display occurs in the workstation.

This new system has been successfully run at 1.75 seconds per revolution which is 4 times faster than the RT-11 system is capable of, and exhibits lower noise. It is possible that system rotational speed can be increased further. The fast rotational speed should allow good measurements on the fly while the magnet is ramping.

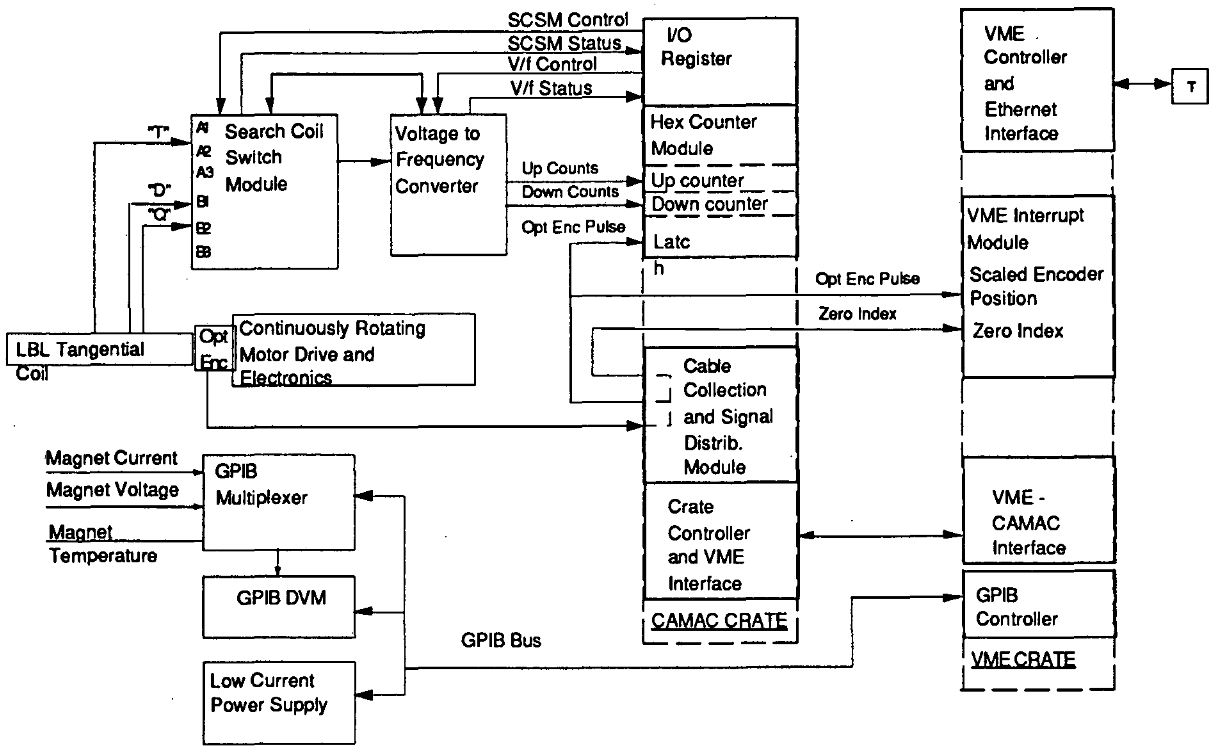

Fig. 1. Block diagram of SSCL Harmonic Analysis System.

The system is flexible and should be capable of utilizing either analog or digital bucking, and acquiring either coil voltage or magnetic flux data. The data is structured to allow smooth integration into a commercial database. On the negative side, it is complicated and not yet well documented. Development and documentation are continuing.

Cryogenic Quadrupole Search Coil Array

This search coil array was described at MT-10[3]. It was designed to measure the strength and harmonics of SSC 1-model quadrupoles. Two problems have occurred with this array.

Electrical continuity has been lost in two of the coils. Initially for one of the coils, continuity would be lost during cool-down and regained during warm-up. Using TDR techniques, the fault was determined to be in the vicinity of the solder connection between the coil and the lead wires. Further cool-down cycles have resulted in a complete loss of continuity for this coil. It should be noted that this array was patterned after a cryogenic dipole search coil array that has undergone many more cool-down/warm-up cycles without failure.

The other problem that this array exhibited was that cryogenic measurements produced a gradient that was 10% lower than warm measurements. The quadrupole gradient is measured by a coil ten cm long at the longitudinal center of the array. The coil array has four equally spaced Rulon bearings. Each bearing rides on two dimples , each dimple 45° from the bottom center line. It was hypothesized that when cryogenic, the array bowed ~0.4 mm reducing the effective radius of rotation of the outer coil bundle. Mechanical measurements at liquid nitrogen temperature confirmed the occurrence of bowing. At each bearing location additional dimples were added to the bore tube above the bottom two dimples in order to constrain bowing of the array. This modification resulted in much better agreement(±1%) between warm and cryogenic measurements.

ALS INSERTION DEVICE

Block Magnetic Measurements

Magnetic moment measurements of insertion device blocks have been made at LBL since 1982[4,5]. The manual procedure used was slow, tedious, prone to operator error, and incompatible with the large number of blocks to be measured for ALS insertion devices.

An improved system has been developed that can process blocks at a rate of up to 40 per hour, is much easier to use, minimizes human error, and stores data in a standard, secure and accessible format[6].

Fig. 2 is a logical block diagram of the hardware components and their interconnections. The system consists of 60 cm diameter Helmholtz coils and a rotating block holder driven by a servo motor. An incremental rotary disk encoder is attached directly to the spin axis. A linear actuator is coupled to the block holder and produces a 90° block flip.

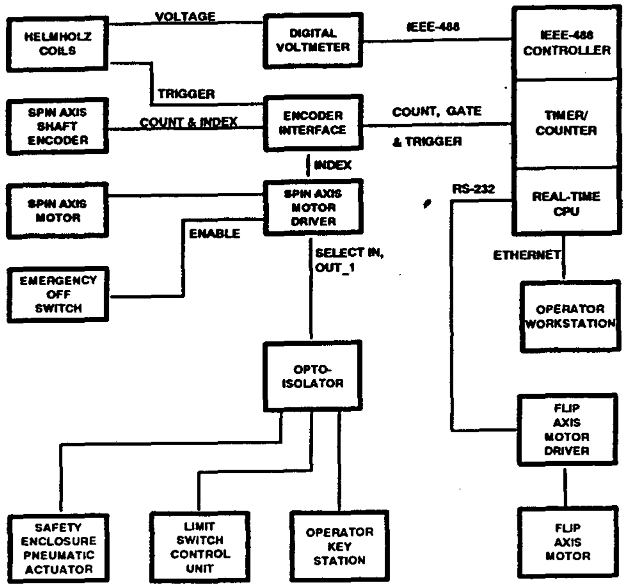

Fig. 2. Block diagram of Helmholtz coil hardware components.

The Helmholtz coil voltage is sampled 256 times per revolution for 10 revolutions. The voltage is corrected for the instantaneous velocity and the values from each revolution are Fourier analyzed separately. The average of the 10 resulting amplitudes is used to obtain the value of the dipole moment while the variation in the amplitude is a measure of the error.

The three components of magnetic moment are determined by first rotating the block so that it rotates about an axis parallel to m_X , and then flipping the block so that it rotates about m_Z. A Fourier decomposition of the sampled voltage for the first orientation determines m_Z and m_Y. Components m_X and m_Y are determined from the second orientation (note the redundancy measurement of m_Y.

This system has been operational since January 1991 and over 5000 Nd-Fe-B blocks have been successfully measured so far.

Insertion Device Magnetic Measurements

The system is in the design stage. The z-axis motion will be pneumatically actuated. The z-position will be measured by laser interferometry. Field profiles will be obtained by both Hall probes and one-period coils. The data acquisition system will be similar to that used for ID block measurements. It is anticipated that a field profile of 4.5 meter long undulators will take between 1 and 2 minutes.

Permeability Measurements

An improved version of the Halbach Permeameter has recently been regenerated to allow testing various heat treatments of vanadium permendur samples[7]. This system measures intrinsic induction [B-μ_0H], B(sample), and the relative permeability [μ=B/μ_0H], versus the magnetizing force, H in oersteds from ~5 to 7000 oersteds.

ALS BEAM LINE MAGNETS

Quadrupoles, Sextupoles and Small Dipoles

Harmonic analysis measurements prototype and production magnets have been made with the analog integrator based system developed by the ALS Magnet Group and the digital integrator based system developed by the Magnetic Measurements Group[8].

Booster Dipole AC Measurements

10 Hz sine wave and 2 Hz sawtooth AC magnetic measurements of the curved ALS booster dipole engineering model magnet were made[9]. Long curved coils were utilized to measure the integral transfer function and integral uniformity. Point coils and a Hall probe were used to measure magnetic induction and its uniformity. The data were logged and processed by a Tektronix 11401 digital oscilloscope. The dependence of the effective length on the field was determined from the ratio of the integral coil signals to the point coil signals. Quadrupole and sextupole harmonics were derived from the point and integral uniformity measurements.

Storage Ring Bending Magnet

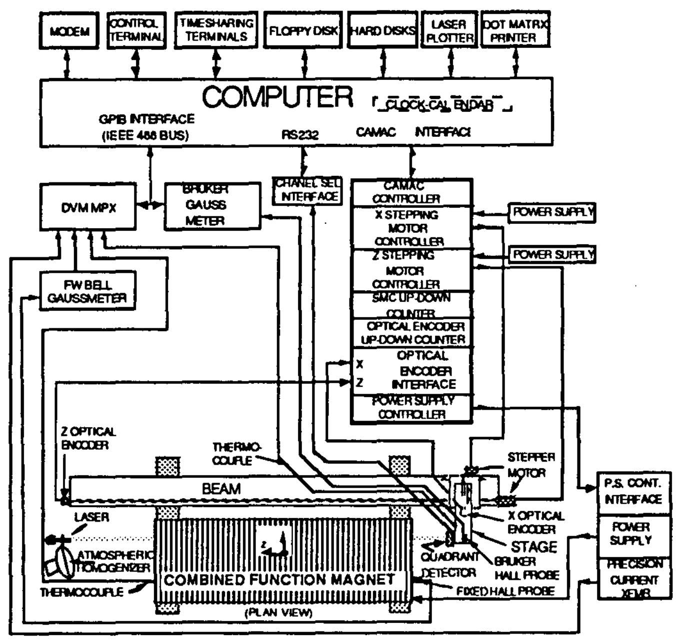

Fig. 3. ALS Storage ring bending magnet magnetic measurement block diagram.

The storage ring bending magnet is a straight, parallel-ended combined function magnet with the following main parameters: bend angle, 10°; magnetic length, 0.865 m; pole tip field 1.047 T and field gradient, -4.036 T/m, (at 700 A); rms field integral tolerance, 1×10^{-3}. The integrated dipole field, the integrated gradient, the core field and the core gradient are measured at excitation currents of 480, 700, and 910 A. The central part of the magnet, extending ±250 mm longitudinally is defined as the magnet core.

Fig. 3 is a block diagram of the instrumentation used to acquire data. Mounted to a Brunson beam is a mechanical stage. Stepping motors turn x and z lead screws which move the stage while rotary optical encoders mounted to the lead screws monitor the stage position. Moving with the stage is a Brüker Hall probe that maps the field, a thermocouple and a quadrant laser beam detector. As the Brunson beam is not perfectly straight and occasionally, poorly aligned with the magnet, the quadrant detector allows us to monitor the x and y offsets of the central mapping position. X positions relative to the central mapping position are determined quite accurately (±10 μm) by the optical encoder. Attached to the lower pole of the magnet is a thermocouple and a fixed Hall probe. Prior to each map, the laser beam is aligned with the central axis of the magnet. The atmospheric homogenizer (electric fan) eliminates temperature gradients which can perturb the position of the laser beam.

A full map takes 3 hours and covers the area from -90 to +90 cm longitudinally and from -3 to +3 cm radially with 1 cm increments both radially and longitudinally. At each of the 1267 positions, the computer records 11 parameters: x and z optical encoder counts; laser measured x and y offsets of the stage in the central position; the mapping field and the fixed Hall probe voltage; the multiplexer reference temperature along with the temperatures determined by the moving and fixed thermocouples; the magnet voltage and precision current transformer voltage; and finally, the time each data subset is acquired. Also saved in the file with the data subsets is a header which includes numerous test parameters. During data acquisition, the mapping field is plotted in real time along with expanded scale (±0.2%) plots of the current and fixed Hall probe output.

Two post-processing programs access the raw data files and generate physical parameters. The plotting post processing program can generate expanded scale plots of any subset parameter. It also allows the operator to choose a segment of the mapping field, correct the data in the segment for current or fixed Hall probe field deviations and then do a linear least squares fit of the data in order to determine how well the mapping stage is aligned with the magnet. The other post processing program generates ASCII files that are transmitted to magnet engineers and accelerator physicists. One ASCII file contains the 11 subset parameters converted to physical parameters, the other ASCII file contains just the mapping field at each position along with a statistical analysis of the other data subset parameters.

Statistics at the nominal 1.5 GeV condition (700 A excitation current) for the eight magnets so far evaluated are given in Table I [10].

TABLE I
STORAGE RING BEND MAGNETS FUNDAMENTAL PARAMETERS

	BL [Tm]	dB/dx L [T]	B [T]	dB/dx [T/m]
Average	0.9057	-3.419	1.0469	-4.038
σrel [10^{-3}]	0.42	0.66	0.25	0.67
Relat. Worst[10^{-3}]	0.88	1.02	0.39	1.02

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