Magnet Measurement Facility for the 7-GeV Advanced Photon Source*

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Abstract

A magnet measurement facility for semi-automatic measurement control and real-time data analysis has been developed to measure more than 1000 magnets for the Advance Photon Source (APS). One dipole and three rotating coil measurement systems and corresponding probe coils are described.

I. INTRODUCTION

The APS magnet system requires more than 1000 conventional resistive magnets for the storage ring (SR), injector synchrotron (IS), positron accumulator ring (PAR), and beam transports [1]. Main characterisitics of the magnets, except those for the beam transport, are listed in Table 1. The magnets are required to measure and evaluate the field strength and field quality to a few parts in 10^{-4} to verify the tolerance requirements. Equally important parameters to be measured for the magnet alignment are the magnetic axis and roll angle with repect to a fiducial within tolerances of 60 μm and 0.3 mrad, respectively. The measured data is also being used for the quality control of the magnet fabrication procedures and the correction of some magnets with unacceptable tolerances.

In order to meet the project schedule and technical requirements of the measurements, a magnet measurement facility has been developed. The facility includes a dipole measurement system, three rotating coil systems for quadrupole and sextupole magnets, Hall-probe field mapping, and various types of probe coils. The measurement systems have been extensively tested in parallel with the development of various prototype magnets.

II. DIPOLE MEASUREMENT SYSTEM

A block diagram of the dipole system is shown in Fig. 1. A 3-D mapping unit with a calibrated Hall probe measures detailed end-field and 2-D field-shape for the prototype and reference magnets. A Hall-cart unit is used to measure the field integral along the designed beam orbit of the reference magnet.

The production dipoles are measured comparatively with respect to a reference dipole. Two sets of curved coils are used, one fixed in the reference magnet and one in the testing production magnet. The two coils in the reference magnet are used as the bucking coils for the field-integral and 2-D field measurements. These coils are calibrated against the Hall-cart measurements.

The probe coils are flat printed circuit coils connected in series according to the curvature of the magnet. A printed circuit coil is 0.5 m long with an average width of 6.8 mm, height of 3.3 mm, and 170 turns.

Table 1
Main Characteristics of the APS Magnets

	Magnetic length(m)	Pole gap, dia.(mm)	Field strength	No. of magnet
SR dipole	3.06	60	0.599T	80
IS dipole	3.10	40	0.696T	68
PAR dipole	0.80	45	1.47T	8
SR quad	.5/.6/.8	80	18.9T/m	400
SR sext	0.24	100	490T/m^2	280
IS quad	0.60	56.56	13.9T/m	80
IS sext	0.20	70.01	130T/m^2	68
PAR quad	0.25	120	4T/m	16
PAR sext	0.20	130	10T/m	10

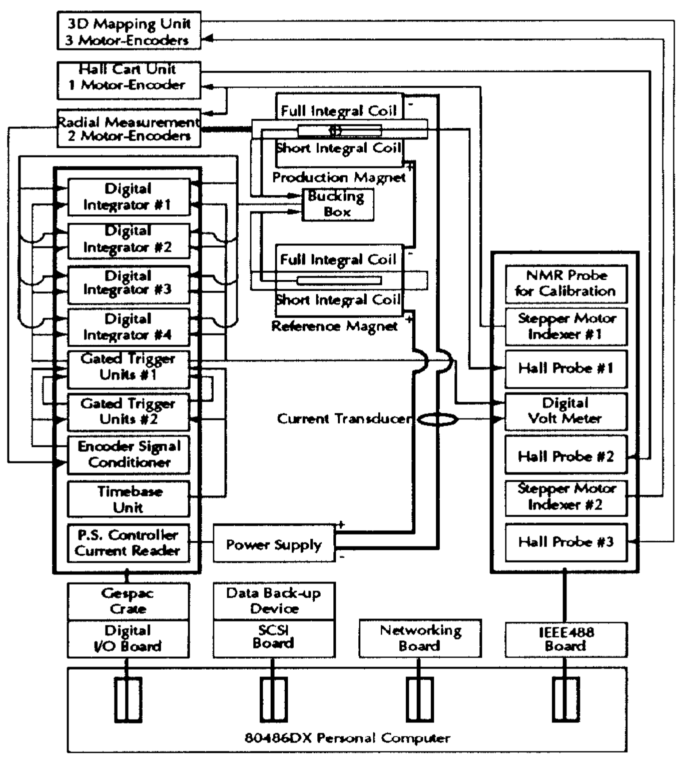

Figure 1. Block diagram of the dipole measurement system.

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Four high-precision digital integrators, which are voltage-to-frequency converters, are used; one each for the field integral and 2-D field of the reference magnet and two for the respective bucking signals between the two magnets. Since the integrator connections conform to G-64 Gespec Crate specifications, IBM digital I/O interfaces and other modules, developed for the measurement control and data acquisition, were modified to configure to Gespec Crate requirements.

An operating system shell on MS-DOS called GPDAS has been developed to provide greater flexibility when taking measurements and performing data analyses [2]. The shell contains the software drivers to interface with GPIB and digital I/O boards, Gespec Crate, and other required PC boards.

The measurement procedures, including control of the magnet current and data analyses in "real-time," are automated. For measurement of IS dipoles, which have an "H-type" cross section, the probe coils are installed and removed manually through one end of the magnet. However, since the pole gap of the "C-type" SR dipole is accessible from one side of the magnet, this measurement procedure is fully automated.

During the prototype and production measurements of IS dipoles, it has been firmly established that relative accuracy and reproducibility of the field strength and field shape measurements are better than 1×10^{-4}.

III. MULTIPOLE MEASUREMENT SYSTEMS

Two of the three systems are modified versions of the rotating coil measurement bench developed at CERN and fabricated by Danfysik [3]. The third system, developed at Argonne, has additional features for measurement flexibilities such as different probe lengths. Shown in Fig. 2 is a block diagram of the rotating coil system. A rotating coil cylinder, supported by two air-bearings, is rotated by a DC motor. A 15-bit absolute encoder triggers the integration of the induced voltage in the coil at 256 angular positions per turn.

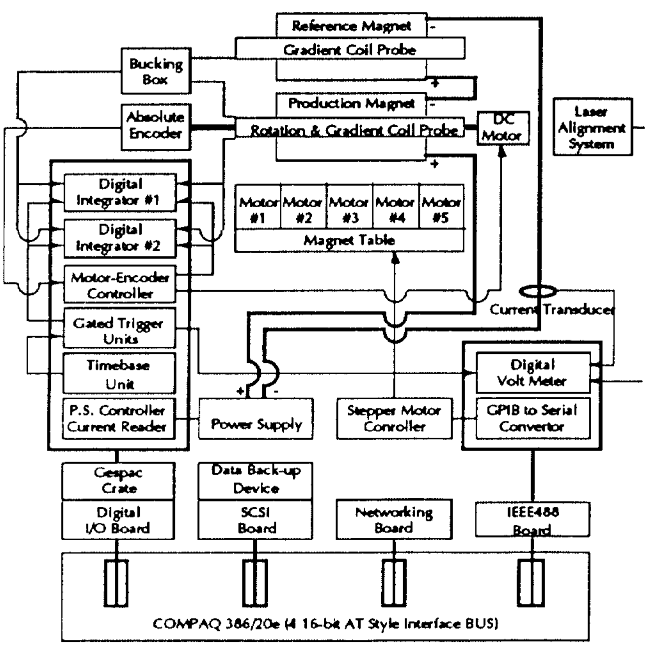

Figure 2. Block diagram of the rotating coil measurement system.

Since the air-bearing positions are fixed to the base table, the magnet position has to be controlled and pre-aligned to the rotating coil axis using five stepping motors. A precision laser and photo-quadrant detector are used for the alignment. The position of the laser, mounted on one end of the base table, is precisely measured from the axis of the rotating coil cylinder. The detector, mounted in a Taylor-Hopson ball, is placed on top of the testing magnet. From the harmonic analysis of the rotating coil measurements, the magnet is aligned to the rotating coil axis. Then, the detector reads the fiducial position with respect to the magnetic center.

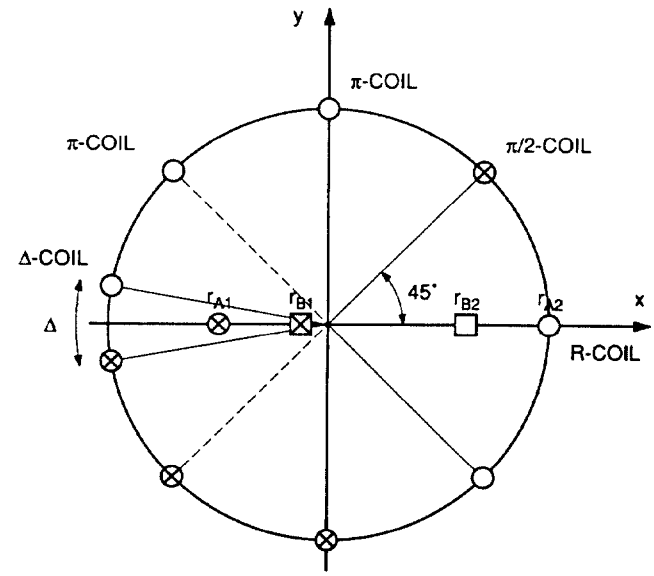

Figure 3. Cross section of the radial and tangential coil geometries.

IV. ROTATING COIL PROBES

One of the critical components for the multipole measurements is the rotating coil probe. Figure 3 represents the cross section of a rotating coil geometry. The probe in Fig. 3 has two different types of coils: "radial" and "tangential." The radial coil set is located in the plane of the x-axis, while the tangential coil set is installed on the cylinder surface. The radial coil set consists of two separate coils, one for measuring the main field and one for multipole coefficients after bucking the main field.

In Table 2 parameters of the two types of coil sets for quadrupole and sextupole measurements are listed. The ratio of the number of turns and the radii of the coils are denoted as N_a/N_b and r_a/r_b, respectively.

The tangential coil set in Fig. 3 consists of a Δ-coil, π-coil, and two π/2-coils. The π-coil measures the dipole field component, while the two π/2-coils measure the quadrupole or

Table 2
Parameters of rotating coils

	quadrupole	sextupole
radial coil		
N_A/N_B	1/2	6/21
r_{A1}/r_{A2}	0.5	0.5
r_{B2}/r_{A2}	0.625	0.6266
r_{B1}/r_{A2}	0.125	0.4224
tangential coil		
N_D/N_Δ	1/6	–
N_Q/N_Δ	1/6	1/7
N_S/N_Δ	–	2/7
Δ-coil	19.471°	15.388°
two π/2-coils	measure $B'\ell$	measure $B'\ell$, $B''\ell$
π-coil	measure $B\ell$	measure $B\ell$

sextupole field component, depending on the connection of the two coils. These coils are also used for bucking the main field and measuring lower harmonics.

The advantage of having two types of coil sets on the same cylinder is that the validity of the measurements can be cross-examined at the same condition. For the SR quadrupoles, for example, the measured sextupole coefficients from the two coils agree within 0.4×10^{-4} at a radius of 25 mm.

For the alignment parameters, however, the two coil sets behave some what differently. Shown in Fig. 4 is the measured position of the magnetic center for six hours. The laser detector, which is positioned on top of the magnet, monitors the stability of the laser beam. The magnetic center measurements from the two coils agree to within 15 μm and vary less than 10 μm in both the x- and y-axes. The roll angle measurements in Fig. 5 show that the tangential coil measurements are stable to within 0.1 mrad, while those for the radial coil vary ±0.5 mrad.

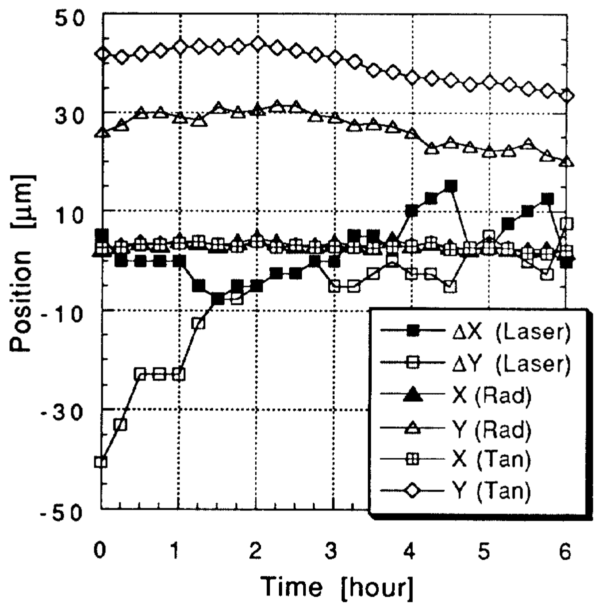

Figure 4. Stability of the laser beam and the magnetic center measurements using radial and tangential coils. The initial data have offsets.

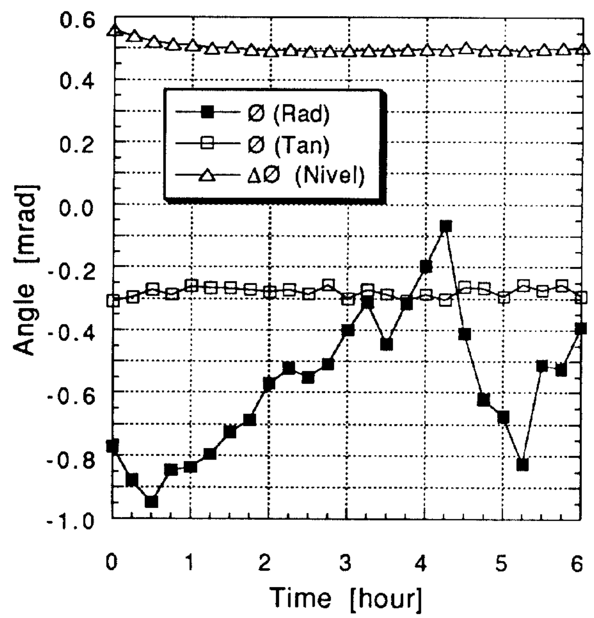

Figure 5. Stability of the magnet roll angle measurements using radial and tangential coils. The electronic tiltometer (Nivel) reading has an initial offset.

V. CONCLUSIONS

The magnet measurement facility meets the technical requirements for measurement accuracies. The relative measurement accuracy and reproducibility of the field integrals and field shapes for dipoles are better than 1×10^{-4}. The three rotating coil systems measure the 2-D and 3-D integral values of the main fields and multipole coefficients with relative accuracies of $\pm 1 \times 10^{-4}$. The measurement accuracies of the roll angle of the main field and the magnetic center to the fiducal positions are ±0.3 mrad and ±60 μm, respectively.

VI. REFERENCES

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