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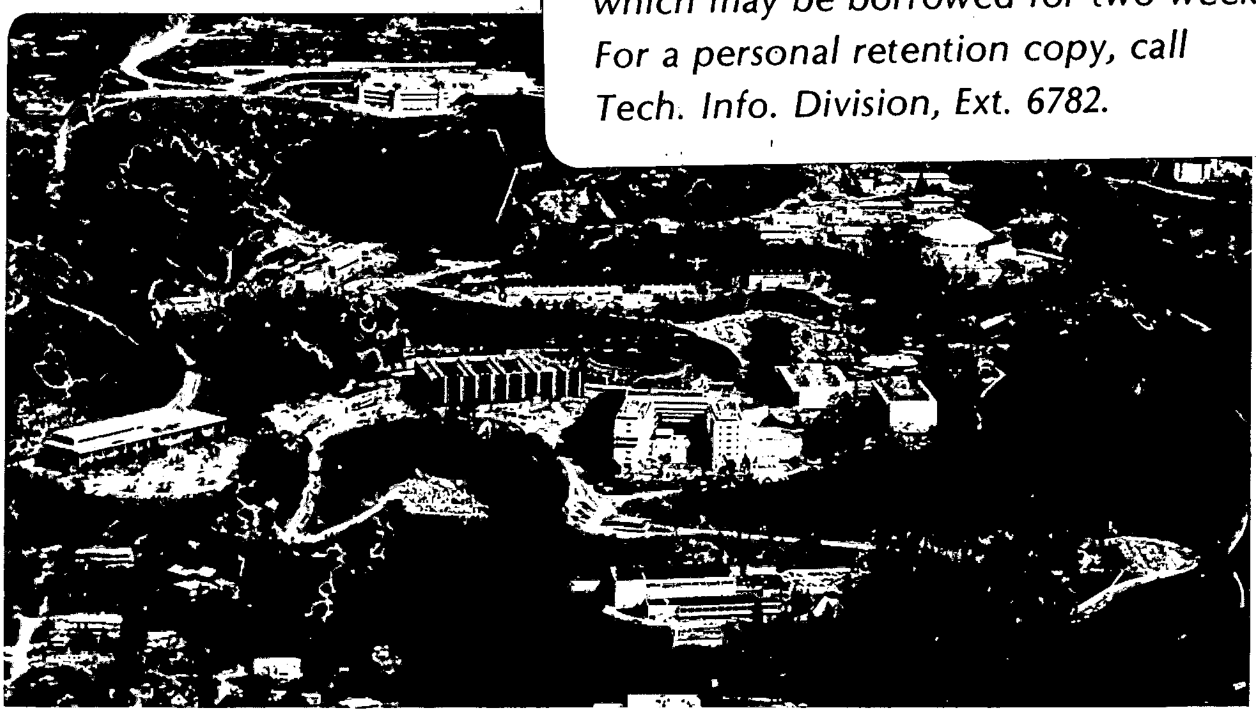

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Résumé - Un wiggler hybrid, vanadium-permendur/terre-rare-cobalt a été dessine, construit et mesurer au Lawrence Berkeley Laboratory (LBL) comme projet conjoint avec le Stanford Synchrotron Radiation Laboratory (SSRL) et le Exxon Research and Engineering Company. Cet article décrit deux techniques de mesures magnétiques utilisées pour caractériser et régler le wiggler. Nous décrivons des mesures à l'aide d'un gaussmètre à effet Hall qui: (1) confirmèrent et quantifièrent les distributions du champ sinusoidal du wiggler, et (2) calibrèrent les ajustements du shunt à flux variable ce qui peut fournir un "réglage fin" pour les pôles individuels. Nous décrivons aussi les mesures des intégrales de l'induction magnétique avec des bobines d'intégration et des intégrateurs électroniques. Bobines et intégrateurs furent utilisés pour (1) calibrer les courrants "end-pole" requis pour annuler les intégrales à demi-aivant, (2) mesurer l'intégrale de la composante horizontale, et (3) mesurer les variations dans la position longitudinale dans le wiggler.

Abstract - A hybrid, vanadium-permendur/rare-earth-cobalt (REC) wiggler has been designed, built, and measured at the Lawrence Berkeley Laboratory (LBL) as a joint project with the Stanford Synchrotron Radiation Laboratory (SSRL) and the Exxon Research and Engineering Company. This paper describes two magnetic measurement techniques used to characterize and tune the wiggler. We describe Hall effect gaussmeter measurements that: (1) confirmed and quantified the wiggler sinusoidal field distributions, and (2) calibrated variable-flux-shunt adjustments, which can provide "fine-tuning" for individual poles. We also describe measurements of integrals of magnetic induction with integral coils and electronic integrators. Coils and integrators were used to: (1) calibrate the end-pole currents required to zero the half-magnet integrals, (2) measure the horizontal-component integral, and (3) measure variations in single period integrals as functions of longitudinal position in the wiggler.

I - INTRODUCTION

A hybrid, vanadium-permendur/rare-earth-cobalt wiggler has been designed /1/, built /2/, and measured /3/ at LBL as a joint project with SSRL and the Exxon Research and Engineering Company. This wiggler magnet will be the source of synchrotron radiation for Beam Line VI at SSRL /4/. The wiggler has 27 periods each 7 cm long. The hybrid magnet design incorporates rare-earth-cobalt material in conjunction with vanadium-permendur poles to achieve high magnetic fields with short periods. It achieves peak fields of 1.21 T at a 1.2-cm gap and a 1.64 T at a 0.8 cm gap. An elevation section of the wiggler magnet is shown in Fig. 1. (The measurement coordinate system is included in Fig. 1.)

II - MEASUREMENTS

A. Equipment

The LBL general purpose Data Acquisition System (DAS), used for magnetic measurements of the wiggler is described elsewhere /5/. Six data acquisition and five data processing programs were written for the wiggler measurements. Commercial Hall effect probes were used to measure three orthogonal components of magnetic induction. The three probes were calibrated to 0.1% and the effective centers were located to ± 0.1 mm. A holder located the three probes at common vertical and lateral positions, but separated longitudinally by a quarter "wiggler period" (17.5 mm). The holder was mounted on a sled which moved 2.5 m longitudinally and 80 mm laterally. Additionally, three "line-integral coils" were designed, fabricated, and calibrated at LBL for measuring magnetic induction integrals.

B. Hall Effect Gaussmeter Measurements

1. Full z-range; $-1100 \lesssim z \lesssim +1100$ mm, $\Delta z = 1$ mm

A primary measurement objective was to characterize the periodic magnetic field distribution on a plane of symmetry ($y = 0$). The approach used was to measure on a uniform grid, to save large quantities of data, and then to use post-processing programs to extract and display details of interest. Figure 2 shows a real-time plot of $B_y(x,0,z)$ at 2201 z-positions and 3 x-positions. Of immediate interest were accurate determinations of the peak/valley magnitudes and positions and the values of the minor components B_x and B_z at the 53 z-positions where $B_y = 0$. The DAS provided processed data minutes after these data were collected; additionally, the raw data are saved (with a backup), so that they are readily available for further analysis.

2. Stud Tuning Calibration Measurements

The calibration of the "variable-flux tuning studs" was accomplished with the DAS programmed to function in a prompting mode, collecting data on command, and providing immediate feedback of processed data so the operator could direct the next operation.

Each of the 57 vanadium-permendur pole pairs is equipped with 4 threaded holes that may accept tuning studs. The tuning studs for pole #29 are shown in Fig. 1. Threading studs toward the poles reduces the local reluctance, thereby reducing flux-density in the corresponding working gap and simultaneously increasing the flux density in the working gaps of the adjacent pole pairs. This effect alternates and diminishes with distance from the adjusted poles, and magnitudes depend on both the gap and the stud position. Calibration involved positioning the vertical component Hall probe to the center of the working gap of a pole pair and measuring magnetic field changes due to adjusting sets of 4 tuning studs associated with the five closest pole pairs. Because the field quality of the wiggler was adequate the tuning studs will not be used initially; however, to better equalize the magnitudes of the peaks and valleys, the calibration data may be used in conjunction with an algorithm to determine the appropriate tuning stud positions.

C. Magnetic Induction Integral Measurements

Integral coils connected to electronic integrators determine magnetic field integrals more accurately than is practical by numerically integrating point measurements. The line-integral coils used for these measurements were conservatively designed to meet a 25 G-cm resolution requirement with a LBL Mod 71 electronic integrator capable of resolving 1 μV sec /6/.

1. Half-Magnet, y-Component, z-Integral Measurements

The wiggler's two end pole pairs are equipped with coils to null the respective half-magnet integrals (of the y-component). A technique was developed that minimized the effect of mispositioning the integral coil /7/.

A combined data acquisition/data processing program (1) prompts the operator to measure the uncompensated integral, (2) allows the operator to successively set end-pole currents, (3) measures and saves shunt potential and integrator output potential, and (4) processes, plots, and prints the half magnet integral vs end pole current. Figure 3 is a copy of the real-time plot associated with an half-magnet integral measurement.

2. Full-Magnet, x-Component, z-Integral Measurements

The horizontal (x) component was measured by flipping (180° about the z-axis) a long integral coil and measuring changes in flux-linkage due to $\int_{-\infty}^{+\infty} B_x dz$.

3. Full Wiggler Period (70 mm) y-Component z-Integral

Prior to mating the upper and lower halves of the wiggler they were measured separately to check for sub-assembly errors. A sensitive full (z)-period ("null") coil was used to detect variations in $\int_{z-35\,mm}^{z+35\,mm} B_y dz$ versus z as the coil was moved along the z-axis. No assembly errors were detected.

III - SUMMARY OF RESULTS

At the wiggler midplane, the vertical magnetic field is sinusoidal along the beam axis as expected. The averaged maximum midplane magnetic fields, for 53 poles (peaks and valleys) at various gap positions are summarized below. The maximum effects of adjusting tuning studs are tabulated. Since for small gaps the variation was better than $\pm 2\%$, tuning studs have not been used. The end pole current settings were determined for 6 gaps, so that the vertical field integral was less than 50 gauss-cm for each half of the wiggler. Below are given the uncorrected half magnet field integrals. At a 1.2 cm gap, a total correction range of 2740 gauss-cm or 137 gauss-cm/ampere is available. End pole coil sensitivity is given. The measured midplane horizontal field integral of the entire wiggler, which is not adjustable, is also tabulated.

Table I. Summary of significant measurement results.

Gap (cm)	Peak/valley data: 55-point average (T)	Peak/valley data: Standard deviation (T)	Tuning-stud max. effect (T)	Uncorrected half wiggler vertical field integrals (μTm): z < 0	Uncorrected half wiggler vertical field integrals (μTm): z > 0	End pole coil sensitivity (μTm/A)	Wiggler horizontal field integral (μTm)
0.80	1.636	0.0079	0.0145	748	308	179	205
1.20	1.207	0.0074	0.0240	-11	-161	137	175
1.63	0.872	0.0059	0.0190	67	-81	119	122
2.70	0.462	0.0038	0.0120	120	13	94	99
4.50	0.191	0.0025	0.0075	93	36	73	86
7.00	0.061	0.0015	0.0045	54	12	50	111

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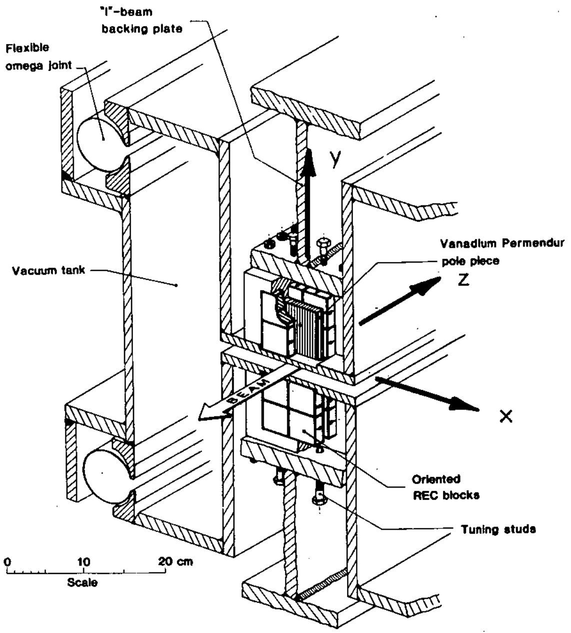

Fig. 1. Beam Line VI Wiggler, showing measurement coordinate system with origin centered at pole pair 29.

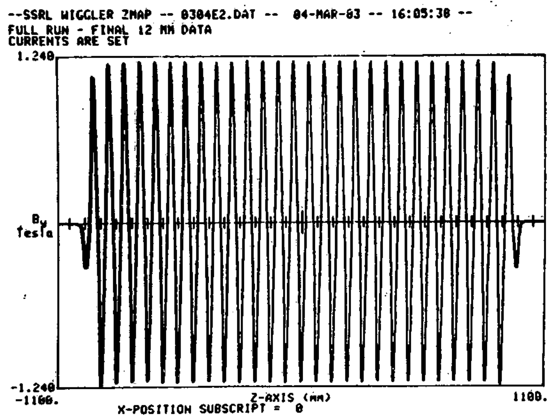

Fig. 2. Real time plot of 6603 data pairs: $B_y(x,0,z)$ vs z; x = 0, x = -10 mm, and x = +10 mm; Δz = 1 mm.

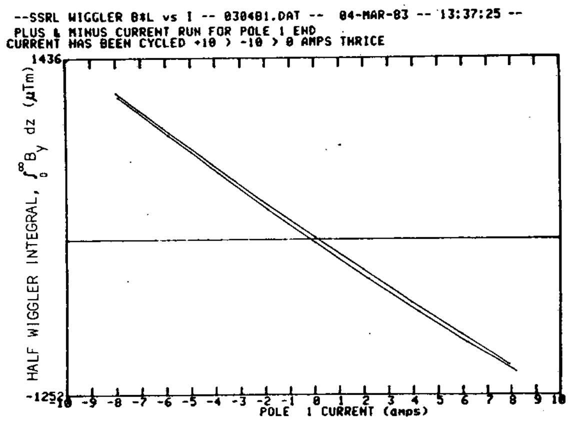

Fig. 3. Half magnet integral coil data.

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