MAGNETIC MEASUREMENT SYSTEMS FOR THE ELETTRA INSERTION DEVICES

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Abstract

The magnetic measurement systems for the ELETTRA insertion devices are described, including those for measuring the properties of individual permanent magnet blocks and complete magnet arrays. Results from initial tests on NdFeB blocks, including measurement of inhomogeneity and field superposition properties are presented.

Introduction

The ELETTRA synchrotron radiation source [1] will contain 11 straight sections in which insertion devices up to 4.8 m in length can be installed [2]. Strict tolerances must be set on the quality of the magnetic field in these devices to guarantee both a high radiation beam quality and satisfactory operation in the storage ring. Field errors arise from magnetisation errors in the permanent magnet material and mechanical positioning errors. In the former case effects can be reduced by magnetic measurements and sorting of the blocks. Techniques have also been successfully developed for correcting field errors in completed devices [3,4].

In order to carry out the necessary tests, both during and after construction, an insertion device magnetic measurement laboratory is being set up. This includes various systems for measurement of individual permanent blocks, magnetic arrays and complete insertion devices. At present two systems are operational, a Helmholtz coil and integrator system for measuring the total magnetic moment in 3 directions of individual blocks, and a fully automated three-axis bench with a Hall plate, for general purpose point-by-point field measurements.

A description of the two systems is given, together with results of initial tests on NdFeB permanent blocks for a prototype undulator to determine their strengh, direction and uniformity of magnetization. Some basic tests of field superposition, and first measurements of a magnetic array, are also reported.

Measurement Systems

Helmholtz Coil and Integrator System

A coil pair has been built to measure the flux linkage generated by permanent magnet blocks, from which the total magnetization may be obtained [5]. The Helmholtz geometry has been used with axial separation = mean radius = 300 mm, with 600 turns for each coil (wire diameter = 0.1 mm). The size of the coil is sufficiently large that blocks with dimension up to 150 mm may be measured with less than 0.1% error.

To integrate the voltage signal we have used a Schlumberger 7061 multimeter, with a resolution of 10^{-7} Vs. The multimeter is also used to read the ambient temperature with a platinum resistence thermometer (accuracy 0.1 °C). Data Acquisition is controlled through a PC/386 and a IEEE-488 bus (GPIB). Programs are written in the "C" language.

In such a system the magnetization (M) of a block of volume V is obtained from the integrated voltage in the coil pair (ψ) for a 180° block rotation by the following:

$$M\,V = \frac{R\,G\,\psi}{2\,n}$$

where R is the coil radius, $G = (1 + (s/2R)^2)^{3/2}$, s is the coil separation and n the number of turns/coil. In the present case the calibration is based on the measured dimensions of the coils (R = 0.595 m, G = 1.407) which results in a calibration of 3.5 10^{-4} m (Wbm/Vs). The sensitivity of the system is therefore 3.5 10^{-11} Wbm. The background noise,the value read by the integrator with no magnet, is 9.1 μVs rms, equivalent to 3.2 10^{-9} Wbm. Reproducibility measurements for a sample NdFeB magnet of size 70x28x7 mm^3, magnetized along the 28 mm axis gave an rms error in the main component of 0.09%, while the rms error in determining the angle of magnetization is 0.06°.

Three Axis Measuring Bench

The three-axis measuring bench, supplied by Microcontrole (France), is based on a long granite beam, along which a carriage moves on air-bearings, driven by a stepping motor. The length of travel of the Z axis is 2.5 m. The carriage supports X (horizontal) and Y (vertical) stages, each with 250 mm of travel, driven by stepping motors. X and Y motions are controlled by rotary encoders, with an accuracy of 10 μm, while the basic positioning accuracy of 0.1 mm along the Z axis can be corrected to 1 μm using an additional linear encoder (Heidenhain). The system is controlled directly using an interface card in a PC computer.

A Hall probe (Bruker BH15, typical accuracy 0.2 Gauss, resolution 0.05 Gauss) has been mounted at the end of an aluminium arm attached to the final Y axis positioning stage of the bench. Magnetic field values are obtained directly from the unit through a GPIB interface. Software has been written in the "C" language for controlling a number of standard types of measurements.

Permanent Magnet Block Measurements

A total of 306 blocks of VACODYM 370HR material have been received from Vacuumschmelze, Germany, with specified variation in total magnetic moment of ± 2%, and maximum angular deviation of 2°.

Helmholtz Coil Measurements

To measure the total magnetic moment of a permanent magnet block along each of the coordinate axes, it is first mounted in an aluminium cube (side 110 mm), in such a way that the geometric center of the magnet coincides with the center of the Helmholtz coil. Measurements are then performed by orienting the magnet with the required magnetization direction pointing towards one of the coils, zeroing the integrator connected to the coils, and then, manually, rotating the cube by 180° so that the magnetization direction points toward the opposite coil. By changing the orientation of the cube each of the three magnetization components can be obtained. In the present case, each component is measured twice (the magnet inside the cube is positioned in two different ways) in order to eliminate a systematic error due to a misalignment of the magnet in the aluminium cube.

A summary of the data obtained is given in Table 1. Generally, measurements are in good agreement with data provided by the magnet supplier, typically within 0.2% for the strength of the main component, and 0.2° for the angle of deviation, although some unexplained discrepancies of up to 0.7% and 0.5° were noted. The full range of main magnetization values lay within the specified range of 4%, while the angles were all within 2.5°.

Table 1. Summary of mean, rms and full spread (in brackets) magnetization values for 122 A blocks, 160 B blocks and 24 C blocks of NdFeB material; minor components are expressed as an angle of deviation.

Block	XxYxZ [mm]	M_x	M_y	M_z
A	70x28x14	± 0.9° (2.2°)	1.2044 T ± 0.9% (4.0 %)	± 1.1° (2.5°)
B	70x28x14	± 1.0° (2.3°)	± 0.8° (2.1°)	1.1857 T ± 1.1% (4.0 %)
C	70x28x7	± 0.3° (0.7°)	1.2112 T ± 0.4% (1.3 %)	± 1.1° (2.1°)

Point Measurements

The magnetic properties of individual blocks have also been studied by taking point measurements of the main field component using the Hall plate bench, using a modified version of the technique described in ref. [6]. The block to be measured is first positioned in a fixed aluminium holder which permits an automatic alignment of the block to the bench coordinate system. A series of 10 measurements are then made automatically, five above and five below the block as shown in fig.1. The measurements are then repeated with the block mounted in two other orientations, in order to remove systematic positioning errors. The data analysis then produces two sets of values of the three magnetization components, coresponding to the top and bottom of the block, by comparing the measured field values with those computed for an ideal CSEM block [7]. The reproducibilty for this type of measurement is within 0.5% for the main component and 0.1° for the angle of deviation, for a single block face, or 0.15% and 0.05° for the average values.

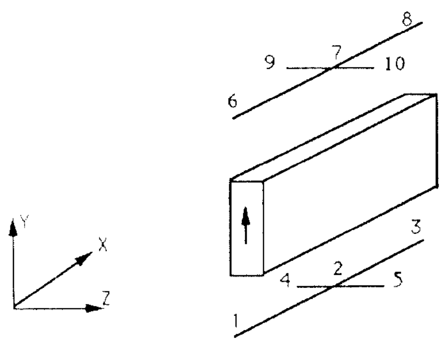

Fig.1 Point measurement scheme.

It has been found that the average values of the magnetizations corespond well to those measured by the Helmholtz coil system, with rms differences of 0.2% and 0.15°. Figure 2 shows a comparison of the M_y values for A blocks measured by the two techniques and the good agreement is evident.

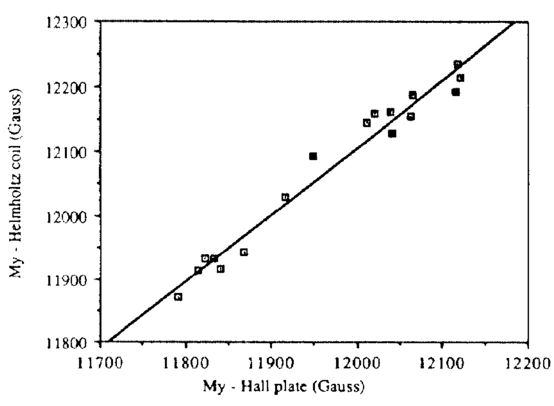

Fig.2 Average main magnetization component obtained from the Helmholtz coil and from point measurements.

The differences in magnetization obtained from the top and bottom of the blocks indicate the level of inhomogeneity in the magnetization. Differences between the top and bottom values of up to 10% in the main component and 0.6° in angle have been observed, as shown in figs. 3 and 4. The figures indicate that for the main component, the variation is dominated by inhomogeneity with a constant mean value, whereas for the minor component, the inhomogeneity is small compared to the variation in the average.

For B blocks, the same technique can be applied but with somewhat reduced accuracy. In this case, inhomogeneity is only observed between left and right i.e. in the direction of magnetization, as for the A blocks.

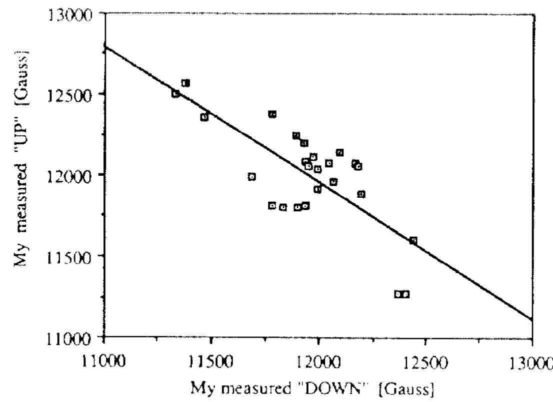

Fig.3 Main magnetization component obtained from point measurements above and below the blocks.

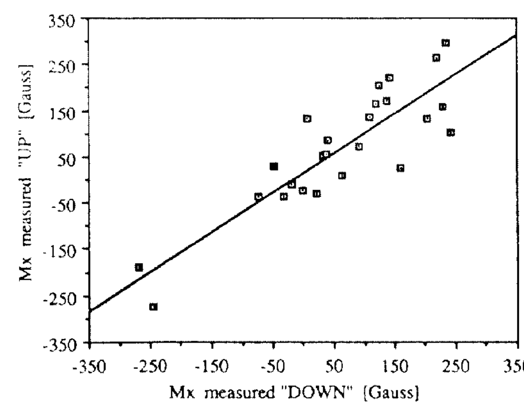

Fig. 4 Minor magnetization component obtained from point measurements above and below the blocks.

Field Integral Measurements

The Hall plate system has also been used to measure the field integral $\int B_y dz$ generated by single A type blocks, both above and below the magnet. By comparing the value of field integral with the computed value for an ideal CSEM block [7] the magnetization value can be obtained. The average values have been found to agree well with those of the single point measurements above (within 0.2%), however, significant inhomogeneity is also evident. Figure 5 shows that differences in integral value between the top and bottom of the block of up to 20% have been measured, and that the differences are correlated, but different in magnitude, to those of the point measurements.

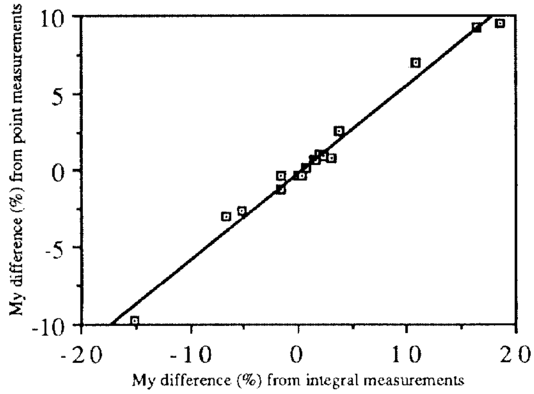

Fig. 5 Differences between the main magnetization component from above and below the blocks obtained from point and integral measurements.

Superposition Tests

The approximation is often made that the permeability of REC and NdFeB permanent magnet material is unity, and can therefore be represented simply as "Charge Sheet Equivalent Material" (CSEM), from which it follows that the field of individual magnet blocks superpose linearly [8]. It has been shown however [9] that differences from unit permeability can have measurable effects on the superposition of the field of two REC blocks ($\mu \sim 1.02$-1.08). Larger effects are expected for NdFeB, since the permeability in the direction perpendicular to the magnetization direction has a typical value of 1.2. To investigate this effect, the magnetic field distribution produced by a pair of horizontally and vertically polarized magnets has been measured and compared with the result expected from the linear superposition of the measured fields of the individual blocks. Figure 6 shows the field difference obtained in this way from the measurements (solid curve) while the result of a calculation using POISSON [10] (with $\mu_{\perp}=1.2$) is also shown (dotted curve). The degree of non-superposition is easily measurable, the maximum field difference being about 2.5 % of the peak field produced by the two blocks. The agreement with the simulations is also very good, despite the fact that the model is 2-dimensional and so the field integral is constrained to be zero. Due to symmetry non-superposition effects cancel in a periodic structure, however, some change to the end field distribution will be produced.

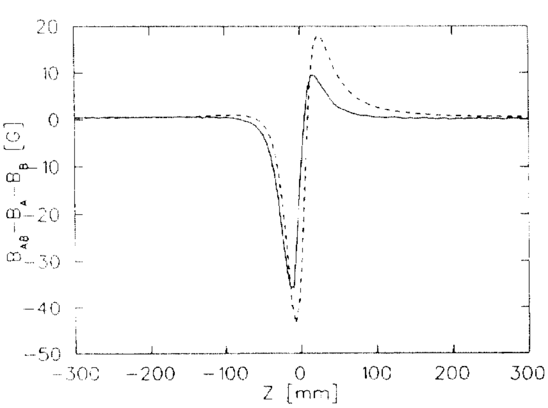

Fig. 6 Field difference due to non-superposition of the field from two blocks, measured (solid) and calculated (dotted).

First Array Measurements

A first magnet section containing nine complete magnet periods each of 56 mm, has been constructed and measured with the three-axis bench. The results obtained (fig. 7) indicate that the variation in field amplitude, 2.3% rms, is significantly higher than expected from a random distribution of blocks with the given variation in average magnetization, confirming that inhomogeneity is also a significant factor. Calculations are in progress to compare the result with that expected from the individual block measurements.

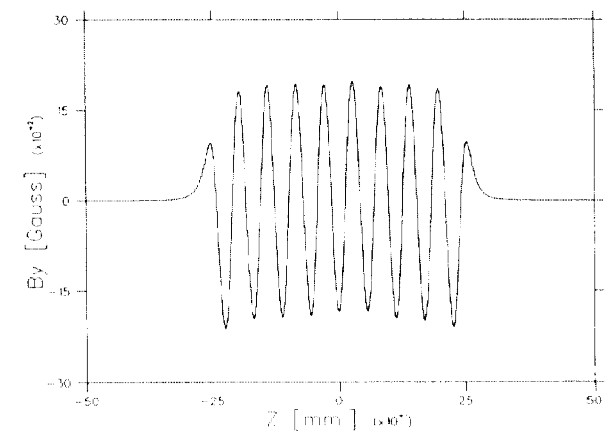

Fig. 7 Main field component in the first nine period undulator array.

Conclusion

Two measurement systems are operational and have given valuable information about the magnetization properties of individual permanent magnet blocks. Assembly and testing of the first periodic magnet arrays has commenced. Two future developments are forseen in the measurement systems. Firstly, a flipping coil bench to perform accurate field integral measurements on single blocks, magnet arrays and complete insertion devices will be installed in June. Secondly, it is planned to develop a combined probe for the three-axis bench to permit point measurement of both B_x and B_y components, together with accurate measurement of field integrals.

Acknowledgements

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