# Magnetic Measurement Facility for the ELETTRA Insertion Devices

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*Abstract*

Recent developments of the magnetic measurement systems for the ELETTRA insertion devices include a stretched-wire flipping coil bench for accurate measurement of the transverse field integrals and a double Hall-plate probe for making rapid point measurements of both transverse field components while the probe is in continuous motion. The characteristics and performance of these systems are presented.

## 1. INTRODUCTION

The ELETTRA storage ring is a 1.5-2 GeV third generation syncrotron radiation source [1], designed and optimized for the inclusion of up to 11 insertion devices [2]. Strict tolerances must be set on the quality of the magnetic field to achieve a good radiation beam quality and to permit satisfactory operation in the storage ring. In order to achieve this, rapid and accurate magnetic measurements must be performed of both single permanent magnet blocks and complete devices. As many as 750 blocks need to be measured for a single 4.5 m ELETTRA insertion device in order that the blocks may be positioned in the device in an optimum way. For the complete device measurements may have to be repeated many times to permit optimization of the field quality using shimming techniques.

Initially a Helmholtz coil system (to measure the total dipole moment of individual blocks) and a three-axis bench with a single Hall plate probe (for making point-by-point measurements were implemented [3]. Since then, a flipping coil bench has been set up for making accurate integral field measurements, and a new probe developed for the three-axis bench to make rapid measurements of both transverse field components.

## 2. FLIPPING COIL BENCH

### 2.1 Description

The stretched-wire flipping coil bench consists of a 3.2 m long granite beam on which are positioned 2 units each consisting of three motorized translation tables and one rotational stage around the main axis. The design closely follows that implemented at the ESRF [4]. The distance between the 2 units can be manually varied up to 3 m but at present a length of 2.5 m is used. The sensitivity of the translational tables is 1 μm, and for the rotational stages is 0.001 deg. The stepping motors are controlled by a board installed in a 386 PC computer. Each axis of a section can be synchronized with the corresponding axis of the other section via software, so that the measuring coil can be rotated at both ends simultaneously and translated in each of the 3 orthogonal directions. The scan length available is 250 mm along the coil (z) axis and 200 mm for the transverse horizontal (x) and vertical (y) axes. The system is made up of standard components supplied by MicroControle (France).

The measuring coil is a Litz wire consisting of 20 strands each of 40 μm diameter, connected in such a way to form a single coil of 20 turns, with a wire separation of 1 cm. The voltage induced in the coil while it is rotating is integrated by a Schlumberger 7061 voltmeter, with a sensitivity of 0.1 μVolt sec which corresponds to a field integral of 5 G mm. A GPIB interface bus is used to communicate with the PC. Data acquisition software has been written in the C language.

In a single measurement the voltage is integrated while the coil is rotated in the forward direction through 360 degrees, in steps of 90 degrees, from which values of both horizontal (Ix) and vertical (Iy) field integrals are calculated. The operation is then repeated in the reverse direction and the values compared: a measurement is accepted only if the difference in each integral component is less then 100 G mm. An integration time of 5 seconds is used, which is slightly greater than the time required to complete a 90 degree rotation.

### 2.2 System performance.

The flipping coil bench was used to make field integral measurements of the permanent magnet blocks of the prototype undulator [5]. Each block was measured in 4 orientations at 3 positions at x=0 and x=± 15 mm, which took an average of 30 mins. per block. The results were subsequently used to calculate the optimum block configuration in the 1.5 m undulator using "simulated annealing" [6]. The typical reproducibility of the system for measuring the field integral of a single permanent block is less than 10 G mm rms., corresponding to 0.04 % for the main field component of a vertically magnetized block.

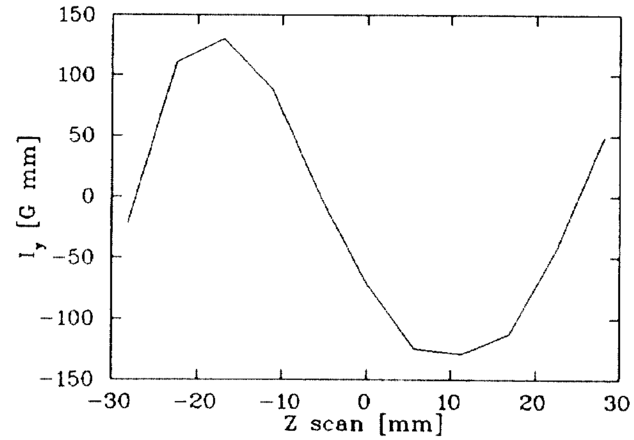

Fig. 1. Typical variation of the field integral with longitudinal coil position in the prototype undulator .

Systematic errors as a result of inaccuracies in the coil geometry (wire separation and angle) and the measurement position along the coil axis are less than ± 25 G mm.

For measurement of a complete undulator the systematic errors are greater but can be overcome by carrying out a series of measurements with the coil translated along the undulator axis (z-direction). Figure 1 shows a typical result from measuring the prototype 1.5 m undulator which has a 5.6 cm period. A smooth sinusoidal variation can be seen, with periodicity equal to that of the undulator. Typically the peak-to-peak variation is 600 G mm for Ix and 300 G mm for Iy. In order to achieve results as good as these it is necessary to pay particular attention to the coil tension. For example, in an earlier phase of operation with badly adjusted tension, non-sinusoidal variations were observed up to 3000 G mm in magnitude. The typical reproducibility of the system for complete undulator measurements is better than 30 G mm for both components.

## 3. HALL PLATE BENCH.

### *3.1 Description.*

To make point-by-point measurements of the magnetic field a three-axis Hall plate bench system was developed [3]. The bench, with a positional resolution of 1 µm, was supplied by MicroControle to a Sincrotrone Trieste specification and a Bruker BH15 Hall plate was employed for measurement. The scan length available is 2.5 m along the undulator (z) axis, and 250 mm in the transverse (x,y) directions. Although accurate, the system was slow, requiring about 40 minutes for a single scan of 2 m length. The other disadvantage was that only the main component of the magnetic field could be measured whereas information about both transverse field components was required. To satisfy this need, it was at first considered to build a system with a search coil probe and an integrator, taking data "on the fly". However, after some tests it was concluded that the reproducibility of this system was not sufficient for our requirements [7]. A new probe has therefore been built, made up of two Hall-plates mounted at 90 degree to measure the vertical and horizontal magnetic field. Data are taken "on the fly" at a speed of 20 mm/sec, which reduces the time neccessary for a 2 m scan to 100 sec.

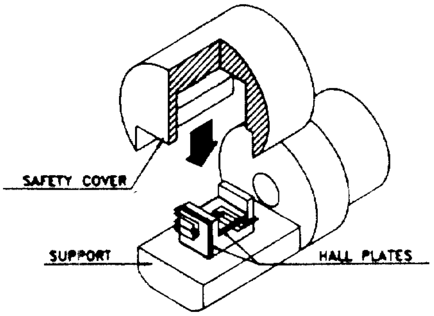

Fig. 2. The double Hall-plate probe.

The Hall plates used are Siemens SBV 585-S1, which have a very low temperature coefficient (5 $10^{-5}$ / °C ) so that in the temperature controlled laboratory (± 2 °C) it is not necessary to thermostatically control the plate temperature. The plates also have a very small active area (< 0.02 $mm^2$) but with sufficiently high output (6 µV/Gauss) that they can be read directly with a digital voltmeter. A non-conductive support has been constructed using plexiglass in order to avoid eddy current effects (see fig. 2). The two plates, glued on this support, are at the same vertical (y) and longitudinal position (z), but offset in the x-direction by about 4 mm, which has to be taken into account in the data analysis. The vertical dimension of the probe is such that undulators with a minimum gap as small as 20 mm may be measured. The constant current source for the plates is a standard CERN type with a measured maximun current variation of 5 $10^{-5}$ at 100 mA. The two plates have been calibrated against a high precision NMR probe (Metrolab, Switzerland) using a reference magnet. The calibration curves were calculated by a least-squares fit of a 12th order polynomial, with a residual error over a ± 1.65 T range of 0.2 Gauss rms.

During data taking the bench Heidenhain encoder is read continously by a PC board (MicroControle) at a rate of about 2 kHz while the probe is moving at 20mm/sec. At the measuring position a TTL trigger is generated by a LAB-PC board (National Instrument) to the 2 voltmeters (HP-3458). The integrating time interval was set to 20 msec in order to reduce the noise signal to an acceptable level of about 1 µV. The effect of the time interval is that each measurement is integrated over a distance of 0.4 mm, but since this is much smaller than the magnet periodicity the error introduced is negligible. During the measurements the data are stored in the internal buffer of the voltmeters and read at the end of the scan by the 386-PC computer via GPIB.

### *3.2 System performance.*

The new system has been used to re-measure the prototype undulator blocks. Each block has been measured in two configurations, taking data at 21 points in the z-direction, at

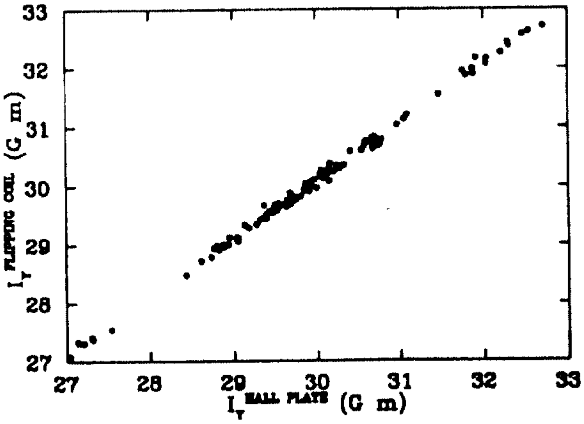

Fig. 3. Field integral measurements of individual permanent magnet blocks made with the flipping coil and with the new Hall probe.

x=0, ± 10, ± 20 and ± 30 mm. The typical reproducibility of the field integral for a single permanent magnet is 40 G mm rms. The data compare well with those taken previously using the single Hall plate, and also with the flipping coil. For example, fig. 3 shows a comparison between measurements of the vertical field integral made with the flipping coil and new Hall probe. The rms difference is 67 G mm, near the limit of reproducibility of the two systems.

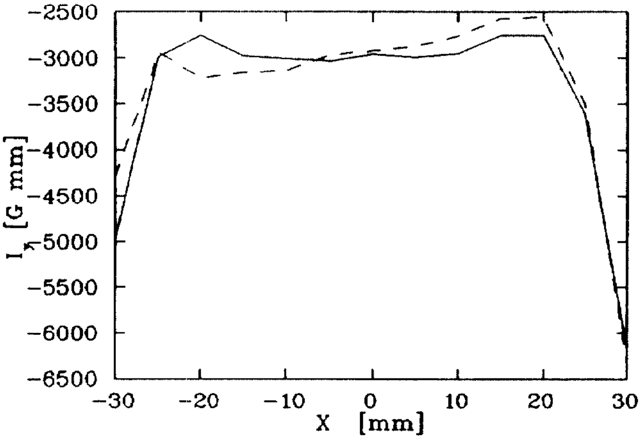

Fig. 4. Field integral variation in the prototype undulator, measured with the flipping coil (dotted) and the new Hall probe (solid).

For the measurement of the prototype undulator the typical reproducibility is 170 G mm for Iy and 150 G mm for Ix (rms). Figure 4 shows the transverse variation of the vertical field integral Iy measured by the Hall plate and flipping coil systems. The agreement is seen to be very good, within 270 G mm (rms). The reproducibility of the trajectory measurement is shown in fig. 5.

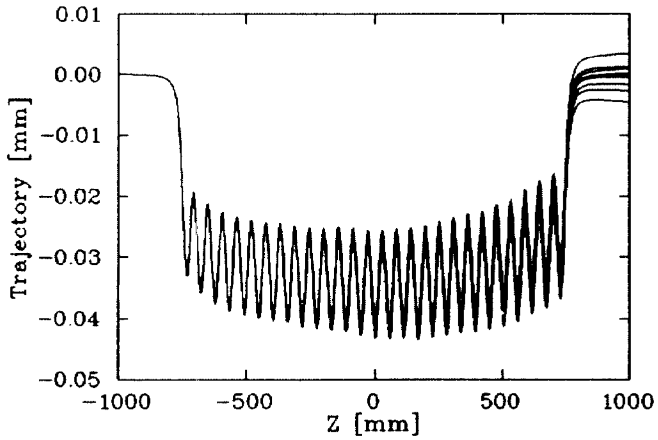

Fig. 5. Result of 10 measurements of the trajectory in the prototype undulator using the new Hall probe.

The measurement of the $B_x$ field distribution is very sensitive to the angular alignment of the corresponding plate to the undulator field. The effect of a mis-alignment however is to introduce a sinusoidally varying component, following that of the main $B_y$ component. This may be removed from the data by a least-squares fitting of the meaured $B_x$ values as a function of the measured $B_y$ values to obtain the angle error ($\alpha$) : $\alpha = \Sigma\ B_{xi}\ B_{yi}\ /\ \Sigma\ B_{yi}^2$. Figure 6 shows a typical measured $B_x$ field distribution, before and after subtraction of the error arising from a probe misalignment of 1.2 deg. A term proportional to $B_x^2$ arising from the planar Hall effect can also be included, however the magnitude of the correction has so far been found to be negligible, probably because measurements have been restricted to the median plane.

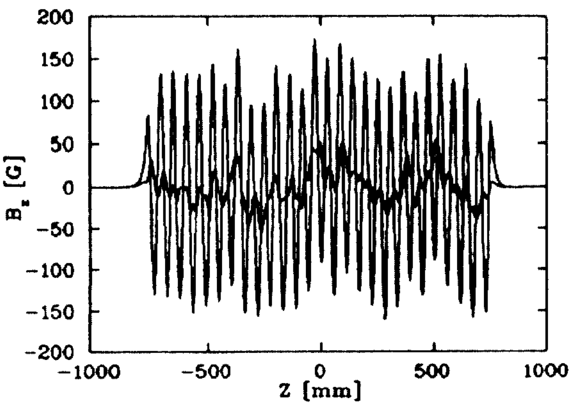

Fig. 6. Horizontal field component, before (large amplitude) and after subtraction (small amplitude) of the error arising from angular misalignment.

## 4. CONCLUSIONS

The new Hall probe system is in routine use for the rapid and accurate measurement of both individual blocks and complete undulator sections. The flipping coil remains useful however as a reference for field integral measurements, because of its better accuracy and reproducibility. Future plans include development of a second smaller Hall plate system, dedicated to the measurement of permanent blocks, in order to allow block measurements to be carried out at the same time as undulator optmization.

## 5. ACKNOWLEDGEMENTS

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## 6. REFERENCES

[1] Elettra Conceptual Design Report, April 1989,Sincrotrone Trieste
[2] R.P.Walker et. al., this conference
[3] D.Zangrando and R.P.Walker, Proc. 2nd European Particle Accelerator Conference, Nice, June 1990, p.1365
[4] J.Chavanne,E.Chinchio and P.Elleaume, European Synchrotron Radiation Facility Report ESRF-SR/ID-89-27,Sept.1989
[5] C.Poloni et. al., Particle Accelerator Conference, San Francisco, May 1991
[6] B.Diviacco et al, Report presented at the 4th International Conference on Synchrotron Radiation Instrumentation Chester (UK), 15-19 July 1991 (Proc. to be published)
[7] R.P.Walker and D.Zangrando, Sincrotrone Trieste, ST/M-TN-91/8, June 1991