FIELD INTEGRAL MEASUREMENTS ON A HYBRID PERMANENT MAGNET UNDULATOR FOR F.E.L.

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Introduction

Accurate magnetic field measurements are required in order to satisfy the specifications on undulator performances imposed by Free Electron Laser operation.
Hall probe gaussmeters are currently used for mapping the field of magnetic devices, however the evaluation of field integrals and multipolar components from numerical elaborations of these data brings to cumulative errors.
Besides Hall probe use could be time consuming for large devices.
In order to obtain very fast and reliable measurements of field integrals, a rotating coil equipment has been developed [1].
This equipment has been tested on a hybrid undulator model eight period long.
The model and the relative local field measurements are described in a previous paper [2].

Measuring technique

The technique described here aims to the direct measurement of the integrals of the magnetic field transverse components around the undulator axis

$$I_x\,[x,y] = \int_{-\infty}^{+\infty} B_x\,[x,y,z]\,dz$$

$$I_y\,[x,y] = \int_{-\infty}^{+\infty} B_y\,[x,y,z]\,dz$$

where $x = y = 0$ corresponds to the undulator axis.

Developing the field components around the axis at the second order in x and y and considering the relations between the coefficients imposed by Maxwell equations brings to the following expressions

$$I_x[x,y]=D_x + Q_1 y + Q_2 x + S_1 xy + \frac{1}{2} S_2 (y^2 - x^2)$$

$$I_y[x,y]=D_x + Q_1 x - Q_2 y + \frac{1}{2} S_1 (x^2 - y^2) + S_2 xy$$

where D, Q, S are the following field integrals.

- D_x = x - Dipole
- D_y = y - Dipole
- Q_1 = Quadrupole
- Q_2 = Skew - Quadrupole
- S_1 = Sextupole
- S_2 = Skew - Sextupole

They can be determined by measuring the voltage induced at the ends of a coil kept in rotation around axes parallel to the undulator axis.

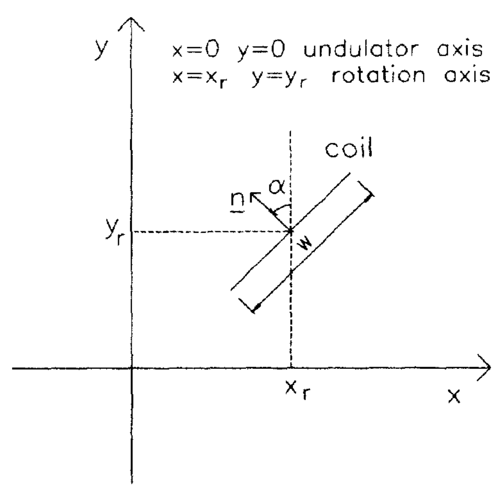

Fig. 1. Choice of the coordinate system

We define the unit vector normal to the coil $\underline{n} \equiv [-\sin\alpha \, , \cos\alpha \, , 0]$ and set $\alpha = \Omega t$ where Ω angular frequency of the coil (Fig. 1).
The voltage induced at the coil ends with the rotation axis in $x = x_r$, $y = y_r$ is

$$V[x_r, y_r] = a_1[x_r, y_r]\cos(\Omega t) + b_1[x_r, y_r]\sin(\Omega t) + a_3[x_r, y_r]\cos(3\Omega t) + b_3[x_r, y_r]\sin(3\Omega t)$$

where

$$a_1[x_r, y_r] = n\Omega w \left(D_x + Q_1 y_r + Q_2 x_r + S_1 x_r y_r + \frac{1}{2} S_2 (y_r^2 - x_r^2)\right)$$

$$b_1[x_r, y_r] = n\Omega w \left(D_y + Q_1 x_r - Q_2 y_r + \frac{1}{2} S_1 (x_r^2 - y_r^2) + S_2 x_r y_r\right)$$

$$a_3 = -\frac{1}{8} n\Omega w^3 S_2$$

$$b_3 = \frac{1}{8} n\Omega w^3 S_1$$

w is the coil width (Fig 1) and n the number of turns

Equipment for measuring field integrals

A seventy turns coil supported by a carbon fiber structure has been built for applying the previously described measuring technique.
The wire diameter used for the coil is 0.1 mm and the turns dimensions are about 10.5 x 730 mm^2.
The carbon fiber structure is pneumatically sustained and can be put in rotation by a D.C. motor with a stability of 10^{-3} at the frequency of 5 Hz.
The rotation axis of the coil can be displaced using micrometrical screws.
This positioning structure for the coil has been designed in order to reduce the weigth and the rotation induced vibrations.

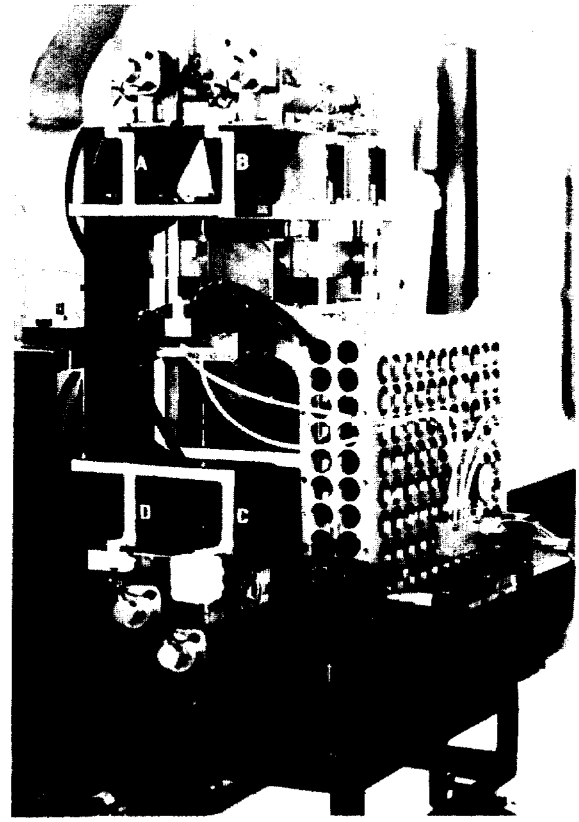

Fig. 2. Hybrid undulator submitted to field integrals measurements with the rotating coil.

Measurements on a hybrid undulator model

We have used the described equipment for measuring the field integrals of our eigth period model of hybrid undulator (Fig. 2).
Considerations concerning the accuracy in the evaluation of Q_1 and Q_2 and the semplicity in performing measurements have led us to displace the rotation axis from the undulator axis 1 mm up and down in the y direction and to use $a_1[0,1]$, $b_1[0,1]$ $a_1[0,-1]$, $b_1[0,-1]$.
For the evaluation of S_1 and S_2 we have found that it is better to use the third harmonic coefficients $a_3[0,0]$, $b_3[0,0]$ rather than first harmonic coefficients a_1, b_1 measured in different point around the axis.
Therefore the following relations have been used.

$$D_x = (1/n\Omega w) \, a_1[0,0]$$

$$D_y = (1/n\Omega w) \, b_1[0,0]$$

$$Q_1 = (1/2n\Omega w)\ (a_1[0,1] - a_1[0,-1])$$
$$Q_2 = (1/2n\Omega w)\ (b_1[0,-1] - b_1[0,1])$$

$$S_1 = (8/n\Omega w^3)\ b_3[0,0]$$
$$S_3 = -(8/n\Omega w^3)\ a_3[0,0]$$

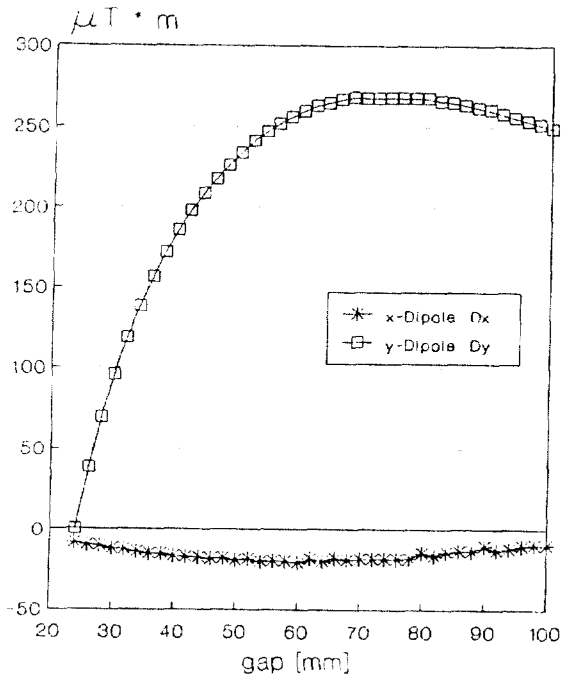

Fig. 3. Integrated dipole as a function of the gap

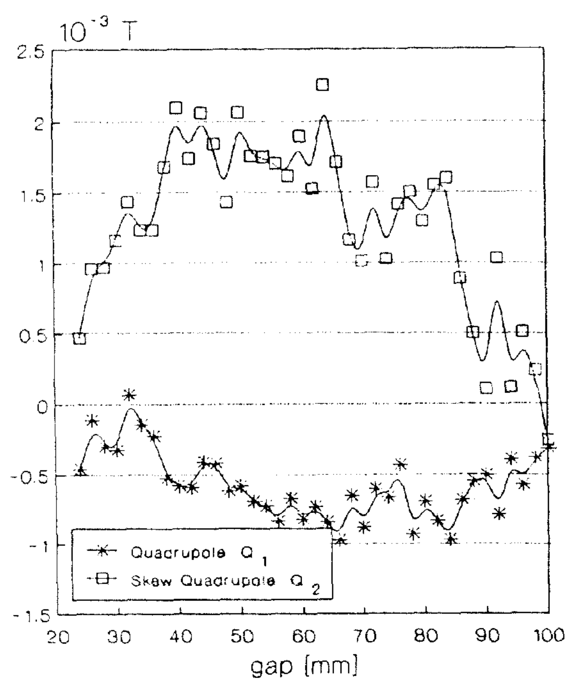

Fig. 4. Integrated quadrupole as a function of the gap

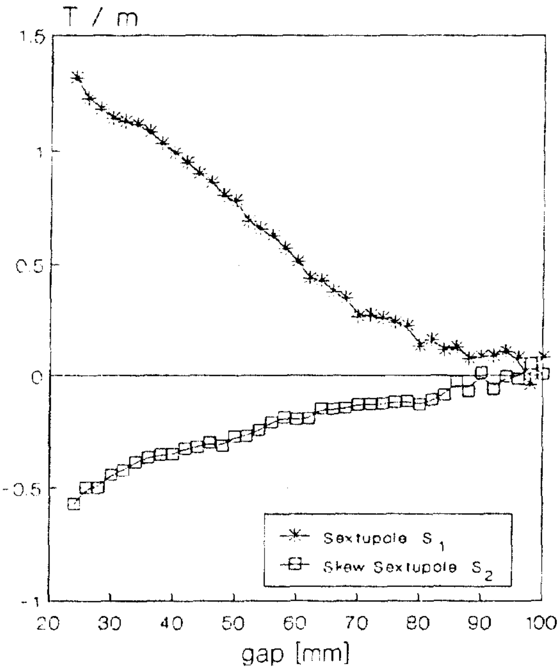

Fig. 5. Integrated sextupole as a function of the gap

Fig. 3 - 5 show the results obtained in the gap range 24 - 100 mm having fixed the current in the correction coils in order to have D_y = 0 at the gap 24 mm.

From these results it follows that a gap dependent correction is necessary when very small residual field integrals are accepted at every gap.

In order to meet these requirements we are developing a control system which allows an automatic variation of the current in the correction coils as a function of the gap. The values of these currents are determined by means of previous measurements of field integrals.

This automatic control system will equipe a 50 period long hybrid undulator under construction in ANSALDO RICERCHE

<u>References</u>

[1] D.H Nelson et al. "Magnetic measurements for tuning and operating a hybrid wiggler" presented at 8th International Conference on Magnet Technology, Grenoble, France, September 5 - 9, 1983.

[2] F Rosatelli et al. "Development of a hybrid permanent magnet undulator protptype for Free Electron Lasers" presented at 11th FEL Conference, Naples, Florida, August 28 - September 1, 1989.