# INSERTION DEVICES I

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*Session WE1 – Wednesday 3rd October 2001 – 9.00/11.35*

Four Talks :

- Pascal Elleaume (Insertion Device technology) – ESRF
- J. Pflüger (Magnetic measurement techniques for the undulator system of the VUV-FEL at the Tesla test facility) – DESY
- Dino Zangrando (Insertion Devices magnetic measurements @ Trieste) – ELETTRA
- Joël Chavanne (Undulator & wiggler construction at the ESRF) – ESRF

## INSERTION DEVICE TECHNOLOGY (P ELLEAUME)

The typical peak field of an insertion device is in the range 0.5-2T with the shortest period possible. This implies a strong gradient. As a result the permanent magnet technology is the most economical solution. Essentially two type of magnet materials are used NdFeB, $Sm_2Co_{17}$ . Assemblies can be made of permanent magnet only or hybrid (permanent magnet + iron pole) which gives a higher field. In a few cases where a long period is required the electromagnet technology is used (elliptical devices at ELETTRA, SuperACO,SLS…). Above a field of 2 T, the superconducting technology is the only solution for short periods. The need for short period and high field is pushing to small gap undulators. The smallest gap is reached by placing the permanent magnet I n the vacuum (Spring-8, ESRF, SLS,…). There is an increasing demand for circular polarization , in this context the Apple II type undulator is the most widely used device.

### SPECIFICATIONS ON Ids

Horizontal and vertical field integral should be < 0.15 Gm .

Horizontal and vertical double field integral should be < 50 $Gm^2$ .

Integrated residual quadrupole should be < 200 G .
Rms phase error should be in the range 1-2 deg .
All these constraints must be satisfied for any gap value.

The specification of the multipole is still unclear. There are two approaches. One consists in specifying a maximum value for the higher derivatives of the field integrals. Another consists in specifying a maximum field integral variation over a range of horizontal coordinate.

### SOURCE OF FIELD ERRORS

The residual field errors comes from:

- The in homogeneities of the magnetization within the magnet block
- The assembly and machining tolerances

The correction of these field errors is made by shimming (iron thin sheets or block movement). Such a shimming is unavoidable, it is made through a number of iterations, it is time consuming . It must be well thought and optimized to minimize the processing time.

### MAGNETIC MEASUREMENT TECHNIQUES

The same technologies used for conventional accelerator magnets are used to measure the field of insertion devices (Hall probe, coils, NMR) but there are some specificities :
i/ precise information on the position where the field is measured is needed for phase and spectrum calculation
ii/ field integrals have to be measured within flat aperture ($10x60mm^2$) which makes conventional harmonic analysis made with rotating coil not practical for the determination of integrated multipoles.

Three type of field measurements are performed :

1 - Single block characterization

Every block of magnet must be characterized before It can be performed either by a Helmholz coil which characterize the total dipole moment. An other alternative, more useful but more time consuming consists in measuring the field integral produced by each block at several horizontal position. Following the block characterization a pairing is made which cancels the errors in adjacent blocks.

2 - Local field measurements of Insertion Devices

Three method of measuring the local field produced by an insertion device can be used:

· The most widely used method is : on-the-fly scanning Hall probes. The stop and go method where the probe is moved and stop before each field acquisition is unpractical due to the noise induced by the vibrations and the associated long measuring time. The importance is not very much in the exact probe calibration but rather on the absence of drift in the probe response during the measurement . In this respect the short measuring time allowed by the on-the-fly field acquisition is an important benefit.

· Pulsed wire method have also been used. The measurment tend to be noisy and sensitive to wire imperfections and non linearities. It is the only method possible when there is no lateral access.

· Small coils + integrator have also been used. The field precision reported are rather poor and limited by the drift in the integrator.

3 – Field integral measurements of Insertion Devices
Several methods have been used by various group :

- Stretched wire
- Pulsed wire
- Flip coil
- Short one period coils (J. Pflüger)
- Long solid coils (suffer from dimensional tolerances)

## OVERVIEW ON TTF1-PROJECT (J. PFLÜGER)

First lasing of the Tesla Test Facility Free Electron Laser : 22.2.2000
Saturation of Self Amplified Spontaneous Emission @ 98mm : 7.9.2001

SPECS ON FEL UNDULATOR @ LINAC
Second vertical field integral $\leq$ 10 $Tmm^2$ (corresponding to a trajectory wandering < 20% of rms beam size at 300 MeV). The field is 0.5T and the period 27.3mm. It is a fixed gap undulator. As a result there is no requirement concerning : field integrals off axis, phase errors, gap dependent effects.

INTEGRATED FOCUSING
The undulator field of TTF1 is superimposed with a FODO type quadrupole lattice in order to focus the electron beam ($\beta$ = 1m). The insertion of the quadrupole into the undulator structure largely complicate the field measurement process and the tuning. For TTF2 and for the TESLA XFEL the larger $\beta$ required allow the placement of the FODO quadrupole between two undulator sections which simplify the undulator manufacture and tuning.

MAGNETIC FIELD MEASUREMENTS

The magnetic measurement present two distinct phases :

1. Trajectory straightening .The horizontal field Bz is measured by small coils (3400 turns, $5x10mm^2$) coupled with an analog integrator. The drift is linearly compensated. The vertical field By is measured by a calibrated Hall Probe. The horizontal field errors are corrected with shims while the vertical field errors are corrected by pole height adjustment. A few iterations allow the reduction of the double vertical field integral from 195 to 6.7 $Tmm^2$

2. Quadrupole alignment and strength tuning. A rectangular coil is moved in y and z (perpendicular to the undulator main axis) in each quadrupole. The measurement is processed to derive the axis and the strength of the quadrupole. The necessary correction in the quadrupole magnets is applied to center the axis and tune the quadrupole strength to the design value. No readjustment of the trajectory is needed. Some interference were induced by the non unity of the transverse permeability of the quadrupole magnets.

## DEVICES FOR VARIABLE POLARIZATION @ ELETTRA (D. ZANGRANDO)

6 APPLE undulators of length 2.2m have been produced for ELLETRA. The period ranges from 48 to 125 mm . An electromagnet elliptical wiggler of length 3.2m is operated with AC excitation in flat top mode.

The new Hall probe bench have been built with a roll, pitch and yaw of ± 10μrad and a flatness and straightness of ± 50μm over the full measuring distance of 5.5 m. The rms repeatability of the field integrals and double field integrals are shown below :

| | Gm | | Gm2 | |
|---|---|---|---|---|
| | Hor. | Vert. | Hor. | Vert. |
| Scan distance 1.4m, By=0.7 T | 0.019 | 0.034 | 0.002 | 0.016 |
| Scan distance 3.8m, Bx/By =0.1/0.6 T | 0.041 | 0.129 | 0.010 | 0.037 |

The planar Hall effect is compensated by fitting the quadratic coefficients from both horizontal and vertical data field collected at different phases of the Apple II.

A stretched wire field integral measuring bench is used . It has a length of 4.2 m, it makes use of Litz wire (40 stands). The measured repeatability of the (double) field integral are 0.02 Gm (0.01 $Gm^2$).

The Hall probe and stretched wire benches agree to a precision of 0.5 Gm for the field integral and 3 $Gm^2$ for the double field integral.

## ESRF INSERTION DEVICES (J. CHAVANNE)

- 86% of the ESRF insertion devices are pure permanent magnets. The other 14% are hybrid types.
- 15% of Ids are dedicated to variable linear/circular polarization

2 in-vacuum undulator are in operation ($\lambda$ = 23mm), 3 under construction (($\lambda$ = 17.18, 21mm). The magnet material used is $Sm_2Co_{17}$ instead of NdFeB for out of vacuum undulators.

The 3D Magnetic design of insertion devices include both the central periodic part of the field (20% of time spent) and the extremities (80% of time). The magnet blocks are assumed to be linear and anisotropic, the iron poles are assumed isotropic and non linear. All simulations are performed with the code RADIA . Several extremities have been optimized which minimizes both the first and second field integrals (extremity B) or the first integral and the phase error from one segment to the next (extremity C).

A flip coil is used with a length of 3000mm. The coil is made of 20 windings. The measurement is made at a sequence of horizontal positions of ± 50mm from the nominal axis and with a step of 2.5 mm. The rms repeatability is 2 Gcm. A fast scan has been implemented which reduces the measurement time from 15 to 1 minute at the cost of an increased rms repeatability of 4 Gcm.

The Hall probe bench has a measuring length of 2500mm. The probes are scanned at a speed of 20mm/s with a typical field sampling distance of 1 mm. The rms repeatability of the field integral measurement is 10 Gcm and agrees with the flip coil measurement to a precision of 50 Gcm. A quadratic correction of Hall Probe is found to be necessary and made by checking the even harmonics in field data.