Insertion Devices at ESRF

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Abstract

15 Undulators and Wigglers are now installed on the ESRF. They have been designed and measured in-house. The magnetic field has been corrected using iron shims which remove all multipoles and fully corrects the radiation spectrum. The measured spectra confirm the expected low emittance of the beam resulting in an unprecedented high Brilliance above 10 keV of photon energy. The observed interaction with the electron beam is negligible.

1. INTRODUCTION

The European Synchrotron Radiation Facility (ESRF) is a third generation synchrotron source optimised to produce Hard X-rays in the 1 to 100 keV range. The commissioning of the source has started in 1992 and it opens to the user community in 1994 [1]. The majority of the beamlines use an Insertion Device (ID) as a source point which generates high fluxes and Brilliance in the 2 to 40 keV range of photon energy.

2. IDs INSTALLED

The following table summarises the types of IDs presently in operation on the storage ring together with their maximum magnetic field in Tesla and period in millimetres.

ID #	ID Type	Bmax [Tesla]	Period [mm]
ID2	Undulator	.48	46
ID3	Undulator	0.40	44
ID6	Undulator	0.50	48
ID9	Wiggler	0.72	70
ID10	Undulator	.48	46
ID11	Wiggler	1.2	125
ID12	Helic. Und	0.4	85
ID13	Undulator	.48	46
ID15	Asym. Wiggler	1.8	220
ID16	Undulator	.38	42
ID18	Undulator	.12	23
ID20	Asym. Wiggler	1.0	210
ID27-A	Undulator	.48	46
ID27-B	Undulator	.37	40
ID32	Undulator	0.50	48

5 other IDs are intended to be installed before the end of the year. All ID segments present a length between 1.7 and 1.5 m. They are made of permanent magnet blocks with a magnetic design optimised for a 20 mm minimum magnetic gap. The large majority of IDs are undulators with a magnetic field lower than 0.5 T. ID12 is a special new kind of helical undulator intended to produce bright circularly polarised radiation in the 0.5 to 5 keV range of the spectrum[2]. ID15 and ID20 are asymmetric wigglers intended to produce circularly polarised radiation above and below the orbit plane[3].

3. MANUFACTURE OF IDs

As seen from the previous table, a large number of different magnetic field configurations have been successfully designed, built and operated in a rather short time (4 years). To do so, all mechanical structures holding the magnets in place have been made nearly identical. The magnet blocks assemblies were produced separately in three phases:

1. Magnetic and mechanical designs are made in-house after some iteration with the users of the beamline. Full drawings are then produced by ESRF.

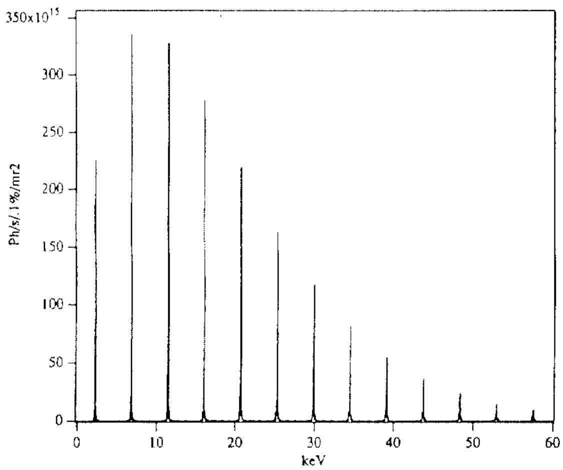
2. Manufacture of the NdFeB magnet blocks and aluminium/stainless steel assembly pieces by the European Industry (Outokumpu, Vacuum Schmelze and Ugimag).

3. Field measurement in the ID laboratory of the ESRF. The measurement includes a characterisation of the integrated multipoles. Special steel plates (shims) are placed at specific places on the surface of the blocks to eliminate all multipoles. The following table show the typical residual multipoles as measured on the 10 conventional undulators.

Dipole	< 20 Gcm
Quadrupole	< 10 G
Sextupole	< 10 G/cm
Octupole	< 10 G/cm2
Decapole	< 10 G/cm3

Note that these values apply for both normal and skew components of the multipoles at any value of the magnetic gap. Because of the large magnetic field the wigglers typically present higher multipoles. The worst has been observed on ID15 with a maximum sextupole of 90 G/cm. This shimming technique has been applied routinely to all IDs produced at the ESRF. In the meantime a refinement of this shimming has been recently implemented that allows the correction of the so-called phase errors allowing an enhancement of the Brilliance on the high harmonic number.

The following figure shows the calculated spectrum from such an undulator assuming a mono-energetic filament electron beam



The Brightness [Ph/s/.1%/mr2] of harmonic # 17 reaches 80% of the one produced by an ideal undulator. Such a "spectrum shimming" is of high importance for a number of users who want Brilliant radiation in the 20 to 40 keV range. As a result, one can safely design a beamline using harmonics 7,9 and higher. The shimming technique used to remove the multipole and optimise the spectrum is highly iterative and involves a large number of field measurements and correction processes. Two kinds of magnetic measuring benches have been developed by the ESRF ID group. One measures the horizontal and vertical field integrals with an absolute accuracy better than 10 Gcm (for a 1.6 m long, 48mm period 0.5 T peak field undulator). It is made of a long rotating pair of stretched wires connected to an integrator . An other one measures the horizontal and vertical magnetic fields along the axis of the undulator with a three axis Hall probe. The field scanning is made on the fly at a typical speed of 10 to 20 mm/sec with a sampling rate around 1 points/mm. The full shimming of an ID requires the successive use of both types of benches. In order to maintain a sufficient production rate of IDs three pairs of these benches have been built . As a result the production capacity of undulators and wigglers of the ESRF ID laboratory approaches 10 segments per year .

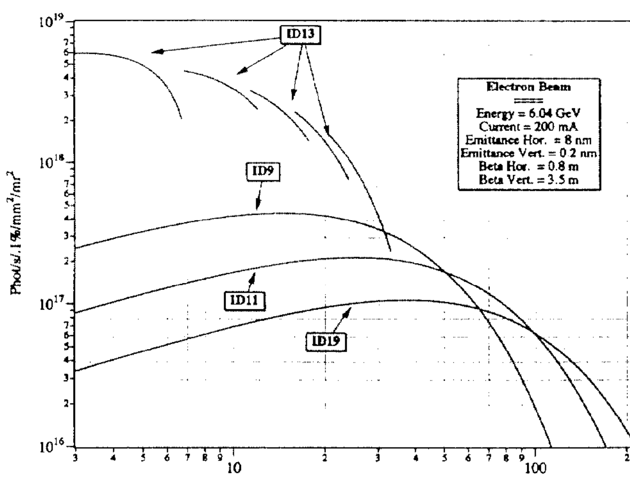
4. CONTROL SYSTEM

The undulator and wiggler mobile carriages are equipped with 2 Bergher Lahr stepper motors allowing a remote control of both the magnetic gap and taper with a resolution of 2.5 µm. The rotation or each motor is followed by an absolute multiturn rotational encoder. A magnetic gap variation of 5mm/sec is achieved in routine which allow the switching on of an undulator field in 4 seconds (field variation between 0.05 and 0.5 Tesla) .

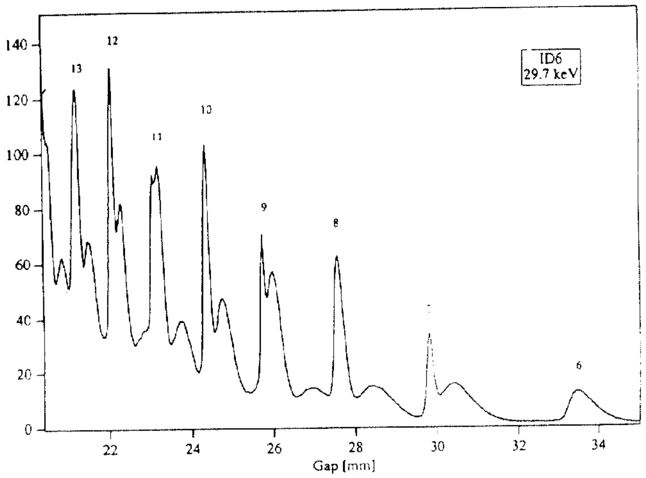
A programmable logic controller handles the brakes of the motor and the safety aspects. In some IDs (3 out of the 15 installed) a two channel power supply is connected to some horizontal and vertical steerer coils placed below the magnet blocks. All components are driven through a VME crate running the OS9 operating system. The software handling the gap change and information exchange with the control room or users is organised as a device server with multi-client capability. The correction of the residual field integral by the coils is handled in a feedback loop in the server which adjust the current in the power supply 20 times per second during the gap motion. Graphical applications which run on HP 700 workstations under UNIX and Xwindow establish the communication between the ID servers and the users. At this time, all users of the beamline are allowed to vary the magnetic gap of their ID at any time. The process of gap change initiated by a user is automatically reported to the machine control room which acknowledges the request. All IDs are left at their nominal gap during electron injection of the storage ring with the exception of ID6 and ID10 which have, in the past, suffered a demagnetisation of the magnet blocks under accidental exposure to the electron beam freshly injected from the booster synchrotron.

5. PERFORMANCE OF IDS

By imaging the central cone of the ID6 undulator, the emittances of the electron beam have been fully characterised. In routine operation horizontal and vertical emittances are 8.5 and 0.2 nmrad according to expectations. The next table presents the Brilliance of the undulators and wigglers for a stored current of 200 mA which is the target value for the end of the year.



Special lattices of the storage ring have been tested during which emittances as low as 4nm (horizontally) and 0.1 nm (vertically) have been recorded that will result in Brilliance as high as 2.0 E19 Ph/s/.1%/mm2/mr2 at 1 Angstroem for a single undulator segment. The following figure shows the spectral density measured on-axis of the ID6 undulator at the photon energy of 30 keV as a function of the magnetic gap between 20 and 35 mm. The narrowness of the harmonic peaks (up to harmonic 14) is due to both the low emittance of the electron beam and the high quality of the magnetic field of the undulator.

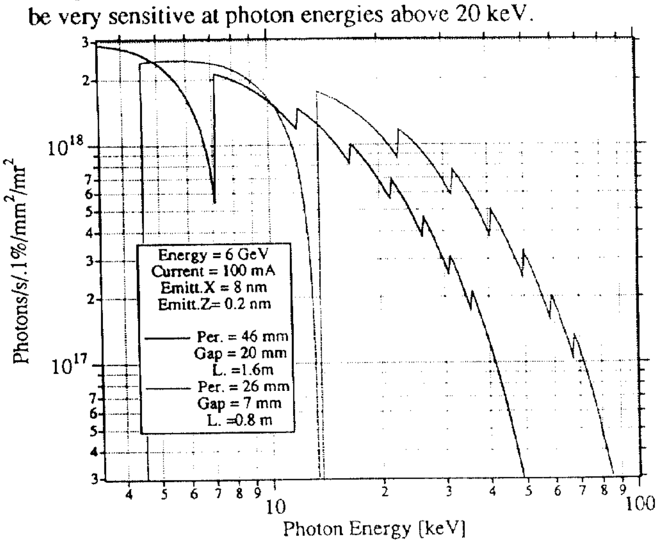


6 INTERACTION WITH THE ELECTRON BEAM

The main interaction observed between the IDs and the stored electron beam is a small closed orbit displacement which, for the present values of the emittances and for all 10 conventional undulators, reaches a few per cent of the rms. beam size of the electron beam. Effects as large as 10% have been observed for some high field wigglers which have been cancelled by mean of the correction coils. No tune shift has been observed on any ID except ID15 which showed a 1E-3 vertical tune shift. Both closed orbit distortion and tune shifts are in accordance with the field measurement. A problem has been observed linked with the imperfect cleanliness of the ID vacuum chambers which are polluted by magnetic debris, either metallic brush hairs left by the constructor or heavy dust particles freed from the neg. material used for distributed pumping. At certain values of the magnetic gap, these magnetic debris form some sort of stalactite-stalagmite arrangements short-circuiting magnetic lines across the beam section thus acting as a target on which a part of the stored beam is lost. Although the impact on the User Mode of Operation is almost negligible, it will take all the shutdowns till the end of this year to replace all defective vessels.

7 FUTURE DEVELOPMENTS

By the end of 1994, more than 20 IDs should be in operation. Among them one should mention three special devices: a superconducting wiggler, a mini gap undulator and a revolving undulator carriage. The superconducting device is a 4 Tesla three pole wigglers presently being assembled by Siemens scheduled for installation on ID15 in September 1994 [4]. This wiggler will extend the critical energy close to 100 keV allowing experiments to be performed at photon energies as high as 500 keV. A small Gifford Mac Mahon refrigerator will be incorporated in the cryostat allowing the re liquefaction of helium in situ resulting in neither liquid Helium nor Nitrogen consumption. A mini gap undulator is being built. It will be placed on a variable height vacuum chamber allowing the magnetic gap to be reduced to the minimum value tolerated by the electron beam (estimated to be around 7 mm). The period is 26 mm, its length is 800 mm, the peak field reaches 0.73 T for a 7mm gap. The next figure presents its Brilliance vs energy compared to a standard 46 mm period 1600 mm long segment. The Brilliance gain will be very sensitive at photon energies above 20 keV.



Finally a prototype revolving undulator carriage will be installed on ID6 in July which will allow the interchange of 4 undulator segments on a single carriage allowing a user to choose the magnetic field arrangement and gap that best suit his needs.

In 1995 ID manufacture and installation will continue with another 10 segments. The re-shimming of some of the existing segments which have not been "spectrum shimmed" is envisaged.

8 ACKNOWLEDGEMENTS

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