SEGMENTED HIGH QUALITY UNDULATORS

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Several issues related to the engineering of permanent magnet undulators and wigglers are addressed. Shimming performs the correction of the integrated multipole components and provides a high brilliance on high harmonic numbers of the radiation spectrum. A design of termination is given which allows the removal of any electro-magnet correction on hybrid wigglers. Another design of termination is presented which allows the phasing of two pure permanent magnet undulators at any gap value. Finally, some magnetic designs are presented which allow a high magnetic field for a short or medium spatial period.

I. ESRF Insertion Devices

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 started in 1992 and it has been open to the user community since 1994. 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. 26 IDs have been installed with fields ranging from 0.1 to 5 Tesla and spatial periods from 22 to 230 mm. All these IDs have been designed, built and measured in-house. They are nearly all made of permanent magnet material with magnet blocks placed in the air outside the vacuum chamber of the electron. The minimum magnetic gap is presently 20 mm and will be reduced to 16 mm in 1995 by changing the vacuum chambers. The source is optimised for a high brilliance which has recently reached the record $1.0\ 10^{19}$ phot./sec/.1%/mm2/mrad2 at a photon energy of 14 keV. A factor 10 improvement is envisaged in the near future.

II. Magnetic Field Shimming

A. Multipole Shimming

Special steel plates (shims) with typical dimensions of 5 x 20 x 0.2 mm are placed at specific places on the surface of the magnetic blocks to eliminate all multipoles. The following table shows the typical residual multipoles as measured on the 12 conventional undulators built so far.

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

These values apply for both normal and skew components of the multipoles at any value of the magnetic gap above 20 mm without any electro-magnet corrector. This shimming technique has been applied routinely to all IDs produced at the ESRF.

B. Spectrum Shimming

A refinement of this shimming has been implemented that allows the correction of the so-called phase errors allowing an enhancement of the brilliance on the high harmonic number. By using this technique it is now possible to routinely build undulators with a brilliance of more than 80% of that of a perfect one, up to harmonic #15. 95% has been reeched on a few undulators. This technique is now routinely applied.

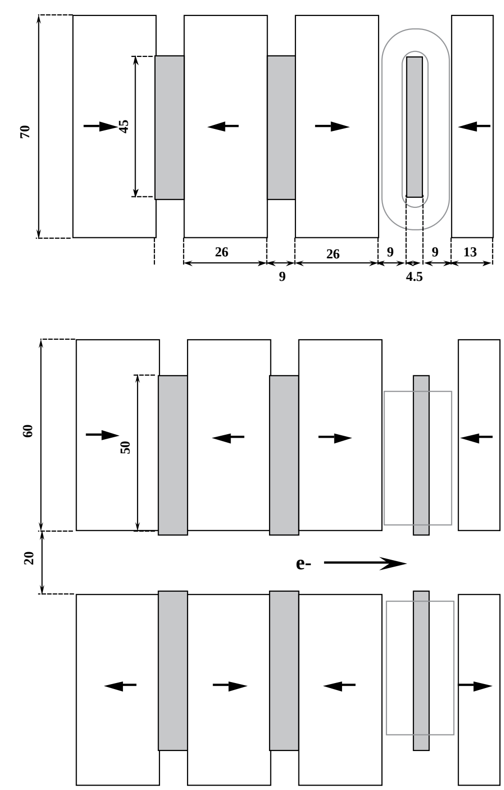

Fig:1 Terminaison of an Hybrid Wiggler generating extremely low field integral at any gap above 20 mm.

III. Undulator Termination

A. Hybrid Termination

One of the most delicate design works in a hybrid wiggler is the termination. Fig. 1 presents a termination of a wiggler that we have designed with our own 3D magnetostatic code [1]. It is optimised to produce negligible field integrals as a function of the magnetic gap. The field integral measured on the 1.6 m long device fluctuates in the range of ± 15 G-cm for both the horizontal and vertical components of the field at any gap value without any electro-magnet correction. The peak field of this wiggler is 0.85 T at a gap of 20 mm. Both terminations were in the most delicate symmetric configuration which prevents any residual field integral error from canceling as it is the case in the so-called antisymmetric configuration. Two of these wigglers are now installed on the ring and are routinely operated without any correction. For safety reasons we have left some space for inserting a coil (see Fig.1), however, this is not used.

B. Phasing Section

The straight sections of the ESRF are 5 m long. The undulators installed in these sections are segmented in three units each 1.65 m long. The segmentation allows the use of several different and/or identical IDs in the same straight section. If the field and period of the adjacent sections are identical, one needs to phase the segments with respect to each other to obtain the optimum brilliance.

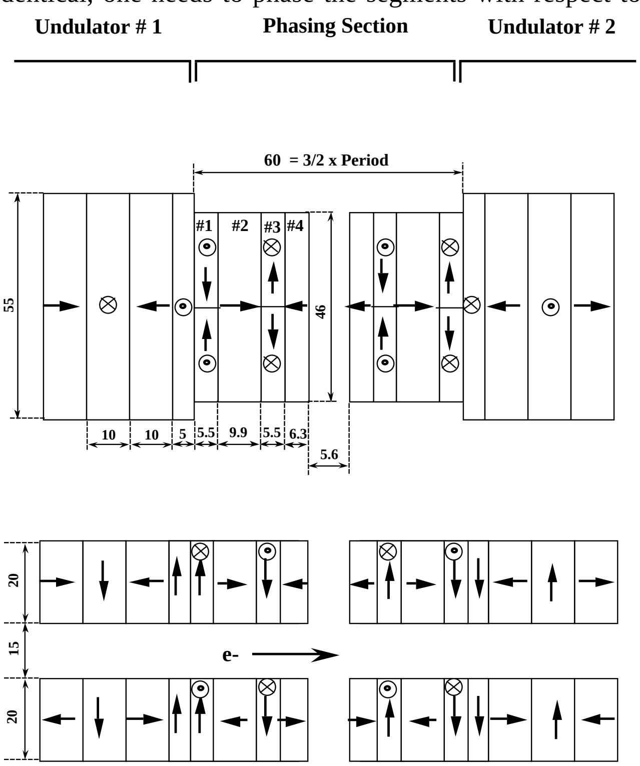

Figure 2: Termination of a pure permanent magnet undulator which allows nearly perfect phasing over harmonics 1 to 21 for any gap value between 15 and 50 mm.

Fig. 2 presents the magnetic design that we have produced which is capable of phasing two undulator segments with a period of 40 mm within the whole gap range of 15 to 50 mm.

Note that we have intentionally left a longitudinal gap between the magnets arrays of 5.6 mm in order to reduce any magnetic or mechanical interactions between each segment. Fig. 3 presents the peak angular flux computed on various odd harmonics of the radiation spectrum from the field of 2 such segments, each 12 periods compared to the one of a single undulator of 25 periods. One notices that the phasing section provides ideal performance up to harmonic 21 at a gap of 15 mm and it has a low dependence on the magnetic gap.

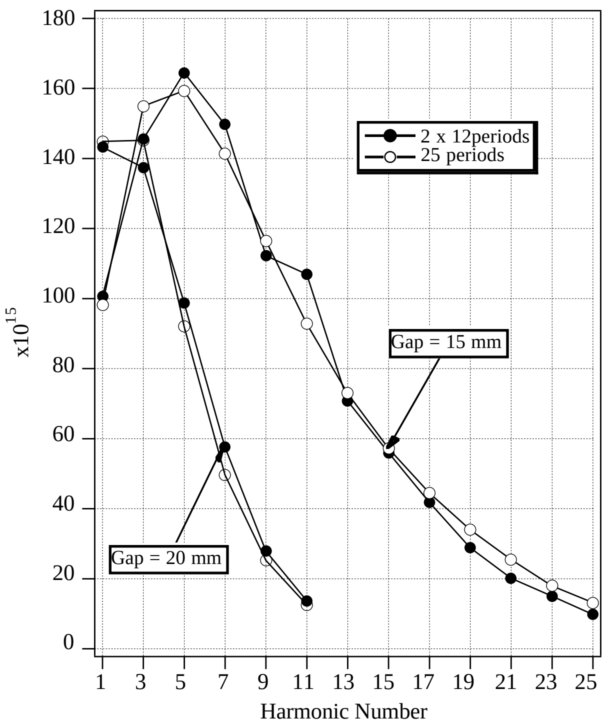

Figure 3: Peak angular flux computed as a function of the odd harmonic of the spectrum for a 25 period undulator and 2 segments of 12 periods phased according to Fig.2.

Note that such performance would not be reached if one removed the phasing section of Fig.2 except if one placed both undulator segments in close contact which would seriously complicate both installation and control. Another advantage with our phasing section is that both undulator segments are still fully independent, one can switch one, two or three segments remotely without any intervention in the ring tunnel. This feature is particularly attractive to match the ring's current condition to the maximum acceptable heat load in the beamline. 6 undulator segments of this type have been ordered and installation in the tunnel should start before the end of 1995.

IV New Magnetic Designs

For some applications it is essential to obtain the maximum field for a given spatial period. One way is to reduce the magnetic gap, another approach is to optimise the magnetic design. Figure 4 presents a magnetic design for a pure permanent magnet assembly which is easy to manufacture and achieves 11% higher field at the minimum gap of 15 mm. Two undulators of this type are currently being measured and will be installed before the end of 1995. The price to pay is a reduction of the transverse roll-off of the peak field.

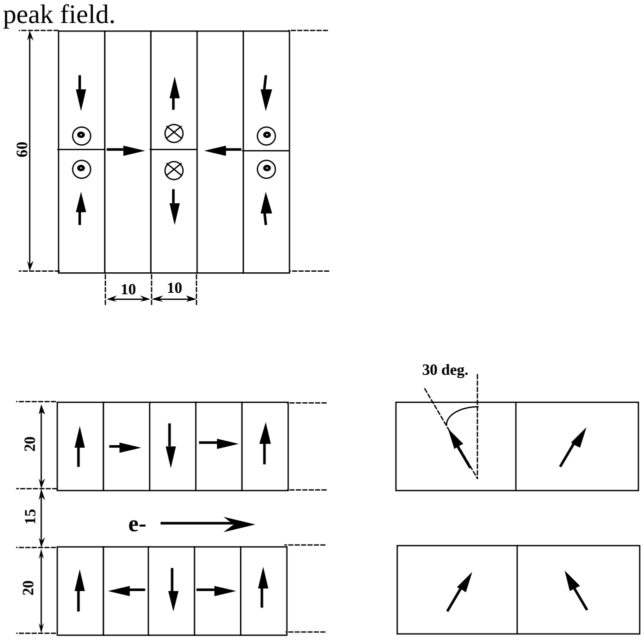

Figure 4: Pure permanent magnet design of an undulator which allows a 11% higher magnetic field than a conventional design of the same period (40 mm) and same gap (15 mm).

For some other applications the highest peak field is desirable together with a reasonably short period. In these cases hybrid technology which combines NdFeB magnets and poles made of cobalt steel with a high saturated field is the most effective. Fig. 5 presents a design of one period of such a wiggler. It presents a

150 mm period. For a magnetic gap of 20 mm a peak field of 1.9 T has been measured in good agreement with the modeling. With the new chambers of 16 mm, a field of 2.15 T is expected. Two of such wigglers have been built and installed on the ring. By reoptimising the design and operating with a 10 mm magnetic gap, we believe that a peak field of 3 T could be reached with a period around 200 mm.

A higher field would require the superconducting electro-magnet technology. A 5 T three pole device has been designed and built by Siemens for the ESRF. It has an effective period of 200 mm, a warm bore with a beam

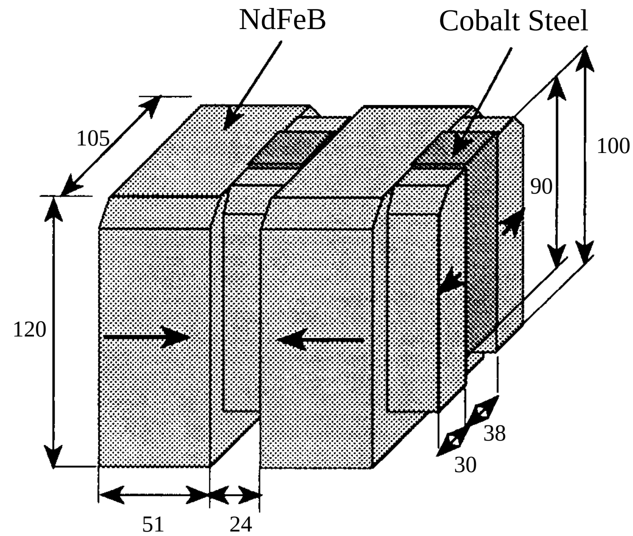

Figure 5: Magnetic design of a high field hybrid wiggler with 150 mm period and peak field of 1.9 T for a 20 mm gap.

stay clear of 16 mm. This wiggler is currently in operation. Its cryostat is equipped with a small refrigerator which cools two shields at 70 and 20 deg K respectively. A Joule Thomson loop pre-cooled by the refrigerator makes the necessary cooling capacity at 4 K to fully recondense the boiling Helium. Such a refrigerator significantly reduces the running costs.

Finally one should mention the installation of three variable polarisation linear/helical undulators with periods of 52 and 85 mm. The concept for this undulator has already been published[3]. Their most important feature is to allow the user to select independently the vertical and horizontal component of the magnetic field together with their phase. They cover the photon energy range from 0.5 to 20 keV with linear/circular polarisation rates in the 90 to 100 % level. Circularly polarised radiation of higher energy is obtained from two asymmetric wigglers[4] with respective peak fields of 1.1 and 1.9 Tesla and from the superconducting wiggler.

VI. REFERENCES

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