Summary and Conclusions of Working Group 4: Insertion Devices

prepared by: J. Bahrdt
with corrections and additions by:
B. Diviaccio, P. Elleaume, E. Gluskin, G. Ingold, E. Moog, G. Rakowsky,
R. Tatchyn

Introduction

At the previous workshop on future light sources held at Grenoble in 1996 it has been concluded that the technology for conventional planar out of vacuum devices of modest length (about 5m) is well established and that the spectral performance is dominated by the emittance and the energy spread.

Since then the insertion device technology developed rapidly towards more ambitious designs. Three main fields can be identified: long undulators for SASE-FEL applications, circularly polarizing undulators and in-vacuum undulators. These topics will be discussed below in more detail.

The requirements for higher photon energies triggered the development of wavelength shifters (up to 10 Tesla planned for SPRING 8), superconducting multipole wigglers (MAXLAB), high field (above 3 Tesla) permanent magnet devices (ESRF, SRRC), mini gap/in-vacuum wigglers and superbends (ALS).

Stretched wire systems have become a standard tool for first and second field integral measurements. Local fields still have to be measured with Hall plates which implies difficulties with respect to calibration, planar Hall effects, drifts and aging. Substantial effort and hardware advancement is needed to meet magnetic measurement requiremnets for the x-ray FEL.

Special computer software for the magnetic design of insertion devices has been developed during recent years which predict fields and field integrals with a high accuracy (RADIA). Codes for the description and propagation of diffraction limited light sources have been written (SRW, PHASE). However, the description of the intermediate range of partially coherent light is still difficult to model in numerical simulations.

Long Undulators

In terms of machining tolerances, complexity and costs the optimum segmentation length for gap tunable undulators seems to be about 2.0-2.5 m. For permanent magnet structures phasing sections have been optimized which work gap independently even for segment distances of several millimeters (ESRF). This design allows an adaption of the ID-length to the needs of the users without altering the field integrals. The correct phasing of hybrid modules can be achieved only if the gaps between segments do not exceed a few 0.1 mm (SPRING 8, BESSY II). The segments are mechanically decoupled, nevertheless, they have to be operated in synchronism (same gap settings) in order to avoid field integral variations.

In a closed loop drive system several axes can be operated in synchronism with an accuracy of 1 μm if the Abbe's comparator principle is applied (linear scales at both sides of the I-beam).

Tolerances and performance of SASE FEL undulators have been discussed for three cases, the TESLA ID, the VISA ID, and the APS FEL ID. All three devices will start operation during the year 1999. Tolerance requirements and beam-based alignment strategies have also been presented for an initial design of the SLAC LCLS undulator, for which prototype R&D studies are currently being planned.

Tight tolerances on the trajectory wander have to be achieved whereas phase errors alone seem to be of minor importance. Second field integral variations below 5 Tmm^2 have been achieved. Averaging of Hall probe measurements is unavoidable to reach such an accuracy. Alternatively, pulsed wire techniques are used, if the business region is not accessable with Hall probes (VISA). The magnetic measurement of two segments in one continuous scan is important.

Undulators with integrated strong focussing (four magnet design (TESLA), Varfolomeev design (VISA)) require new measurement techniques (moving coils, pulsed wires etc.). The translation of the quadrupole centres to outside fiducials is essential for the alignment of the undulator modules especially for the VISA in-vacuum device.

Laser interferometer based alignment of the modules is restricted to a length of some 10 m. Beyond this distance beam based alignment is necessary (measuring the dispersion by varying the beam energy instead of the quadrupole strength once the beam passes the quadrupole off center). Between segments diagnostics and correction tools are available (wire scanner, cavity monitors etc.). Pick up monitors as well as wave guide monitors and correction coils are provided inside the undulators (TESLA).

All SASE FEL-undulators currently under construction are fixed gap devices. If tapering becomes important (approaching 10 KeV radiation) new drive systems have to be designed. For very long undulators automatic shimming techniques will be useful.

The three FEL-devices under construction are hybrid (TESLA and APS) or planar pure permanent magnet designs (VISA). It has been agreed upon by the working group participants that the desired field quality can also be achieved with a planar helical pure permanent magnet design. The peak field however would be lower. Studies on superconducting designs for SASE FEL undulators are currently under way. Prototypes have not yet been built and new measurement techniques for these devices have to be developed.

A crossed undulator for production of circularly polarized light has been proposed by Kim. A long horizontal undulator and a short vertical undulator are separated by a dispersive section. A monochromator is not needed in this design since the first undulator radiates coherently due to the bunched beam. Fast helicity switching can be done either with the dispersive section or with special designed optics.

New Designs for Variable Polarization, Reduced Higher Order Contamination, Less On-Axis Power Density

A large number of new designs have been developed which reduce higher order contamination and/or on-axis power density like a new quasiperiodic scheme, (this device has been invented independently at ELETTRA in collaboration with Sasaki and at the ESRF and it has been built and tested with beam at the ESRF), the Figure 8 and the 3 row EPU (SPRING 8), the PERA (ELETTRA) or the APPLE 8 (Sasaki). The APPLE design has become a standard design which is now under construction or in operation at many laboratories (SSRL, ALS, SPRING 8, SRRC, PLS, ELETTRA, BESSY II, ESRF).

For fast helicity switching various schemes based on double undulators (for right and left handed polarization) have been designed. The electron beam is either displaced for two parallel trajectories (SLS) or deflected by a chicane (BESSY II) and the photon beam is chopped inside the beamline. Another solution is a dynamical displacement of the electron beam (SPRING 8). At the ESRF a chicane type double undulator (HELIOS) has been in operation since 1993.

New technological problems with circularly polarizing permanent magnet devices have been solved. The field integral dependence on gap and phase motion can be minimized with a new end termination (ESRF). New shimming techniques like magnet block movement (ALS), iron shims in a specific configuration (ELETTRA) or permanent magnet shims (BESSY II) guarantee a good field quality. The magnet blocks can be produced with significantly lower inhomogenities compared to the situation several years ago (north south pole effect smaller than 0.5%). However, it is still necessary to apply both techniques: The sorting of the magnets and the shimming of fully assembled magnet arrays.

New pulsed electromagnetic devices for polarized light are in operation at NSLS, APS, ELETTRA and ESRF. Switching frequencies of the elliptical/helical undulators can not exceed 10 Hz since these devices have to be operated in the flat top mode. Elliptical wigglers are also operated up to 10 Hz (APS), or, when higher switching rates are particularly desired and operation in the transient regime is acceptable, may be operated at up to 100 Hz (NSLS). Closed orbit distortion can be compensated with correction coils driven by appropriate function generators and/or look-up tables and fast DSP-electronics. Hysteresis effects introduce field errors which can be compensated.

Small Period and In-vacuum Undulators

Pushing the photon energies to higher values requires smaller periods and smaller gaps. During recent years the in-vacuum undulator technology has been developed at SPRING 8 and other places to a stage where an in-vacuum design seems to be less expensive than a flexible vacuum chamber and may be the only reliable technology for several meter long devices and magneticgaps below 6 mm.

In-vacuum devices have now reached a level of maturity such that they can be seriously considered from the outset in new proposals.

After baking magnet coatings of Ti+TiN allow pressures of 6.e-11 mbar (SPRING 8) and Ni-plated Sm_2Co_{17} magnets show pressures below 1.e-10 mbar (ESRF). A Cu plated Ni foil on top of the magnets and water cooled RF-fingers at the taper transitions reduce problems due to image current heating. A magnet material with a high coercive force is used in order not to demagnetize the magnets during bakeout.

Phase errors below 5 degrees (rms) have been achieved. At this point where the basic technological problems of the in-vacuum devices have been solved more delicate devices are under construction such as an in-vacuum revolver type undulator (SPRING 8) and a 25 m long in-vacuum device

(SPRING 8). The SLS plans to explicitly take advantage of enhanced performance of medium energy storage rings (2.4 GeV) by providing extended tuning range and higher photon energies via short-period undulators. An in-vacuum device for 5-17.5 keV photons using up to the 11th harmonic will be operated at a 4 mm gap.

Periodic checks of the ID performance, especially for in-vacuum devices, is recommended. Field integral checks are necessary and the measurement of higher harmonics (width and shape) or of polarization characteristics is as important but more time consuming.

The smallest magnetic gaps routinely used are 3 mm (NSLS, in vacuum) and 8 mm (APS, fixed chamber, ESRF, in vacuum, and SPRING 8, in vacuum). Long-term experience at smaller gaps is not yet available. Machine studies at the ESRF show lifetimes of 62 h and 30 h at magnetic gaps of 6 mm and 3 mm (ID length=1.6 m and β_y=2.7 m) and still 2 h at a gap of 0.8 mm (scraper measurements). The stability of the magnetic material is not ensured if the magnet array is scraping the beam. In this respect Sm2Co17 is more resistant than NdFeB.

Shielding against hard radiation will become an important topic for very small gaps. Hence, not only the injection rate but also the injection efficiency is a parameter to be optimized for topping up operation.

Studies at the ALS show achievable betatron functions of 0.3 m horizontally and 0.06 m vertically over a region of about 100 mm with additional quadrupoles. Small betatron functions over a larger range might be provided via integrated strong focussing magnets as proposed by Tatchyn.

Superconducting small period devices have been built and tested (NSLS, Forschungszentrum Karlsruhe). If a superconducting undulator can be operated as a cold bore in-vacuum device, highly in saturation and at an operating current 10% below the quench current the peak field could be about 40% higher compared to a hybrid for a period length of about 20 mm and a gap of about 8 mm. For 10 mm period length and 4 mm gap this margin decreases to about 10%. This result is based on devices built at NSLS. Today new superconducting wires could possibly provide higher current densities. A warm bore device would not have an obvious advantage because insulation and heat shielding needs additional gap space. In addition to machining accuracy, winding errors become important for highly saturated iron. Low phase errors have been demonstrated below saturation. Almost no information is available for multipole errors of such devices. Operational challenges as a fixed field device used for a single pass FEL are expected to be less formidable compared to a tunable device operated at a storage ring.

Further advancements in superconducting technology, such as, e.g., the development of reliable wires with diameters down to the few-mil range, could also lead to the practical development of flexible variable-period insertion devices with short (1-2 cm) mechanical periods. While such undulators can substantially reduce power loading of beam line optics and provide fully flexible polarization control and wavelength tuning, the high cost of the required control system at present appears to be an obstacle to device lengths in excess of 100 periods.