TECHNICAL DESCRIPTION OF THE MAX II UNDULATORS

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ABSTRACT

The third generation synchrotron radiation source MAX II is today equipped with 2 undulators and a third is under construction for installation in 1996. These hybrid devices have identical C-frame carriages, drive systems and a fibre-optical control system connected to a common VME-computer. The technical aspects of these devices are described, together with their integrated magnetic characteristics and expected spectral capacities.

1 INTRODUCTION

Three undulators for the 1.5 GeV ring MAX II [1] with periods 6.6, 5.88 and 5.2 cm are either installed or under construction. U6.6 will be the source for a beamline being constructed as a collaborative project by research teams from Linköping and Lund Universities, aimed at XPS, XES and spectromicroscopy with submicron lateral resolution. U5.88 will serve the "Finnish beamline" maintained by a consortium from universities in Finland and Sweden for photon-electron spectroscopy of gaseous, liquid and solid samples. U5.2 constitutes the source of a beamline for core spectroscopy (XAS, XES, XPS) in the 100 - 1200 eV range, which is being set up by a constellation of research groups from Uppsala University. U6.6 and U5.2 were installed in 1995 and U5.88 will be installed later this year.

2 MAGNETIC DESIGN

All undulators are permanent magnet devices based on a centrally symmetric (pole at longitudinal centre) hybrid magnet configuration. NdFeB-magnets of grade 450i from Outokumpu Magnets (today operating under the name Neorem Magnets) and pure iron poles are used. The mechanical design and dimensioning of all three devices is identical except for the thickness of poles and magnets, which is varied to make up the correct period. The most important dimensions and characteristics of the magnet systems are summarized in table 1. Transversely the magnets are square-shaped. This is not exactly the optimum shape for minimum magnet material, but it doubles the possible rotational positions of a magnet in the assembly as compared to a rectangular shape and thus greatly facilitates magnet sorting.

Mechanically the two hybrid arrays are mounted on backing beams of steel. The cross section of these I-beams is chosen for a maximum deflection of 15 μm at the maximum magnetic and gravitational loading. Subassemblies of five poles connected by aluminium holders, which support the poles from their sides over their total height are bolted directly to the backing beams. Fig 1 shows the principle of the mechanical assembly.

Table 1. Undulator parameters

Undulator	U5.2	U5.88	U6.6	
Magnet size 88 mm x 88 mm x	16.5	18.9	21.0	mm
Remanence of magnet material	1.2	1.2	1.2	T
Coercivity (HcJ)	1500	1500	1500	kA/m
Pole size 71 mm x 50 mm x	9.5	10.5	12.0	mm
Number of full field poles	99	87	77	
Total length	2661.5	2656.5	2652	mm
Maximum peak field	0.565	0.655	0.740	T
Maximum magnetic force	8800	12200	15400	N
Minimum magnetic gap	22	22	22	mm
Maximum magnetic gap	300	300	300	mm

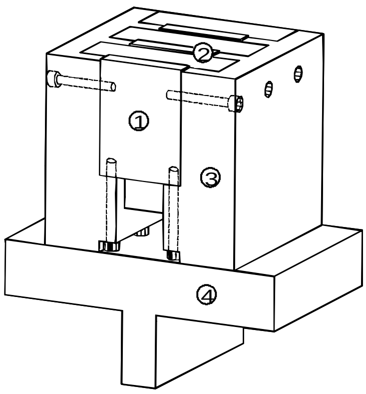

Fig 1. Mechanical schematic of the hybrid structure

Special jigs used both for putting together the subassemblies and for their alignment onto the beams assure a pole position accuracy of 20 μm longitudinally and 100 μm laterally, despite the fact that the pole thickness (ground to ±10 μm) is the only narrowly toleranced dimension of the parts. After the assembly is finished a final grinding step over the pole tips locates the pole tip surfaces of the array within ±20 μm of a common plane. In this way the rms error of the longitudinal pole tip locations, which in the hybrid configuration is the dominant mechanical field error source, can be held below 40 μm without time consuming individual alignment of the poles in a coordinate measurement machine. This accuracy is good enough to keep mechanically induced field errors neglible as compared to the level caused by magnet imperfections, despite a rigorous magnet sorting procedure. As the final step the permanent magnets are inserted from the top into the boxlike compartments formed by the poles and aluminium holders with the aid of a special magnetically shorting insertion jig.

The periodic structures are terminated by special end modules, which contain a half strength pole (field integral half of that of a full field pole) equipped with a correction coil and zero potential field clamps at the very end. The geometry and the size of the two outermost magnets are optimized by 3D FEM-modelling for minimum change of the field integral with gap and minimum total multipoles. Fine tuning of the field integrals versus gap is performed with the correction coils. By individually regulating the coils at each end, both the first and second field integral can be corrected.

3 SPECTRAL CHARACTERISTICS

Table 2 contains the most important spectral characteristics of the three undulators. Such quantities as brilliance and maximum photon energy have been calculated based on design characteristics of the electron beam and the measured magnetic field of the undulator (for U5.88, which is not yet measured, design goals are used). The most important design parameter has been the minimum photon energy of the first harmonic, corresponding to the minimum gap setting, since no useful radiation is generated at lower energies.

All undulators are completely tunable utilizing odd harmonics only. This condition is satisfied if the tunable range of the fundamental and third harmonic overlap. The maximum photon energy given in table 2 is taken as the point where the brilliance has dropped to 30 % of its maximum value. The gaps of all undulators can be tapered in order to achieve a wiggler-like operating mode, in which higher harmonics are continuously overlapping, giving a fairly flat spectrum.

Table 2. Spectral characteristics

Undulator	U5.2	U5.88	U6.6	
Max. K (deflection const.)	2.74	3.60	4.56	
Minimum photon energy	87	49	29	eV
Maximum photon energy	1150	1000	750	eV
rms phase error	3.5	3.0	7.2	deg
wiggler mode (tapered gap)	0.45-	0.25-	0.20-	
photon energy range	2.0	2.3	2.8	keV
Maximum brilliance (10^{17}ph/s/mm^2/mrad^2/0.1%BW)	5.2	4.2	3.3	

4 CARRIAGE

A standard undulator carriage for the MAX II ring was developed and deployed for all three undulators. It features an open C-type frame and a three point kinematic support, allowing easy removal of an undulator from the key-hole shaped vacuum chamber without demounting any structures. The kinematic mounts are based on ball transfer units which can act as multidirection wheels for moving the carriage on grooved rails.

The frame has been dimensioned for a maximum magnetic force of 4 tons, at which the roll angle deflection of the backing beams is less than 50 microrad. The basic stiffness comes from two pillars housing vertical ball screw drives and linear bearings for L-shaped slides supporting the backing beams. In order to alleviate the stiffness requirements on the pillars and reduce the total load on the gap change mechanism, disc spring assemblies taking up most of the magnetic force have been added. The spring systems are supported by a lever system with pivots located in the neutral plane of the pillars, so that spring forces cause no bending of the pillars.

The mechanism for gap changes consists of a single standard induction motor and a gear train transmitting the motion to two ball screw shafts with opposite handed threads for the upper and lower backing beams. The gap and its taper is monitored by two linear encoders mounted directly onto the backing beams. Gap tapering is achieved with the aid of a clutch in the gear train, allowing rotation of only one ball screw shaft.

Carriage control, ie. gap monitoring, changing and maintaining trim coil currents, limit switch checking etc. have been established locally,while the control computer is located in a remote VME crate [2]. The VME-computer with OS-9 real-time operating system is accessible through Ethernet, which makes it possible to control insertion devices through the local area network. Communication between the computer and insertion devices goes through an optical fibre bus, which is immune against electrical interference. The main parts of the local control system are shown in figure 2.

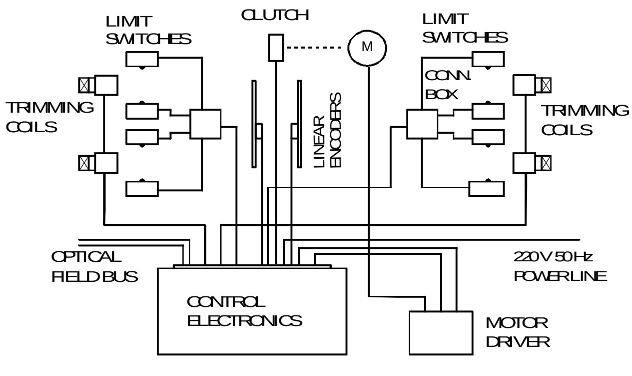

Fig 2. Schematic of the undulator control system

5 MEASUREMENT AND SORTING OF MAGNETS

All components of the average magnetic polarization of each magnet block were measured in a standard Helmholz coil setup. A rather disappointing result of the sorting procedure for U6.6 based on these measurement results led to the conclusion that polarization inhomogeneities in the magnet block must also be considered. Therefore additional measurements consisting of a number of Hall probe scans close to the large surfaces of the magnet blocks were were performed on the U5.2 and U5.88 magnets. This information was used in building a magnet block model comprizing 16 homogeneously magnetized sub-blocks. The 48 parameters of this model were obtained with the aid of a genetic algorithm minimizing the rms difference between measurement results and the corresponding analytically calculated fields. This procedure was not developed in time to be utilized in the sorting of of U5.2 magnets, but later field calculations for this undulator based on the 16-block model gave much better correlation to the measured field than calculations based on integrated polarization only (see fig 3). A survey of the polarization inhomogeneities revealed by this process showed that a fairly frequently encountered configuration, in which the polarization vector is tilted outwards from the centre in a flowlike pattern, caused the largest errors in the field calculations based on average polarization only.

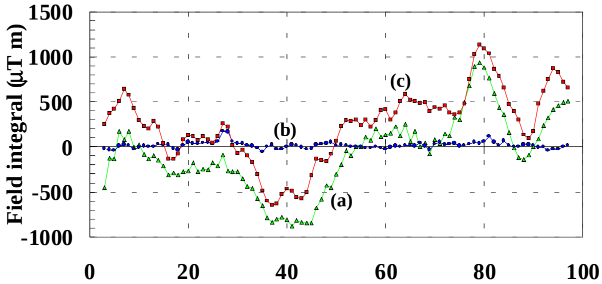

Fig 3. The field integrals of U5.2 derived by: (a) Hall probe measurement, (b) calculation with homogeneously magnetized blocks and (c) calculation with 16-sub-block model

Magnet sorting was done with aid of another genetic algorithm. Unit polarization field traces on the optical axis (3 for the homogeneous model and 48 for the 16-block model) were calculated by 3D FEM-modelling of the hybrid magnet structures employed and used to sum up the total field of each configuration created by the genetic algorithm. For U6.6 the field integral was used as fitness criterion, while U5.2 and U5.88 were sorted for minimum rms phase error at pole centers.

6 FIELD MEASUREMENTS AND TUNING

Undulator fields were measured in a special insertion device measurement bench, in which both automatic Hall-probe scans and direct integral measurements with a flip coil can be performed [3]. Longitudinal Hall scans on the optical axis were done with 1 mm steps and integrated numerically to give the 1st and 2nd field integrals and phase errors. Integrated multipoles were evaluated by transverse scans with the flip coil on a 5 mm grid. Fast and accurate measurements of the 2nd field integral were obtained by tapering of the flip coil [4], which proved especially useful in determining correction coil current settings at different gap widths.

Fine tuning of the field was done by shimming. Steels shims of varying size and thickness (up to 1 mm) were placed on the free magnet surface adjacent to pole tips. For U6.6 this shimming was done in a logical manner based on calculated field traces of different shim locations and sizes to correct errors in the on-axis field and to reduce field integral multipoles. The electron trajectory obtained is shown in fig. 4. For U5.2 a genetic algorithm minimizing phase errors at pole locations was employed, leading to a considerable improvement (see fig. 5).

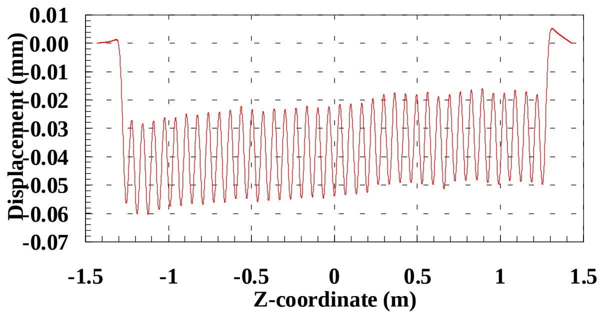

Fig. 4. The electron trajectory of U6.6

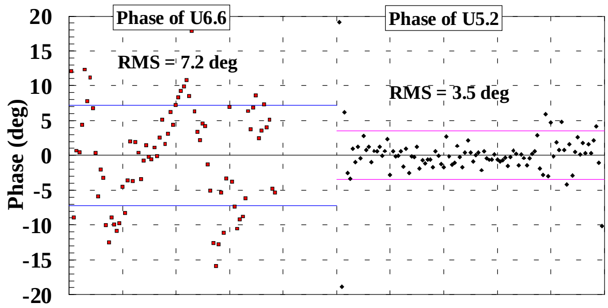

Fig. 5. The phase at pole locations in U6.6 and U5.2

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