INSERTION DEVICES FOR THE MAX IV LIGHT SOURCE

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Abstract

The foreseen insertion devices and expected brilliance for the MAX IV light source are presented. The planned MAX IV light source consists of three low emittance storage rings and a 3 GeV linac. The linac is used as a full energy injector. The three storage rings will be operated at 700 MeV, 1.5 GeV, and 3.0 GeV, which makes it possible to cover a large spectral range from IR to hard X-rays with insertion devices optimised for each storage ring.

INTRODUCTION

There is a general interest within the synchrotron radiation community, especially at medium energy rings, in producing undulator radiation with as short a wavelength as possible, which implies using the higher harmonics of the fundamental wavelength. The period length of the undulator should hence be as small as possible. The search for high brilliance also requires that the beam has a low emittance. The development of the insertion device technology has, together with the development of low emittance storage rings designed for the production of synchrotron radiation, been the key to the enormous increase in brilliance of the synchrotron light sources over the past decades. The future MAX IV light source will be ideal for the installation of small period insertion devices and the low emittance of the electron beams will make it possible to obtain undulator radiation with extremely high brilliance.

THE MAX IV LIGHT SOURCE

A fundamental challenge for the design of the proposed MAX IV facility [1] is that the scientific demands call for a facility which will deliver spontaneous as well as coherent radiation of very high quality over a broad spectral range, from IR radiation, VUV radiation and soft X-rays to hard X-rays. To achieve this in one single ring would require a 3.0 GeV ring equipped with a number of very long straight sections. An alternative approach, made possible by the compact MAX IV design, is to add a second ring at 1.5 GeV energy on top of a 3.0 GeV ring. The plan is also to complement the two new rings by the 0.7 GeV MAX III ring, which will be relocated from the present laboratory. All rings will be operated in top-up mode with a 3 GeV linac as full energy injector. The Linac will also be used to generate short spontaneous X-ray pulses and coherent radiation in a second phase. The MAX IV storage rings will provide electron beams with extremely small emittance. The construction of a facility with three storage rings with different energy of the stored beam has allowed an optimization with very few compromises. The low photon energy beamlines are then placed in a ring of lower electron energy. Long undulator periods and high K-values can thus be avoided. The 0.7 GeV ring will be the prime source for IR and UV radiation and extends the photon energy range for undulator radiation down to a few eV. The magnet lattices of the 1.5 GeV and 3.0 GeV storage rings are identical. The parameters of the rings are summarized in Table 1. The 0.7 GeV MAX III ring has been described elsewhere [2]. The 1.5 GeV storage ring is placed on top of the 3.0 GeV ring. The two rings, each with a 12-fold symmetry, are rotated 15° relative to each other. The beamlines from the straight sections will thus be spread out evenly on the hall floor. The Radio Frequency system will probably be a 100 MHz system and Landau cavities will be used to decrease the electron density and thus increase the Touschek beam lifetime and also decrease the heat load on the insertion devices from the resistive wall effect. The dipoles adjacent to the straight sections will have a soft en design, also to decrease the heat load on small aperture insertion devices on the straight sections [3]. The MAX IV storage rings are hence adapted for the installation of undulators with a cold bore.

The 0.7 GeV MAX III storage ring is located in the area into which the two injection straight sections are pointing. The 3 GeV injector Linac is housed in a 300 m long tunnel, 5-7 m below the floor level of the MAX IV rings. The insertion devices for the generation of short pulse light and in a later stage coherent light, are placed close to the Linac axis and below the ground level.

The MAX IV project is not yet financed but the fund raising process of the project has started.

Table 1: Basic machine parameters

Ring	0.7 GeV	1.5 GeV	3.0 GeV
Circumference [m]	36	287.2	287.2
Electron energy [GeV]	0.7	1.5	3
Circulating current [A]	0.5	0.5	0.5
Energy acceptance [%]	2	3	3
Horizontal emittance	14	0.34	0.8 *
Momentum compaction	0.035	7.45×10^{-4}	7.45×10^{-4}
Betatron tunes Qx/Qy	3.7/2.7	26.59/9.18	26.59/9.184
Coupling	0.1	0.1	0.01
Nr of straight sections	8	12	12
Straight section length	3	4.6	4.6
RF [MHz]	100	100	100
Energy loss/turn [keV]	7	42	712 *
Power consump. [MW]	0.2	0.5	1

* Incuding superconducting wigglers

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FLAT FIELD INSERTION DEVICES

The straight sections of the MAX IV storage rings are 4.6 m long and the vertical beam stay clear aperture is 4 mm in the 3.0 GeV ring and 6 mm in the 1.5 GeV ring. For out-of-vacuum devices, such as conventional planar undulators or elliptically polarizing undulators, extruded Al vacuum chambers can be used. With a 1 mm wall thickness of the extruded Al chamber and a 0.5 mm clearance between the chamber and the pole faces, the minimum vertical aperture of the insertion devices is 7 mm in the 3.0 GeV storage ring and 9 mm in the 1.5 GeV storage ring. The out-of-vacuum devices will be tailored to the specific needs of the beamlines where they are installed. The out-of-vacuum insertion device technology is a mature technology and the out-of-vacuum insertion devices for MAX IV can be built with existing technology.

The most challenging insertion devices for the MAX IV storage rings are the insertion devices for beamlines on the 3.0 GeV storage ring requiring high brilliance radiation in the hard X-ray regime. These undulators will by necessity be in-vacuum insertion devices since a small magnetic gap is needed in order to obtain a high undulator peak field in combination with a short period length.

Superconducting wigglers

Two superconducting wigglers will be installed in the 3.0 GeV ring. The wigglers to be installed in MAX IV will be of the same type as the existing superconducting MAX-Wigglers at MAX-lab [4]. The function of the superconducting wigglers is twofold, they are sources of synchrotron radiation for experimental stations but they are also working as damping wigglers, lowering the emittance of the storage ring.

Superconducting undulators

Superconducting undulators is a most promising future technique for short period high field undulators. A superconducting undulator using NbTi superconducting wire at 4.2 K will have an effective field about twice that of an in-vacuum hybrid undulator at ambient temperature. Superconducting undulators is however not yet a mature technology but development work of superconducting undulators is carried out in Europe [5,6], Asia[7] and the USA[8,9,10,]. By the time of the assembly of the MAX IV storage rings it may be expected that the present challenges of superconducting undulator technique have been overcome. The expected peak field in superconducting undulator is found by using a generalised expression of the peak field in a superconducting undulator found in [6]. The expected peak fields and period lengths of the superconducting undulators are shown in Table 2 for the 3 GeV ring and Table 3 for the 1.5 GeV ring.

In-vacuum undulators

Undulators built with permanent magnet technology are either of hybrid type, whereby the construction includes poles made of iron or other soft magnetic material, and permanent magnet material or constructed from permanent magnets only. The hybrid type undulator is capable of giving a higher effective field than the permanent magnet undulator and is hence the most interesting option. The in-vacuum undulators will operate at small gaps and hence the more radiation resistant magnetic material Sm_2Co_{17} is chosen instead of NdFeB, which has higher remamence but also is more sensitive to radiation. The peak field in a hybrid undulator for a specific period length and magnetic gap is found by carrying out an optimisation procedure of the geometry of the iron poles and magnet material in the undulator. The magnetic material Sm_2Co_{17} (Br = 1.05 T) is used as the permanent magnet material and iron is used as the pole material. The expected peak fields and period lengths of the in-vacuum undulators are shown in Table 2 for the 3 GeV ring and Table 3 for the 1.5 GeV ring.

Cryogenically cooled in-vacuum undulators

Currently hybrid type undulators working at temperatures far below ambient temperature are being developed [11]. This will enhance the peak field in the undulator since the permanent magnet material shows an increasing magnetic field performance with decreasing temperatures. The temperature of the magnet structures in a cooled hybrid undulator is foreseen to be about 140 K. The most important effect of the cooling is the large

Table 2: Flat field undulators for the MAX IV 3 GeV storage ring

Undulator	Description	Magn. Gap [mm]	Phys. Gap [mm]	Per. Length [mm]	Peak Field [T]	*K*-value	Length [m]	Periods
SCU 14.0	Superconducting Undulator	4.4	4.0	14.0	1.70	2.21	3	214
PMU 19.0	Sm_2Co_{17} Hybrid Type @ 300 K	4.2	4.0	19.0	1.28	2.28	3	157
CPMU 17.5	NdFeB Hybrid Type @ 140 K	4.2	4.0	17.5	1.38	2.25	3	171

Table 3: Flat field undulators for the MAX IV 1.5 GeV storage ring

Undulator	Description	Magn. Gap [mm]	Phys. Gap [mm]	Per. Length [mm]	Peak Field [T]	*K*-value	Length [m]	Periods
SCU 16.5	Superconducting Undulator	6.4	6.0	16.5	1.49	2.30	3	181
PMU 23.0	Sm_2Co_{17} Hybrid Type @ 300 K	6.2	6.0	23.0	1.02	2.19	3	130
CPMU 21.5	NdFeB Hybrid Type @ 140 K	6.2	6.0	21.5	1.13	2.26	3	139

increase of the intrinsic coercivity, which makes NdFeB material at least as resistant to radiation damage as Sm_2Co_{17} material. The other beneficial aspect of the cooling is the higher remanence achieved. The peak field in a hybrid type undulator operating at cryogenic temperatures is found by carrying out an identical optimisation procedure as above. The magnetic material is NdFeB (Br = 1.35 T at 140 K, Br = 1.18 T at 293 K [11]), and iron is used as the pole material. The cold hybrid undulator is at a temperature of 140 K. The expected peak fields and period lengths of the cryogenically cooled in-vacuum undulators are shown in Table 2 for the 3 GeV ring and Table 3 for the 1.5 GeV ring.

The expected brilliance for the flat field undulators installed in the 3 GeV ring is shown in Figure 1 and the expected brilliance from the flat field undulators installed in the 1.5 GeV ring is shown in Figure 2.

ELLIPTICALLY POLARISING UNDULATORS

The MAX IV facility is very well suited for elliptically polarizing undulators (EPUs). The availability of both 1.5 and 3 GeV electron beam energy allows the independent optimization of EPUs for the soft and hard x-ray regime. An EPU cannot be constructed as an in-vacuum device due to its complicated mechanical structure, but the small vertical dimensions of the beam vacuum chambers allows the use of short periods to extend the high energy part of the photon spectrum. The addition of the MAX III ring with its existing 69.1 mm period EPU will then provide a continuous coverage with elliptically polarized photons from a few eV to about 2 keV.

Figure 3 shows the expected brilliance from the 1.98 m long 69.1 mm period EPU with 57 poles on MAX III ring, a 4 m long EPU with 41 mm period and 193 poles on the 1.5 GeV ring and a 4 m long EPU with 35 mm period and 226 poles on the 3 GeV ring

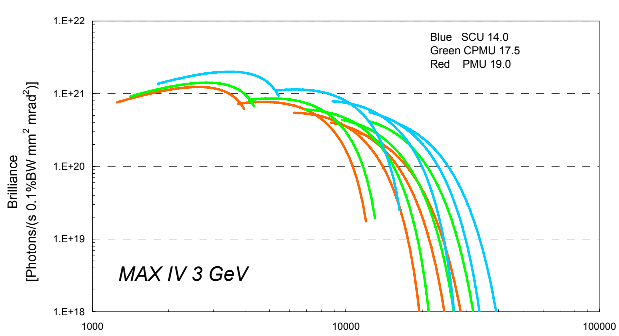

Figure 1: Brilliance at the 3.0 GeV ring for the harmonics 1, 3, 5, and 7 of undulators with a K-value in the range 0.5-2.2.

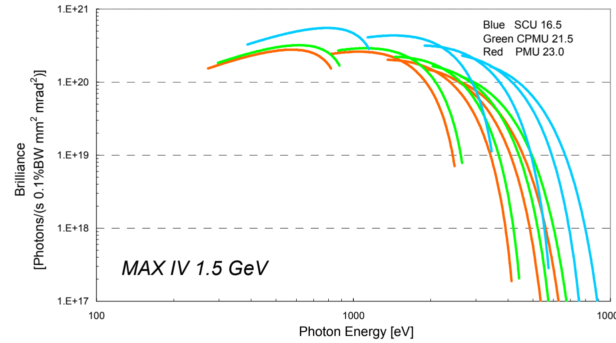

Figure 2: Brilliance at the 1.5 GeV ring for the harmonics 1, 3, 5, and 7 of undulators with a K-value in the range 0.5-2.2.

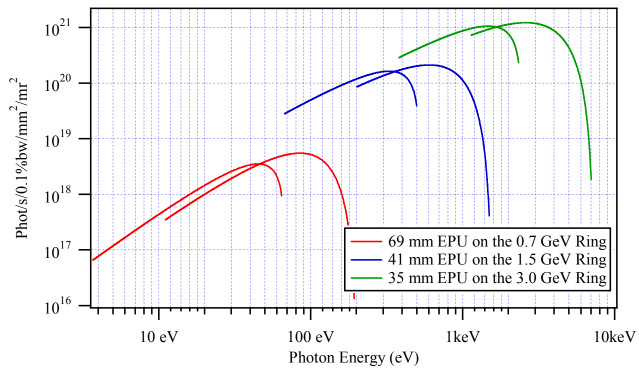

Figure 3: Brilliance from elliptically polarizing undulators at the three different storage rings at the MAX IV light source.

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