MAX 4, A 3 GEV LIGHT SOURCE

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Abstract

A proposal for a new synchrotron light source, MAX 4, is presented. The main components are two identical storage rings operated at different electron beam energies and equipped with superconducting insertion devices. Small beam emittances will yield high brilliance radiation over a wide spectral range.

A small horizontal emittance is achieved by using a large number of cells with gradient dipoles flanked by horizontally focusing quadrupoles. A small magnet aperture allows strong gradients in dipoles and strong sextupole components in quadrupoles. This results in an equilibrium emittance on the order of 1 nmrad. A full-energy injector, enabling top-up operation, will be a 3 GeV S-band linac with an energy doubling system. This opens up the possibility to produce short, intense radiation pulses, coherent as well as spontaneous.

INTRODUCTION

The aim of the MAX 4 conceptual design study is to define a high-performance facility succeeding the existing MAX facility during the next decade. Since some of the design work remains to be done, some of the parameter values given in this report might be subject to changes.

The backbone of the MAX 4 facility consists of two similar storage rings operated at different electron energies. One ring will be placed just above the other and rotated half a super-cell to distribute the beamlines from the insertion devices (ID) evenly. This solution, compared to a single, larger ring, gives us the possibility to cover a wider spectral range with high brilliance radiation. It also provides a sufficient number of straight sections for insertion devices and fits in a smaller building. The insertion devices will be the primary light sources.

The bunches in the storage rings will be stretched by a harmonic cavity system. The elongation of the electron bunches limits the resistive wall effect, increases the Touschek lifetime and reduces the heating of the cold bores in the superconducting insertion devices. Time-resolved experiments will be carried out at the linac, which is superior to the storage rings in this respect.

As an injector, a linear accelerator is chosen. The linac is optimised for coherent radiation production and fulfils the specification for topping up injection. The field of coherent radiation generation is now developing quickly and much experience is now gained at the first generation of FELs. New ideas for critical elements are currently being developed. We feel it is a bit premature at this stage to exactly define the coherent radiation sources at MAX 4 that should go in operation one decade from now.

THE STORAGE RINGS

Design Philosophy

The storage rings are designed to take advantage of the features of superconducting undulators, which offer a short period length with a high K-value. The main consequences for the rings are:

- The small undulator period opens up the possibility to use a large number of periods. A small electron beam emittance is needed to take advantage of this, especially when utilising the higher harmonics.
- Small lattice magnet apertures suffice; the ring admittance is defined by the small undulator gaps. A small magnet aperture is in fact a necessity for creating the small beam emittance in a ring of small size since strong multipole magnets can be introduced.
- The small gap undulators and the small beam emittance make it necessary to spend some effort on beam lifetime issues. Even if a topping up injection method is foreseen, the rings must have a decent beam lifetime to restrict the injection repetition rate and the radiation background.

Magnet Lattice

A very simple basic cell consisting of a dipole magnet flanked by horizontally focusing quadrupoles is used. The vertical focusing is taken care of by the dipole gradient, which also reduces the horizontal emittance. The chromaticity correcting sextupole components are introduced in the shape of the quadrupoles and by discrete sextupoles flanking the dipoles. An octupole component is also introduced in the quadrupole magnets to increase the dynamic aperture.

Each ring consists of twelve super-cells. Each super-cell consists of five basic cells plus matching-sections. This lattice results in a very small equilibrium emittance, which is further reduced by the damping effect of the strong insertion devices. The emittance for the X-ray ring is approximately 1 nmrad with five superconducting undulators. The emittance of the soft X-ray ring is a factor of four smaller.

The small aperture size allows for strong multipole magnet. A compact lattice results in smaller betatron functions, which gives a good admittance-aperture relation.

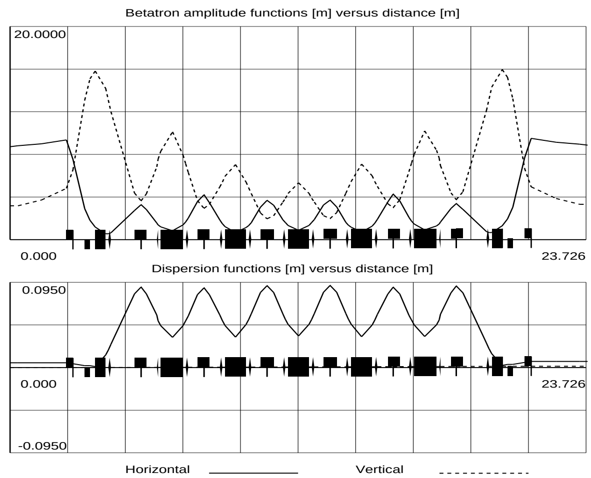

Figure 1. Magnet lattice.

The lattice functions of one of the 12 super-cells in each ring are seen in fig. 1. The main parameter values are given in table 1.

Table 1. Ring parameter values.

	X-ray Ring	**Soft X-ray Ring**
Circumference	285 m	285 m
Operating energy	3 GeV	1.5 GeV
Current	0.5 A	0.5 A
Energy loss/turn	770 keV	50 keV
Hor. emittance	1.2 nmrad	0.3 nmrad
Q_h	26.6	26.6
Q_v	9.6	9.6
Hor. admittance	17 μmrad	17 μmrad
Vert. admittance.	1.2 μmrad	2.8 μmrad
Energy acceptance	4 %	4 %
Straight section length	4.6 m	4.6 m
RF	100 MHz	100 MHz
Touschek lifetime	30 h	42 h
El. scattering lifetime	131 h	73 h
Bremsstrahlung lifetime	195 h	195 h
Total lifetime	21.7 h	23.4 h

Magnet Design

The magnet system is of the MAX III kind[1]. The magnets are machined out of solid iron blocks resulting in an integrated girder-magnet design.

Radiation Performance

The operation of two storage rings at different electron energies and with very small electron beam emittances results in a high brilliance over a wide spectral range. The calculated brilliance for the two rings is shown below. The brilliance of the MAX 2 ring, being a high performance ring today, is shown as a comparison.

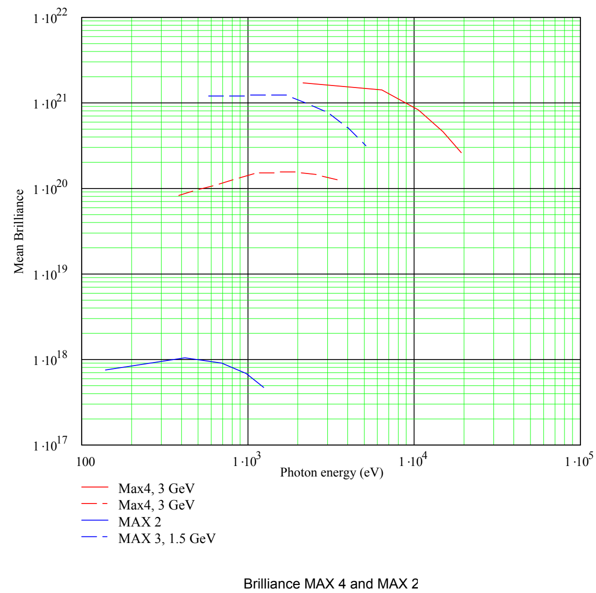

Figure 2. Brilliance

Insertion Devices

As mentioned above, the insertion devices, and especially the small gap superconducting ones, define the ring design. The following devices were used for the brilliance calculations above.

Table 2. Parameter values of the SC undulator

	X-ray ring	Soft X-ray ring
Period length	13 mm	16 mm
Full gap	4 mm	6 mm
Nr. of periods	250	200
Maximum K	2.2	2.2

Dynamic Aperture and Beam Lifetime

The dynamic aperture calculated is larger than the vacuum chamber aperture, which is sufficient for injection and for the beam lifetimes calculated.

For the beam lifetime calculations, the same gas composition and pressures as measured in MAX II are used. The Touschek life-time is increased by Landau cavities as already used in MAX II[2].The Touschek life-time is surprisingly high in the soft X-ray ring taking into account the low electron energy and the very small emittance. This result can however be explained by the combination of a high momentum acceptance and the limited transverse momentum.

RF System

A 100 MHz RF system, similar to the systems now being introduced into the MAX II and MAX III rings[3], will be used. This low frequency is chosen to get a large bucket height at relatively low RF power.

Table 3. RF system

	X-ray ring	Soft X-ray ring
Operating frequency	100 MHz	100 MHz
Cavity shunt impedance	3.4	3.4
Nr. of cavities	10	4
Transmitter power	30 kW	30 kW
RF voltage	1.6 MV	0.5 MV
Nr. of transmitters	20	4
Harmonic nr.	5	5
Nr. of harm cavities	2	1
Bunch length without harm. system	1.4 cm	1.9 cm
Bunch length with harm. system	9.7 cm	9.8 cm

THE MAX 4 LINAC

Design Philosophy

The MAX 4 linear accelerator will be used as injector for the two storage rings. Even in the topping up mode, only a very small fraction of the linac capability will be used. The linac can thus be used also as an electron source for a free electron laser (FEL) system.

At the first glance, the two missions of the linac might seem contradictory. The figure of merit of the injector is stability and re-producability while the FEL electron source demands flexibility. We are now investigating the possibility to introduce multiple electron guns and pre-programmed modulators to fulfil the demands for both modes of operation.

Linac System

The building blocks of the MAX 4 linac will be similar to those now used at the MAX injector[4]. In the MAX 4 case, however, one station consisting of a modulator, klystron and SLED cavities feeds two linac structures.

The endpoint energy of 3 GeV can be reached with 15 units, each consisting of one klystron feeding 2 linac sections. By installing 17 units, some redundancy is offered.

Table 4. Injector Linac

Endpoint energy	3 GeV
Total length	300 m
Repetition rate	10 Hz
Frequency	3 GHz
Nr. of klystron stations	17
Klystron power	35 MW
Nr. of linac structures/klystron	2
Structure length	5.2 m
Energy gain/station	200 MeV

Coherent Radiation Generation

Several coherent radiation generators can be considered. A classical SASE FEL is contemplated but we are also investigating other schemes such as that shown in figure 3.

One interesting version is to use a HG laser as the seed. This laser has the following interesting properties:

- An energy range up to 30-40 eV with a power of a few kW. This power is sufficient to dominate over the spontaneous radiation.
- The ability to deliver very short pulses. The amplified radiation will be a replica of this time structure plus the slippage time.
- The radiation is close to the Fourier limit.
- A terawatt laser drives this HG laser. The repetition rate is thus limited to some kHz.

A 600 MeV electron bunch is sufficient to operate a FEL amplifier at 40 eV. A 6 m long undulator is needed to reach saturation with powers in the GW range. The next step is to guide the bunched beam into an undulator tuned to a harmonic of the seed laser to generate coherent radiation in the 100 eV range. The 600 MeV beam originates from an electron gun positioned three linac stations downstream the linac exit.

The radiation from the harmonic radiator mentioned above is then used as a seed for the next step, acting on an electron bunch of higher energy. This bunch originates from another electron gun placed i. e. 10 klystron stations upstream the linac exit and has an energy of 2 GeV. This FEL is then tuned to the output of the first FEL and the 2 GeV bunch is fed into a harmonic radiator to generate harmonics of the first laser.

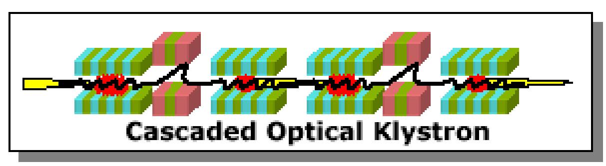

Fig.3. Cascaded optical klystron scheme.

ACKNOWLEDGEMENT

The funding from the Knut and Alice Wallenberg foundation has initiated the work on the conceptual design for the MAX 4 facility.

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