COMMISSIONING OF THE METROLOGY LIGHT SOURCE

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Abstract

The Physikalisch-Technische Bundesanstalt (PTB), the German national metrology institute, has set up the low-energy electron storage ring Metrology Light Source (MLS) in close cooperation with BESSY. This new storage ring is dedicated to synchrotron-radiation-based metrology and technological developments in the IR, UV, VUV and EUV spectral range. As the very first dedicated THz storage ring source it can be operated in a special low-α mode for the generation of short electron bunches. In this mode MLS will deliver coherent radiation in the far-IR/THz spectral range with enhanced intensity as compared to the normal mode of operation. The electron energy can be tuned to any value from 100 MeV, the injection energy, up to 600 MeV and the electron beam should cover the range from one stored electron (1 pA) up to 200 mA. The installation of the storage ring was completed in April 2007 [1], first beam could be stored 5th June 2007.

INTRODUCTION

The potential for using electron storage rings as almost ideal radiation source for basic radiometry from the UV to the X-ray range has been taken up only by a few institutes [2]. Among those, PTB, the German National Metrology Institute, has been using synchrotron radiation for photon metrology at the electron storage rings BESSY I and BESSY II for about 25 years. At present - after the end of operating of BESSY I in 1999 - PTB operates a laboratory at BESSY II with main emphasis on the EUV and X-ray region [2, 3]. The new low-energy storage ring MLS [4] which is located in the close vicinity of BESSY II in Berlin-Adlershof will serve as a calculable radiation source for the visible to the soft X-ray range [5] with special flexibility in its operation parameters. Bending magnet beamlines and an undulator beamline optimized for spectral purity will provide monochromatized radiation from the UV to the soft X-ray range (down to 4 nm in wavelength) for detector-based radiometry, reflectometry and quantitative spectrometry The use of IR and THz radiation will be possible at dedicated beamlines [6]. Additionally, the MLS will be the first machine designed and prepared for the production of stable coherent synchrotron radiation in the far-IR and THz region. This option will strengthen the MLS as a strong THz radiation source. In this contribution we will report the status of the installation and commissioning.

Parameter	Value
lattice structure	double-bend achromat
circumference	48 m
length of straight sections	2 × 6 m; 2 × 2.5 m
electron beam current	1 pA to 200 mA
electron energy	200 MeV to 600 MeV
injection energy	100 MeV
max. magnetic induction of bending magnet	1.3 T
charact. photon energy	12 eV to 314 eV
nat. emittance (at 600 MeV)	100 nm rad
source size (1 σ at 600 MeV)	250 μm (h) × 200 μm (v)

Table 1: Main parameters of the Metrology Light Source

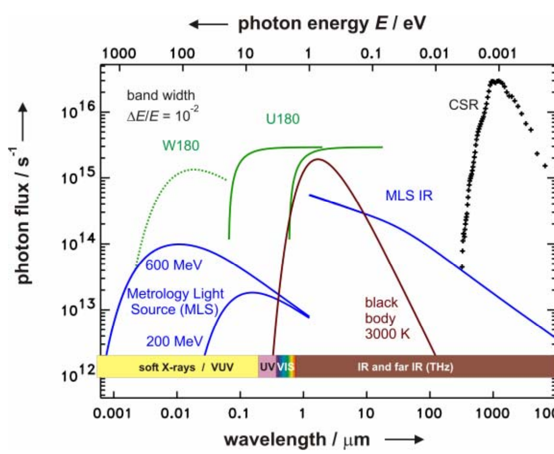

Figure 1: Calculated photon flux available at the MLS for 200 MeV and 600 MeV electron energy emitted from a bending magnet, the undulator U180, and the wiggler W180 (undulator U180 operated in the wiggler mode) compared to the radiation from a black body of 3000 K for typical angular acceptances. The increased flux in the infrared spectral range (MLS IR) is caused by the larger acceptance angle of the special port of the dipole chamber at the MLS-IR beamline. The expected coherent synchrotron radiation (CSR) flux of the MLS operated in the low-α machine optics mode is also shown.

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DESIGN AND INSTALLATION

Injector

The design of the 100 MeV racetrack microtron is based on the microtrons operated at the storage rings ASTRID (100 MeV microtron), ANKA (50 MeV microtron), and BESSY II (50 MeV microtron), but with newly designed 180° dipoles, a full metal UHV system, and a fluorescence screen beam viewer and fast current transformers for almost each turn. The microtron was delivered in November 2006 by DANFYSIK and achieved a 100 MeV beam with peak currents of about 10 mA for the first time in January 2007 [1].

Ring Layout

The MLS magnetic ring with a circumference of 48 m consists of eight bending magnets, 24 quadrupole magnets, 24 sextupole magnets and four octupole magnets, and has two long and two short straight sections [7]. The MLS magnets have been produced by the Budker Institute of Nuclear Physics, Novosibirsk, Russia.

The assembling and installation of all the girders, the bending magnets and the multipole magnets begun end of April 2006 and were completed the end of 2006. The adjustment of the magnets was done with two Taylor Hobson balls mounted on the overall cross bar. The cast-iron girders with machined surfaces on the top and the multipole magnets have been produced with such narrow margins that there is no need for adjustable elements in between to avoid problems due to vibrations and long-term misalignment. The dipoles are installed on a movable support construction for an easy handling of the vacuum chamber [7].

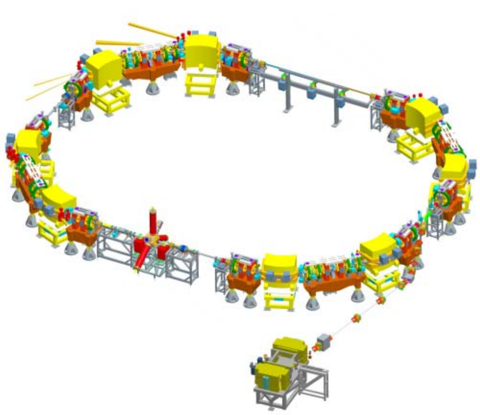

Figure 2: Layout of the MLS

Vacuum System

Due to the severe vacuum requirement ($5 \cdot 10^{-10}$ mbar) and the narrow space conditions in the storage ring, each of the four quadrants of the MLS was baked out in an external oven at temperatures up to 200 °C. The vacuum chambers were delivered in September 2006. The vacuum system of the ring was closed in February 2007.

RF System

A 500 MHz RF system was designed for the MLS. A new type of Higher-Order Mode (HOM) damped normal conducting cavity with ferrite damping antennas is used [8]. An 80-kW-cw-RF plant with Inductive Output Tubes (IOT) was installed. The conditioning of the cavity started in February 2007 and in March 45 kW power was successfully applied to the cavity

Injection Scheme

Four slotted pipe kicker magnets based on the design used at the DELTA electron storage ring and one air-cooled septum magnet are used for the injection [8].

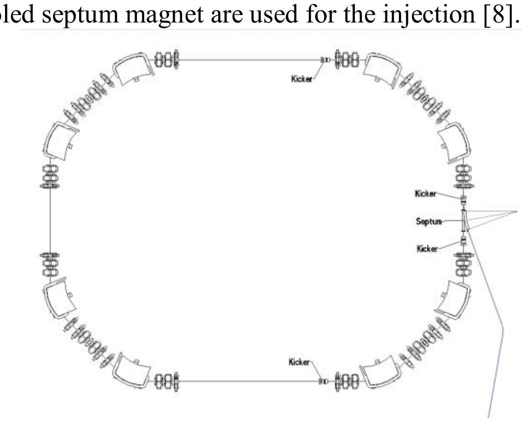

Figure 3: Lattice of MLS ring with pulsed elements

Figure 3 shows the positions of the MLS kicker magnets in the storage ring and the injection septum in the middle of the short injection straight. The beam is delivered from the microtron on the lower right corner. The electron beam is injected through an active septum magnet, where a thin vacuum beam pipe is situated inside the C-shape pulsed magnet core. A pulse current of up to 2500 A is available for the necessary bending radius into the beam trajectory of the storage ring.

The kick angles needed for the kicker bump are 3.6 mrad for the two outer kickers. This translates into a on axis kicker field of about 5 mT at a magnet length of 0.28 m, with estimated pulse currents of 560 A. Inductivity of the slotted pipe kicker magnets is about 0.5 µH. Due to a phase advance of 3x180° between the outer kickers, the other two kickers on the short straight only contribute 0.1 mrad to the bump. They could be switched off, but they are needed to close the bump precisely in presence of magnet optical errors.

COMMISSIONING

The installation of the MLS was completed and its commissioning started in April 2007. First successful injection into the MLS was performed on 19th April 2007 and it lasted until 6th June that first beam could be stored (Fig. 4). Lifetime at these very low currents (some µA) was very good - approximately one hour (Fig 5).

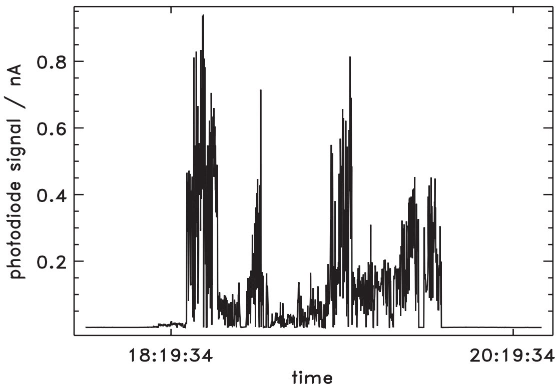

Figure 4: Synchrotron radiation of the first stored beam on 6th June (at 105 MeV electron beam energy) observed with photodiodes in the PTB diagnostics front end. From the photodiode responsivity a calibration factor of 0.3 nA photodiode current per 1 μA electron beam current can be estimated.

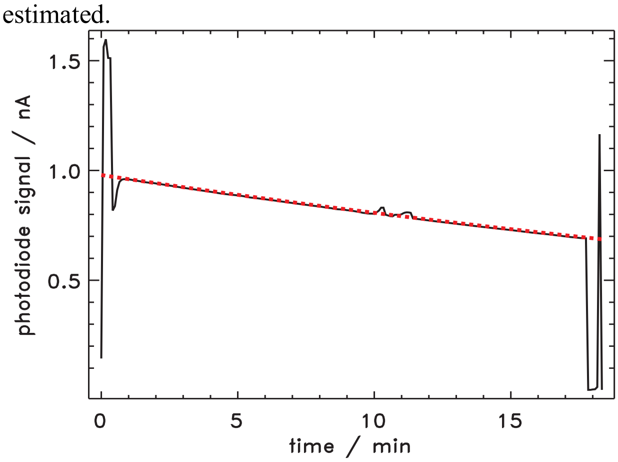

Figure 5: The measured beam lifetime (1/e) at an electron energy of 105 MeV and at a stored electron beam current of several μA is approx. 1 h (red curve).

In this phase the machine development goes still in parallel with a lot of hard ware activities leaving only certain time slots for commissioning which are further reduced sometimes due to hardware errors which show up when the new hardware is used in practice. Some problems and errors that appeared

- first turn diagnosis restricted initially to the six foil monitors installed because the BPM systems and the strip line are designed for a 500 MHz signal while the injected beam was bunched according the 3 GHz RF of the microtron. As without an intensity dependent signal we could not make much progress the high pass filter of three differently positioned BPM knobs and of the strip line were removed and the beam signal was enhanced by use of an RF amplifier chain up to 105 dB. The BPM signals were of limited use due their strong orbit dependence, but the enhanced strip line signal was a good guideline for further optimization. After beam could be stored the signal provided from the PTB diagnostic diodes proved to be an excellent and very sensitive development tool.
- injecting with dipoles only (everything else switched off) we had to raise the dipole field by 5% to get a full turn. An independent measurement with a deflecting dipole and a foil monitor in the transfer line confirmed that the injection energy was as high as 105 MeV. A rescaling of all power supply settings by a factor of 1.05 gave a significant improvement of the intensity after one turn.
- there is a strong influence of the microtron set up on the settings in the transfer line needed to steer the beam properly into the storage ring. Several times carefully adjusted transfer line settings were obsolete the other day due to another micotron adjustment. We are still in the process to define the exact conditions of a microtron set up to guaranty a reproducible passing of the transfer line.
- the horizontal correctors in the SR had a sign convention different from the convention of BESSYII generating some confusion. As the injection into MLS is counter clock wise and into BESSYII clock wise while having the same polarity for the steerer magnets, the steering direction was indeed opposite. The magnet polarities in MLS were changed in order to avoid future confusion for personal working simultaneously on both storage rings.
- checking the action of the injection kicker magnets using the horizontal steerers it was found that they had the wrong polarity. After switching the polarity we achieved several thousand turns but still no storage.

The timing of the septum had to be shifted about 10 μs away from the peak value timing of the pulser current. This eddy current related delay was higher than expected.

- essential was the tuning of the injection arc optics. which guaranties the correct phase relation between the two outer kickers. The kicker were replaced by a static two steerer bump in the opposite arc- and closing of that bump was confirmed on a foil monitor in the injection arc. No excursions should be observed on that screen when the bump amplitude changed. Starting from a symmetric optic setting and using only quadrupole circuits which preserved the arc symmetry the static bump could be closed, implying that the kicker bump must have been closed simultaneously.

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