# COMMISSIONING AND OPERATION OF THE METROLOGY LIGHT SOURCE

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*Abstract*

The Metrology Light Source (MLS) is dedicated to metrological and technological developments in the UV and EUV spectral range and in the IR and THz region. The new electron storage ring of the Physikalisch-Technische Bundesanstalt (PTB) is located next to the BESSY II storage ring in Berlin - Adlershof. The MLS with its 48 m circumference can be operated at any electron beam energy between 105 MeV and 630 MeV. The electron beam currents vary from 1 pA (one stored electron) up to 200 mA. These specific modes of operation were achieved during the initial one year phase of the commissioning of the storage ring until April 2008, when the regular MLS user operation started.

The basis for this success was the previously commissioned microtron which is the main part of the injection system.

## INTRODUCTION

The concept of the MLS was in detail described in former presentations [1]. Here we shortly resume the main parameters in Table 1. Some aspects of the MLS commissioning and operation are covered by other contributions [2] to this conference [3, 4]. The MLS operating conditions are shown in Table 2. This operation conditions were successfully implemented during a one year commissioning period, where solutions were found for two important tasks:

- To achieve an excellent injection efficiency
- To overcome different levels of current limitations caused by ion effects

Table 1: Main MLS parameters

| Parameter | Value |
|---|---|
| lattice structure | double bend achromat |
| electron energy | 105 MeV to 630 MeV |
| circumference | 48 m |
| /revolution time | 160 ns |
| RF frequency | 500 MHz |
| revolution frequency | 6.25 MHz |
| damping times (transversal) | 5 s at 105 MeV<br>25 ms at 630 MeV |
| natural emittance (600 MeV) | 100 nm rad |
| injector type | microtron |

Table 2: MLS operating conditions

| Parameter | target | achieved |
|---|---|---|
| electron beam current | 1 pA to 200 mA | 200 mA at 105 MeV<br>1 pA to 175 mA at 630 MeV |
| lifetime at 105MeV | not a user mode | 0.3 h at 200 mA<br>0.6 h at 175 mA |
| lifetime at 630 MeV | 7 h at 100 mA | 4 h at 175 mA<br>8 h at 100 mA |
| time for injection and ramp up | 10 min at 200 mA | 10 min at 120 mA |
| injection frequency | 1/5 Hz | 1/5 Hz |
| operating tunes | Qx = 3.39<br>Qy = 1.37 | Qx = 3.186<br>Qy = 2.224 |

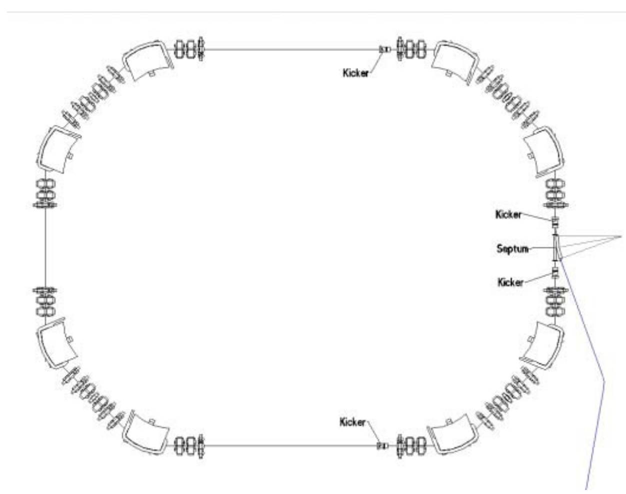


Figure 1: The four kicker injection bump covers half of the storage ring.

## INJECTION AND ACCUMULATION

Four slotted pipe kicker magnets and one air-cooled septum magnet are used for the injection [6] (Figure 1). One of the most difficult tasks was to establish an efficient accumulation scheme. With the kickers triggered with a repetition rate of 1/5 Hz, it is now possible to accumulate up to 3 mA / shot out of an 8 mA 300 ns long 3 GHz pulse delivered from the microtron. Accumulation up to 120 mA takes 5 min. The accumulation rate is very sensitive to fields generated in the sextupoles, especially to the harmonic ones. As soon as these magnets generate field (from a main power supply current, from hysteresis of the sextupole magnet or even from hysteresis of the integrated steerer magnet), strong ion-beam effects are observed suspending further accumulation.

The chromaticity has to be very accurately adjusted to values slightly above zero while in the injection straight a 4 mm horizontal orbit bump is present (to center of the closed orbit into the middle of the physical aperture), which couples orbit and chromatic effects. Therefore the sextupole power supply circuits were separated along the center of the long straights and set to zero current on the injection side. Chromatic corrections at injection are done completely in the half of the ring opposite to the injection straight. Additionally, the initially unipolar power supplies on the injection side were changed to bipolar ones, allowing a cycling procedure which removes the remaining magnetic fields in these magnets. While the chromatic sextupoles can be switched on at higher energies allowing a symmetric sextupole distribution around the lattice, the harmonic circuits at the straights are only excited in a compensated way with zero integral strength. Some other measures that were necessary to achieve an efficient accumulation were:

- Strong transversal beam coupling
- Introducing a positive dispersion at the injection point and adding to the machine a slight energy offset compared to the injector energy
- Applying an octupole magnet as a coherent damper. The necessary octupole field strength changes according the vacuum conditions
- Appropriate choice of tune – the tune window at highest currents is very small (2 kHz)
- Strong cavity detuning of -45°

## CURRENT LIMITATIONS FROM IONS AND COUNTER MEASURES

Soon after the first accumulations, a rigid beam current limit at 10 mA was observed. The striptool picture in Figure 2 shows the accumulated current in mA (green) and the current increment during one second (blue) vs. time. The scale for the blue curve is ranging from -0.1 mA/s to 0.25 mA/s. The striptool was updated every second. The first 8 shots are properly accumulated without any subsequent losses, but exceeding an accumulated current of about 6 mA there was a significant beam loss within the first 3 s after the injection trigger. At 10 mA these current losses were so high, that the total beam current was in saturation. Further investigation on the saturation current showed that the beam blows up with current and fills the horizontal aperture of the chamber (+/-35 mm) completely. One source of this beam blow-up is a strong beam ion interaction present at injection energy. Therefore different counteractive measures were taken to reduce ion effects.

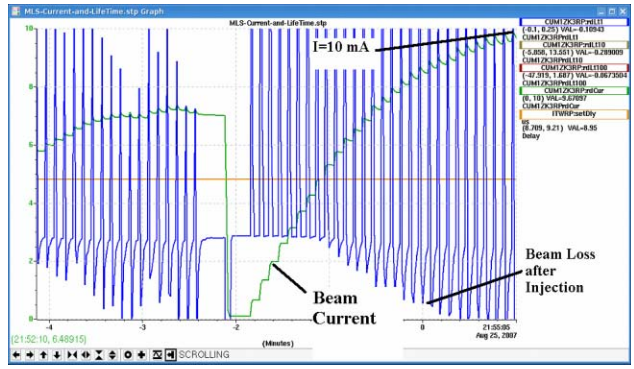


Figure 2: Early example of an accumulation into MLS.

### *Clearing Voltage*

Eight regular BPM knobs (at the start and the end of each straight section) are used as clearing electrodes with a continuously applied DC-voltage. Since there is no improvement regarding the accumulation condition or the lifetime when rising the voltage further than -300 V this value is used now at the MLS. The use of this low clearing voltage does not mean that higher voltages would not reduce the ion beam interaction further, as it can be seen by an observation depicted in Figure 3. As the electrical connectors of the BPM knobs are not suited to withstand high voltages, the maximum clearing voltage tried was -600 V. In order to be able to accumulate beam currents above 100m A it was necessary to apply -1500 V DC as an additional clearing voltage to one connector of a 30 cm stripline. Other clearing voltage setups where tried but did not improve the operation:

- Up to 28 instead of 8 BPM stations with voltages from -300 V to -600 V. Increasing the voltage gave no improvement in any arrangement of the clearing electrodes. With use of an increasing number of clearing electrodes the improvement by each additional electrode reduces drastically. Most efficient are that ones on the ends of the straights.
- In addition, a positive voltage at a counter electrode.
- More striplines with voltages up to -2500 V.
- Comparison of stripline vs. a BPM at the same clearing voltage shows a similar performance. Interesting to note is the difference of time scales in their action on the beam. Switching on the clearing voltage on a electrode at the saturation current leads to immediate current increase while at the stripline there can be a delay of some tenth of seconds.
- Clearing gap of up to 80 ns could not be observed to be helpful, most likely because the beam volume is widened up strongly with higher single bunch currents due to intra beam scattering.

Our present standard operation setup achieves good injection rates and lifetimes. During the next machine shut down, costum-built clearing electrodes will be installed to release the BPMs for their main purpose of orbit measurement. As a consequence of different observations regarding the importance of a well distributed arrangement of clearing electrodes we choose a set of 8 electrodes, 2 on each straight. Those will be formed like BPMs to keep the increase of the machine impedance as small as possible and will be equipped with high voltage connectors.

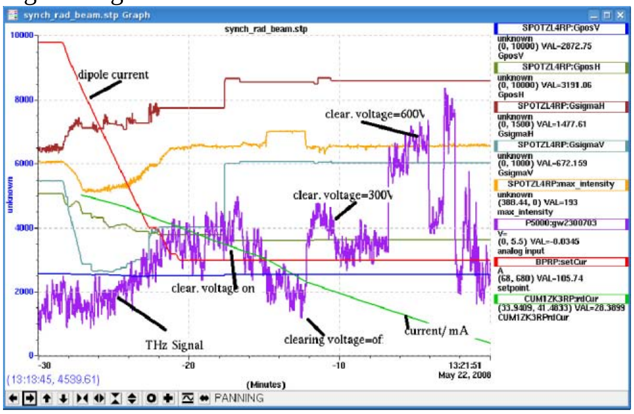


Figure 3: Effect of the clearing voltage on the THz signal of the beam at an intermediate energy (~200 MeV). While ramping down in the regular user optics an increase of the THz signal (violet curve) is observed but only if a clearing voltage is attached. Doubling the clearing voltage also doubles the THz signal strength. As the THz signal strongly depends on the bunch length [3] this observation proves the presence of ion induced bunch lengthening and its dependence on the values of the clearing voltage.

## *Resonant Beam Shaking*

Without ion clearing the beam current is presently limited to 20 mA. With ion clearing the current turned out to be limited to 80 mA. To overcome this limit it is necessary to excite the beam in one of its tune frequencies. We found the horizontal tune frequency the most efficient, so that horizontal beam shaking is an essential part of routine operation .

## *Beam Scrubbing*

Although the base pressure from the start was in the order of $10^{-9}$ mbar, beam scrubbing at highest available energy resulted in a very effective method to achieve regular operation conditions. In a first step the magnet cycling sequence to achieve injection conditions after high energy operation had been changed. From originally approaching the dipole from the lowest possible PS current we established a closed loop including only regular ramping states thus avoiding beam losses during beam scrubbing. This shortens the refill time and lowers the radiation level. Then a state-machine-generator program was installed, which submits all commands needed for an automated beam scrubbing cycle (see Figure 4). Reasonable operation conditions were achieved after 10 weeks of beam scrubbing with an accumulated dose of about 15 A*h at 630 MeV (Figure 4). The horizontal tune shift with current during this period dropped from 6.5 kHz / mA to 3.5 kHz / mA. After accumulating 130 A*h at 630 MeV the tune shift is as low as 0.25 kHz / mA and disappears for currents of more than 50 mA.

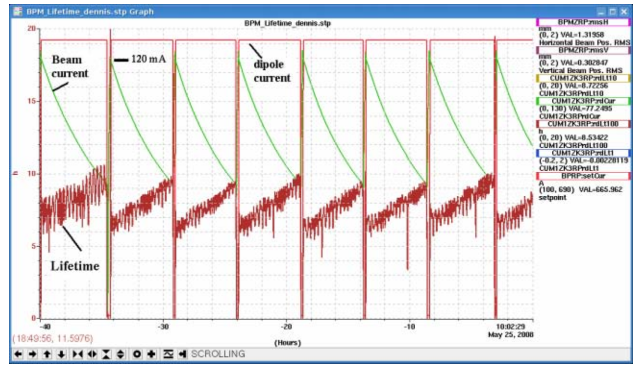


Figure 4: Example of automated beam scrubbing. The whole refill cycle needs about 10 min.

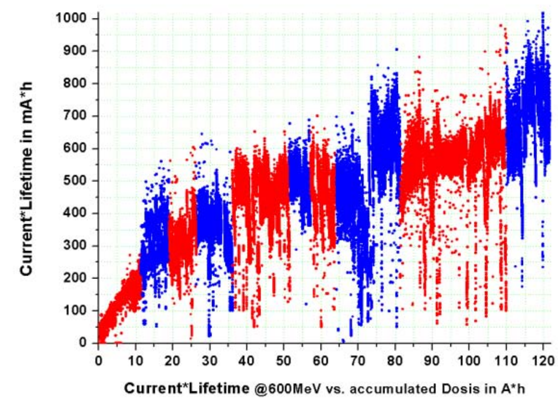


Figure 5: Product of current and lifetime vs. the total accumulated dose at the MLS still increases after a total of 130 A*h.

## SUMMARY

The MLS has been successfully commissioned. The user operation started in April 2008. The injection, accumulation and ramp procedures have been established and the initial current limit imposed by the interaction of the electron beam with trapped ions could be overcome by several simultaneously acting countermeasures.

## ACKNOWLEDGEMENT

We are very indebted to N. Hertel, P. Lilja and B. Bosch.

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