

BEAM LIFETIME OPTIMIZATION BY ADJUSTING THE SEXTUPOLES AT THE MLS AND BESSY

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Abstract

The Metrology Light Source (MLS) is a dedicated electron storage ring for metrology applications with three families of sextupoles. The existing setting of the three independently powered sextupole families respective to lifetime were roughly determined by scanning their strengths against each other. As a flexible machine the sextupole families of the MLS can be regrouped into new families, which increase the complexity of the scan procedure. Consequently the former strategy would be too time-consuming for refined global scan and it has to be complemented with physical constraints. Therefore a scheme has been developed to keep the chromaticity in a reasonable range during the scan and to reduce the degree of freedom, which is even more important at BESSY II with increasing number of independent sextupole circuits. This paper presents the principle of sextupole scan and the experimental results at the MLS and preliminary tests at BESSY II.

INTRODUCTION

The MLS of PTB is dedicated to metrology and scientific developments in the THz to extreme UV spectral range [1]. The main parameters are listed in Tab. 1 [2].

Table 1: Main Parameters of the MLS Storage Ring

Parameters	Value
Lattice	4 DBA
Circumference	48 m
Electron energy	629 MeV
RF frequency	500 MHz
Injection energy	105 MeV
Characteristic photon energy	1.7 eV to 364 eV
ξ_0 @ standard user mode	$\xi_{hor}=-3.4, \xi_{ver}=-5.6$
ξ_0 @ low emittance mode	$\xi_{hor}=-3.9, \xi_{ver}=-6.9$

Three independently powered sextupole families, named S1, S2 and S3, are used to correct the chromaticity and adjust the dynamic aperture. Sextupole strength scan on the machine is a straightforward way to optimize the lifetime. By contrast, dynamics simulations are superior only based on an accurate model of the machine taking account of the imperfections, perturbations, nonlinearity and so on.

The setting of sextupoles in the user mode was determined by very coarse sextupole scans. Performing global sextupole scans is needed for the present user optics to optimize the lifetime. Time-consuming three dimensional sextupole scan, or more-dimensional

sextupole scan at the MLS and BESSY II might last hours or even days. Therefore a physical constraint should be introduced to reduce the degree of freedom and shorten the scan duration. All the sextupole settings leading to chromaticity values out of the expected range will be filtered.

Sextupole scans have been successfully conducted at the MLS to optimize the lifetime in different operation modes. Preliminary scans have been performed on the BESSY II storage ring.

OPTIMIZATION ALGORITHM

A scan tool written in Python has been developed to execute the optimization with the features of chromaticity and sextupole response matrix measurement, chromaticity correction and sextupole scan for lifetime optimization.

$$\xi_{tot} = \frac{1}{4\pi} \oint [m(s)D(s) + k(s)]\beta(s)ds \quad (1)$$

The effective total chromaticity ξ_{tot} expressed as Eq.1 [3], in which $m(s)$, $D(s)$, $k(s)$, $\beta(s)$ represent the values of sextupole strength, dispersion function, quadrupole strength and beta function along the storage ring. The measured chromaticity is respectively regarded as the linear summation of each sextupole family's contribution to the natural chromaticity. The sextupole chromaticity response matrix for a 3D scan is calculated based on the measured chromaticity deviation caused by current increments in each sextupole family, as expressed in Eq. 2:

$$\begin{pmatrix} d\xi_{hor} \\ d\xi_{ver} \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} & a_{16} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} & a_{26} \end{pmatrix} \cdot \begin{pmatrix} dI_{s_1} \\ (dI_{s_1})^2 \\ dI_{s_2} \\ (dI_{s_2})^2 \\ dI_{s_3} \\ (dI_{s_3})^2 \end{pmatrix} \quad (2)$$

where $d\xi_{hor}$ and $d\xi_{ver}$ denote the horizontal and vertical chromaticity deviations, dI_{s_1} , dI_{s_2} and dI_{s_3} the current increments in the three sextupole families and a_{ij} the elements of response matrix. The $d\xi$ is proportional to dI_s according to Eq. 1, however the model in Eq. 2 considering the second-order terms fits better to the experimental data. The coefficients of quadratic terms in the order of $10^{-4} \sim 10^{-3}$, which are insignificant to the first-order ones in the order of 10^{-1} , should be considered when

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the current in one sextupole family has been dramatically changed.

The chromaticity can be corrected to expected value based on the response matrix. A scheme keeping the chromaticity in a proper positive range during the scan reduces the degrees of freedom and significantly shortens the scan time. Moreover, chromaticity can be kept quasi-constant in the scan. Tab. 2 shows that the chromaticity in the scan can be well controlled even when the sextupole strength is remarkably changed. Hysteresis in the scan contributes to the difference between measured and estimated value, but it is not necessary to make the tool more complicated to minimize the small differences.

Table 2: Verification of the Response Matrix

Sextupole [S1 S2 S3] / A	Measured [ξ_{hor} , ξ_{ver}]	Estimated [ξ_{hor} , ξ_{ver}]
[10 17 -6]	[-0.6905,-0.048]	[0.7032,0.0798]
[12 18 -5]	[0.7780,-0.050]	[0.7750,-0.029]
[24 25 3]	[0.0362,0.6157]	[0.0062,0.6141]
[11 22 -6]	[-0.018,2.5964]	[0.0616,2.5742]

LIFETIME OPTIMIZATION AT THE MLS

Standard User Mode

Standard user mode is characterized by a horizontal emittance of ~ 100 nm rad. It takes up to 60% of the scheduled user time, with ~ 5 hours lifetime at 190 mA. Sextupole settings were scanned for better lifetime.

The scan results show the lifetime can be improved by 5%, which means the current sextupole setting is already in the vicinity of global optimum setting. This paper will focus on the improvement in low emittance mode at MLS in the next section.

Low Emittance Mode

The low emittance mode at MLS is characterized by a horizontal emittance of ~ 25 nm rad. It is successfully used for near field microscopy and EUV reflectometry [4]. The previous lifetime at $I = 190$ mA is less than 1 hour, and greater demands from the users for low emittance mode motivate the lifetime optimization to move forward.

A four-dimensional sextupole scan with positive chromaticity values has been conducted for low emittance mode. The scan objectives are S1, S2P1, S2P2 and S3.

All lifetime data are normalized to the corresponding value at the same current of the previously used setting. Therefore the lifetime*current ($I^*\tau$) in the scan is calculated as the product of normalized lifetime and the value of $I^*\tau$ at 150 mA in previous low emittance mode, which is ~ 240 mA*h used as the reference value.

The boundaries of the scan range are confined by the capability of power supplies and the chromaticity value. The current upper limitations of S1, S2P1 and S2P2 are 25A, 25A and 35A. The estimated horizontal and vertical chromaticity are constrained to small positive values. The plots in Fig. 1 are two of the six 2D projections of the 4D scan results, which give the value of $I^*\tau$ as a function of sextupole setting. A certain combination of two sextupole families with varying settings of the other two families in

the 4D global scan cannot yield to a unique $I^*\tau$, so the color indicates the maximum $I^*\tau$ at one specific point. A maximum lifetime increase of $\sim 30\%$ has been observed in the scan.

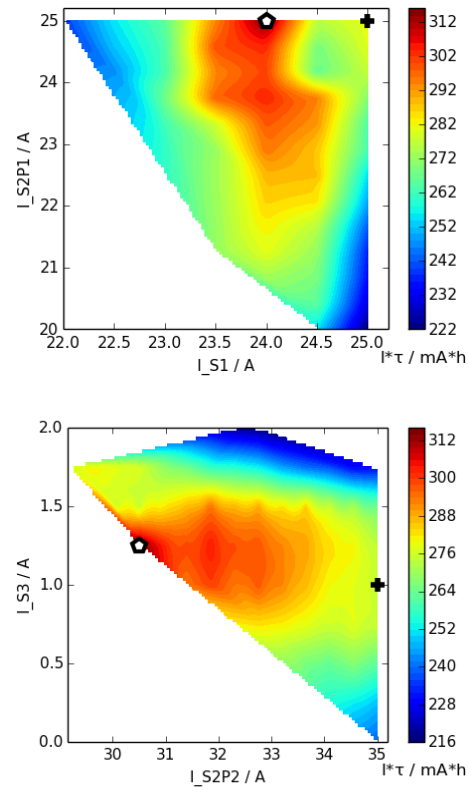
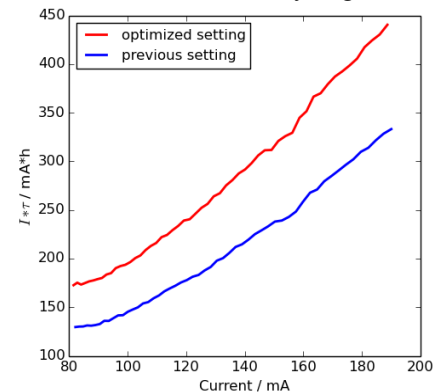


Figure 1: Measured current*lifetime in S2P1/S1 scan (top) and S3/S2P2 scan (bottom). The black crosses and pentagrams mark the previous and optimized settings.

To verify the lifetime improvement, the optimized setting and the previous setting are alternately uploaded into the machine to compare the lifetime and beam size. The upper plot in Fig. 2 shows that the lifetime has been significantly improved by $\sim 32\%$ with the optimum current setting [S1 S2P1 S2P2 S3] = [24 25 30.5 1.25] /A. The lower plot in Fig. 2 depicts the beam sizes variation over current. The vertical sizes are nearly the same, and the horizontal size with the optimized setting is even smaller than with the previously used one, which means the lifetime increase is not caused by larger beam size.



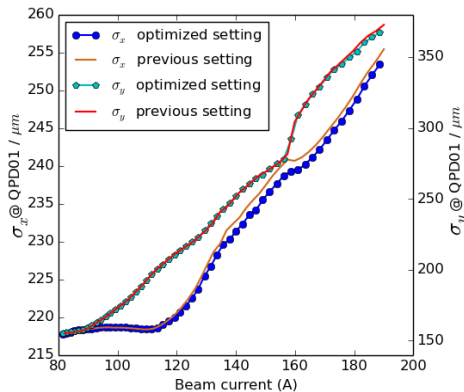


Figure 2: Comparison of the optimized and previous setting: current*lifetime vs time (top) and beam size vs current (bottom).

FIRST SCANS AT BESSY II

The BESSY II storage ring is based on 16 double-bend achromats, with two sextupole families for chromatic optics corrections and additional two harmonic sextupole families for nonlinear effect compensation. The family at the positions without dispersion and with high horizontal β function values is named as S4, correspondingly the other family with high vertical β function values named as S3. Each family is divided into two subbranches, in which the sextupoles located near a straight section with high horizontal β function values are marked as D-straight and those located near a straight section with low horizontal β function value marked as T-straight [5]. Therefore four independent units: S3D, S3T, S4D, S4T, are used in the scan to gain better lifetime.

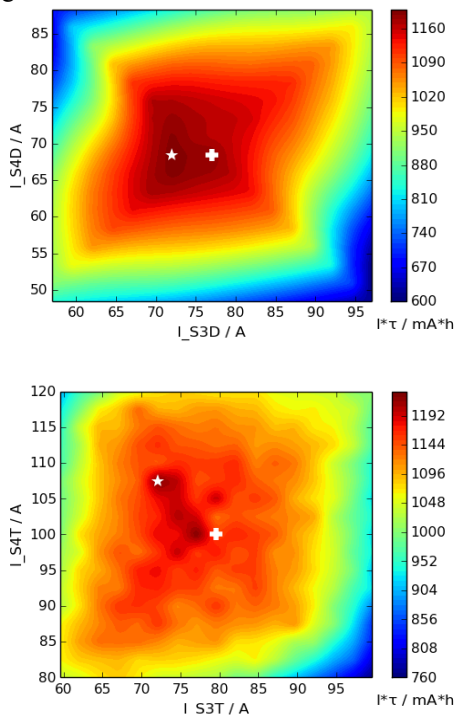


Figure 3: Measured current*lifetime in S3D/ S4D scan (top) and S3T/S4T scan (bottom). White crosses and stars mark the present and optimized settings.

Local scans using an existing Labview tool [5] have been executed on the BESSY II storage ring. The results in Fig. 3 show that the present sextupole setting is in the vicinity of a local optimum one. The impact of the sextupoles in the S4 family on the injection efficiency was not considered in the scan.

CONCLUSION AND OUTLOOK

A global optimum sextupole setting has been found by scanning the sextupoles strength on the real machine for the MLS low emittance mode, which is now applied in user operation. The achieved lifetime gain ~30%. The improvement indicates that MLS can provide smaller beam size with the same lifetime according to users' request.

The Python tool works effectively in the lifetime optimization at MLS. More efforts will be put on the code compatibility to allow easy usage at BESSY II. Furthermore, a multi-objective algorithm considering the lifetime and injection efficiency in top-up mode should be investigated.

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