MITIGATING THE PERTURBATIONS CAUSED BY U 180 AT THE METROLOGY LIGHT SOURCE

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Abstract

The Metrology Light Source is equipped with an electromagnetic undulator with a period length of 180 mm. User requests demand operation of this undulator in a wide energy range from 100 MeV through 629 MeV for user and dedicated low alpha modes. Mitigating the perturbations caused by the undulator to an acceptable level for all user requests, requires each quadrupole in the lattice to be powered individually. To what extend this recently implemented capability allows the restoration of the main properties of the machine optics for various settings of the undulator is presented in this document.

STATUS OF OPTICS MODELING AT THE MLS

As described in [1], applying LOCO [2] to the MLS was not very successful, as it did not allow fitting down to the noise level of the BPMs. The effect of the vertical focusing of the dipole was not properly accounted for. Comparisons of the β functions obtained by LOCO and by independent measurements differed substantially. Since the vertical tune determined by LOCO was off by about 200 kHz when the dipole was modeled as a conventional hard edge dipole with an arch length of 1.2 m or by 100 kHz when the fringe field was considered (described by the parameter $f_{int} = 0.5$, see [3]), modeling the focusing effects of the dipole seemed to be the key of getting a better model. LOCO's predictors for the statistical error, the χ^2/DOF [4] is many standard deviations away from the perfect value of one and the standard deviation of the difference between the modeled and the measured responses matrices is about 10 to 20 times the noise level of the BPMs which is about 330 nm in both planes.

Modeling the focusing effects of the dipole

Therefore, LOCO's predictions for the following approaches were investigated, either fitting the gradient of the dipole, fitting the fringe field parameter f_{int} or by fitting both quantities simultaneously.

As shown in Table 1, fitting the gradient of the dipole dramatically improves the quality of the model. A χ^2/DOF of about nine for the hard edge dipole or of 2.5 for the soft edge dipole can be obtained. The differences in the fractional tune between LOCO's predictions and measured are below 5 kHz in both planes. Fitting the fringe field leads to similar results. The best fit can be achieved if both the fringe field and the gradient of the dipole are

Table 1: The quality of the LOCO fit is presented in the last two columns (χ^2/DOF and $\sigma(\text{mod.} - \text{mea.})$). The mean values of the measured BPM noise is .330 μm. The quantities varied for considering the focusing effect of the dipoles are shown in the first column. In the second column the difference in the fractional tune as predicted by LOCO and from direct measurements is shown. The quadrupole gradients are fit per power supply. Beam energy was at 629 MeV when the measurements were taken.

Dipole model	$\frac{\Delta \text{Frac.Tune}}{\text{kHz}}$	$\frac{\chi^2}{DOF}$	$\frac{\sigma(\text{mod.}-\text{mea.})}{\mu m}$
a) RBEND	[28.6, 233]	307.5	5.32
b) ditto, fit grad.	[5.6, 0.2]	9.38	0.849
c) $f_{int} = 0.5$	[14.4, 96.3]	67.1	2.48
d) ditto, fit f_{int}	[0.4, 4.2]	2.92	0.499
e) ditto, fit grad.	[2.0, 3.4]	2.45	0.459
f) ditto, fit grad. and fit f_{int}	[1.5, 3.9]	2.24	0.441

varied simultaneously. The remaining $\sigma(\text{mod.} - \text{mea.})$ is about 1.5 times the noise level of the BPMs.

Each time the k-values of the quadrupoles were fitted per power supply (24 parameters) and the dipole gradients or the fringe field were fitted as a family (one parameter each).

Comparing LOCO's predictions with tune shift measurements

The quality of the refined model is convincingly demonstrated by referring to Figure 1. Comparing the β functions obtained when additionally the fringe field parameter and the gradient of the dipole magnet are fitted shows a good agreement with β functions gotten by tune shift measurements. For details of the tune shift measurement see [5].

THE UNDULATOR U180

The MLS is equipped with an electromagnetic undulator U180 consisting of 23 periods with a length of 180 mm, causing a substantial tune shift and beta beat. These deleterious effects increase when the beam energy is reduced as shown in Table 3.

To achieve proper operation of the ring providing good beam quality for all users, the optics perturbations cause by the undulator have to be mitigated. Specifically, the tune and the life time should be restored as best as possible. Additionally, the optical functions should be kept fixed at the position of the beam ports maintaining the beam properties for the users.

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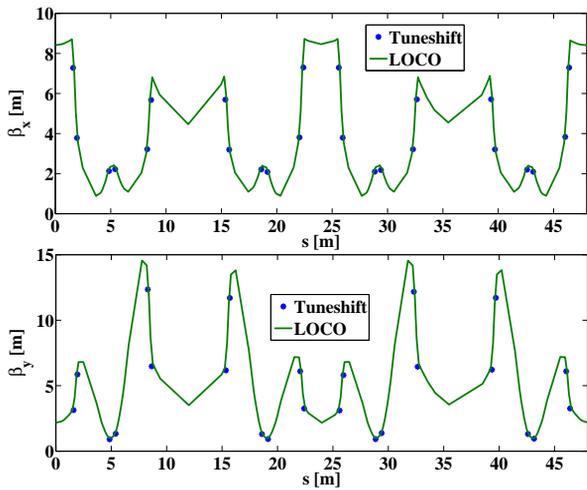
Figure 1: Comparison of the optical functions for the user mode at 629 MeV obtained from LOCO and by tune shift measurements.

Table 2: Beta beat and tune shifts caused by operating U180, for various beam energies.

Energy	$\Delta\nu_y$	Beta beat	
MeV		max [%]	RMS [%]
629	0.034	18	11
450	0.060	34	20
200	0.223	360	96

Modeling the focusing effects of the undulator

The impact of the undulator was modeled in two steps: First, the machine optics was determined utilizing LOCO when the undulator was off. The approach labeled f) in Table 1 was chosen for obtaining the model. In the second step, a measurement was taken with the undulator turned on. During the following LOCO analysis only the model of the undulator was varied. All other parameters fitted in the first step remained fixed. The undulator is modeled as a succession of 23 units. Each consists of four SBENDs describing the sinusoidal dipole field. In the fit the bending angle and the angles of the faces are fitted as a single parameter.

The model obtained by the procedure outlined above is subsequently used for determining the quadrupole settings required for a specific compensating scheme.

Schemes for mitigating the optics perturbations caused by the undulator U180

Schemes investigated for mitigating the perturbations caused by the undulator U180 at a beam energy of 629 MeV include:

- Generating a local vertical tune shift of the same value as caused by the undulator at the location opposite the

undulator and restoring the tune by the global tune bump (*opposite tune*).

- First, fix the tune employing all focusing and defocusing quadrupoles excluding the ones located next to the undulator. Secondly, restore the β functions in the center of the straight opposite the undulator utilizing the quadrupoles next to the undulator and finally restore the tune with the global tune bump (*first tune then beta*).

- Setting the α functions to the values of the unperturbed optics and additionally trying to restore the β functions at the critical locations as best as possible while keeping the original tune fixed (*alpha matching*).

- Using the global tune bump for restoring the tune to the unperturbed value (*tune bump*).

Comparison of the lifetimes obtained for the schemes investigated

The β functions obtained for the procedures listed are shown in Figures 2 and 3. All of these functions are the outcome of a LOCO analysis.
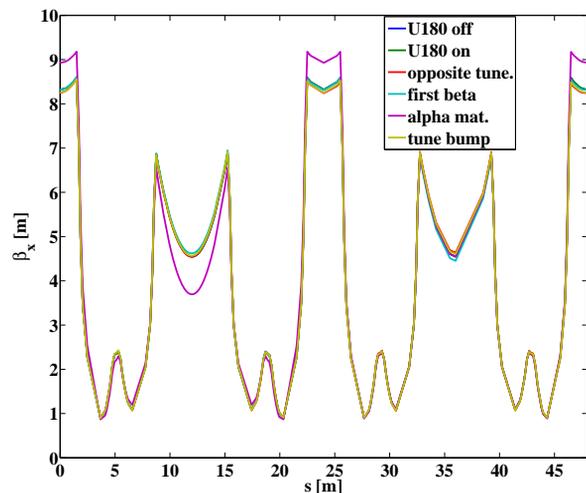
Figure 2: The horizontal β functions for the compensation schemes investigated were obtained from a calibrated optics. The quadrupole values and the bending radius of the undulator were obtained by a LOCO analysis at 629 MeV. The compensation schemes are as listed in Table 3.

A compilation of the the life times obtained for each of these schemes at a beam energy of 629 MeV at a beam current of about 135 mA is shown in Table 3.

Since for three of these schemes the life time is roughly the same and the mode termed *alpha matching* minimizes the undulator-driven beta beat, it will be implemented as default for the tune feed forward.

Furthermore, for energies of 450 MeV and 200 MeV this scheme could be implemented (see Figures 4 and 5).
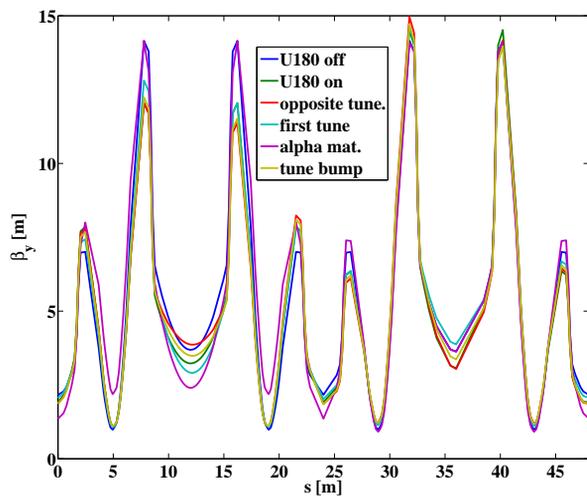
Figure 3: The vertical β functions for the compensation schemes investigated were obtained from a calibrated optics. The quadrupole values and the bending radius of the undulator were obtained by a LOCO analysis at $629\,\mathrm{MeV}$. The compensation schemes are as listed in Table 3.

Table 3: Life time obtained for the different compensation schemes (beam energy $629\,\mathrm{MeV}$).

mode	current	life time
	mA	h
standard user mode	135.0	13.9
undulator on	133.3	12.5
opposite tune	132.5	14.6
first tune then beta	131.5	12.6
alpha matching	130.6	14.0
tune bump	128.0	14.4

CONCLUSIONS

With the refined optics mode of the MLS a good agreement between LOCO's predictions and tune shift measurements could be made. LOCO's results comply with independent measurements. Furthermore, calibrating the focusing properties of the undulator U180 was successful, allowing to provide the currents needed for establishing effective compensation schemes for the optics perturbations caused by the undulator at differing beam energies. Similarly, at beam energies of $450\,\mathrm{MeV}$ and $200\,\mathrm{MeV}$ quadrupole settings based on the calibrated model could be found, allowing to restore the β functions to an acceptable level (see Figures 4 and 5).

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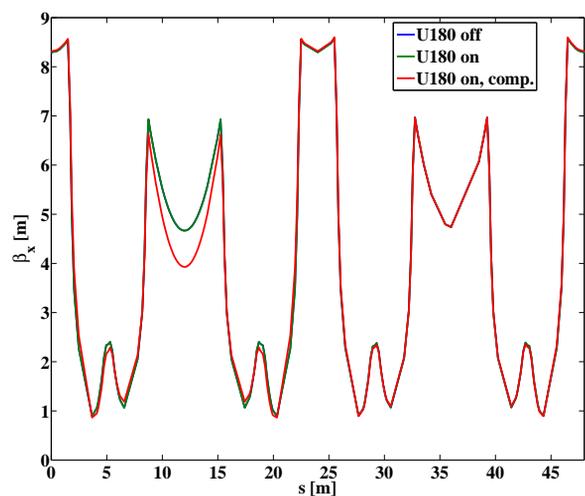
Figure 4: Horizontal β functions before and after compensating the undulator U180 at $200\,\mathrm{MeV}$.
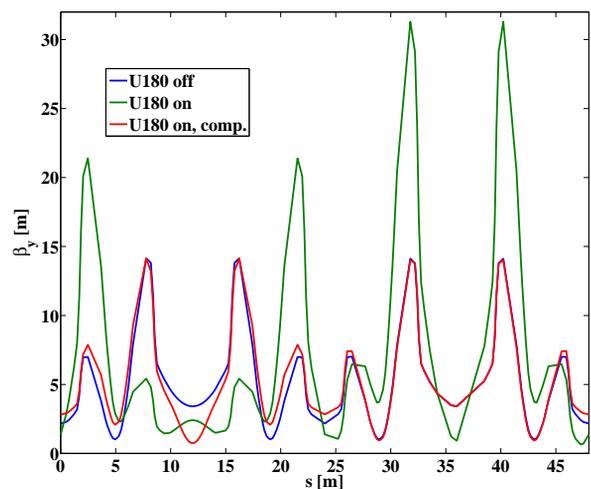
Figure 5: Vertical β functions before and after compensating the undulator U180 at $200\,\mathrm{MeV}$.

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