BETA FUNCTION MEASUREMENT IN THE SOLARIS STORAGE RING

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Abstract

One of the most essential lattice function used for transverse beam dynamics studies of the storage rings is a beta function. It characterizes the linear properties of magnets layout and allows to optimize the compatibility of the model and the machine by reducing the beta-beating. Moreover, the calculation of other parameters like transverse beam emittance, dynamic aperture, energy spread and others, requires knowledge of the quantity of beta function along the ring. Various methods of measurement of this function used in Solaris will be presented.

INTRODUCTION

Beta function is a lattice-dependent amplitude function describing the linear optics in accelerators. A reliable measurement method is essential for transverse beam dynamics studies, therefore several independent measurement methods should be used. Most common methods base on individual magnets scan or model-dependent algorithms like LOCO (Linear Optics from Closed Orbit) [1, 2].

Solaris storage ring has a periodic lattice which optical functions for one Double Bend Achrat (DBA) cell [3–5] is presented in the figure 1. For beta function measurement two families of magnets are used — quadrupoes and corrector magnets. Each DBA contains three quadrupoles, marked on the picture with the red kite, and three correctors magnets which are the additional coils on sextupoles (marked with green hexagons).

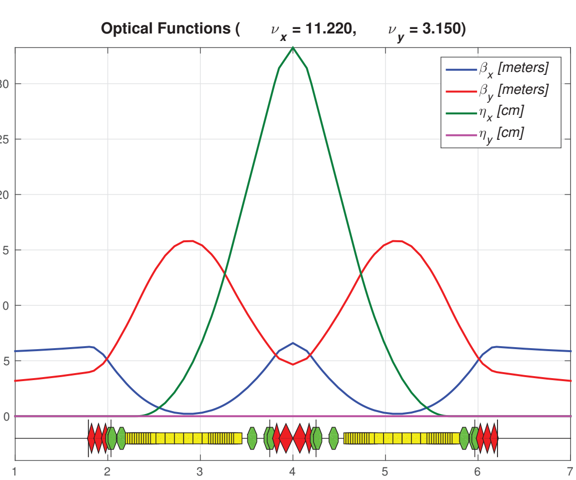

Figure 1: Twiss functions in DBA cell.

BETA FUNCTION MEASUREMENT METHODS

In Solaris synchrotron light source facility three methods are used — LOCO, beta calculations from a quadrupole change induced tune shift and Orbit Response Matrix (ORM) based calculations.

Quadrupole Scan

First attempt to measure the beta function at quadrupole magnets locations based on inducing betatron tune shift by local excitation of individual quadrupole magnet. Beta function for both horizontal and vertical planes can be obtained by solving equation:

$$\beta_{x,y} = \pm\frac{2}{\Delta k}(\cot(2\pi Q_{x,y})\cdot[1-\cos(2\pi\Delta Q_{x,y})] + \sin(2\pi\Delta Q_{x,y}), \tag{1}$$

where ± sign applies to the horizontal (x) and vertical (y) plane, respectively, Δk is a quadrupole strength change and $\Delta Q_{x,y}$ is the tune shift. For small tune shifts, equation 1 can be approximated with a formula:

$$\beta_{x,y} = \pm 4\pi\frac{\Delta Q_{x,y}}{\Delta k}. \tag{2}$$

Solaris storage ring has two quadrupole families: SQFO placed at the ends of each DBA cell and SQFI at the centre of the achromat. All magnets along in one family are connected in series, therefore the individual quadrupole excitations are obtained by shunting of 1% supplying current through the 2.2 Ω power resistors. Disadvantage of this method is a hysteresis piles up leading to significant measurement errors. To limit this phenomena, careful shunts cycling has to be performed before each measurement, what on the other

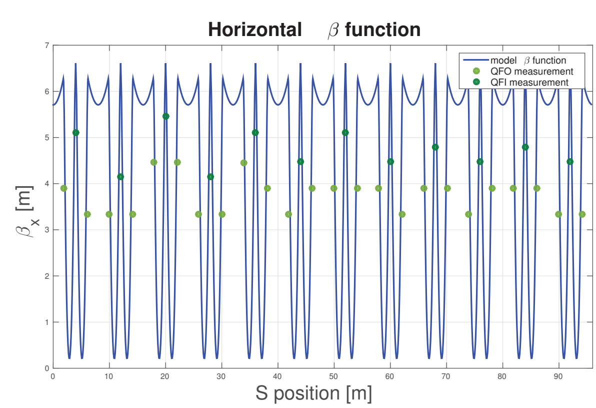

Figure 2: Horizontal β function measured in SQFO and SQFI magnets locations.

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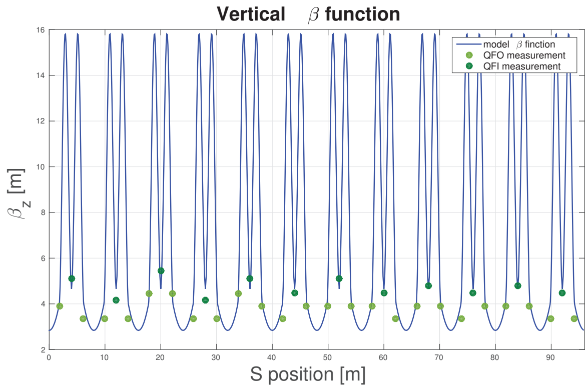

Figure 3: Vertical β function measured in SQFO and SQFI magnets locations.

hand lengthens the measurement time significantly and can lead to other errors like position-change tune drifts.

Figures 2 and 3 presents horizontal and vertical beta function measurement results comparing to the model function. The maximal horizontal beta beating is 26.84% with 5.69% RMS beta beating. For the vertical plane the maximal beating is up to 33.52% with 9.91% RMS beating.

ORM Calculations

Another method to calculate the beta function is to measure local orbit distortion Δx_{CM} induced by the corrector magnet kick $\Delta\theta$ by solving the equation:

$$\Delta x_{CM} = \Delta\theta \frac{\sqrt{\beta(s)\beta(s_0)}\cos\left(\Delta\phi(s) - \pi Q\right)}{2\sin\left(\pi Q\right)} + \Delta\theta\frac{\eta(s)}{\alpha L}, \quad (3)$$

where s_0 is the location of the corrector magnet, s is the location of BPM, $\Delta\phi$ is a phase advance between s and s_0 locations, η is a dispersion function, α — a momentum compaction factor and L is an effective length of the corrector magnet.

The phase advance between corrector magnets and corresponding BPMs for Solaris lattice are negligible, hence equation 3 can be simplified to the formula:

$$\beta_{x,y} = 2 \cdot \tan\left(\pi Q_{x,y}\right) \cdot \frac{\Delta x_{CM}}{\Delta\theta}. \quad (4)$$

Solaris storage ring is equipped with 36 corrector magnets realized as the additional coils on sextupole magnets supplied individually with bipolar power supplies what eliminates hysteresis problems described in previous measuring method.

Figures 4 and 5 present the results of beta function calculations from orbit distortion. The maximal beta beating for the horizontal plane is 13.14% with 6.07% RMS beating, whereas for the vertical plane the maximal beating is 23.49% with 4.21% RMS beating.

LOCO

Third model-dependent method named LOCO uses comparison of the orbit response, model lattice and magnet fits

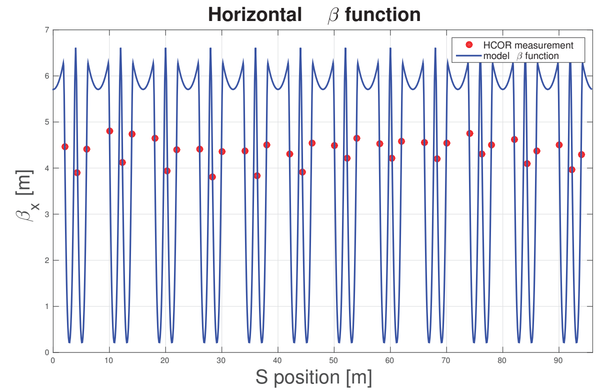

Figure 4: Horizontal β function measured in HCM and VCM corrector magnets locations.

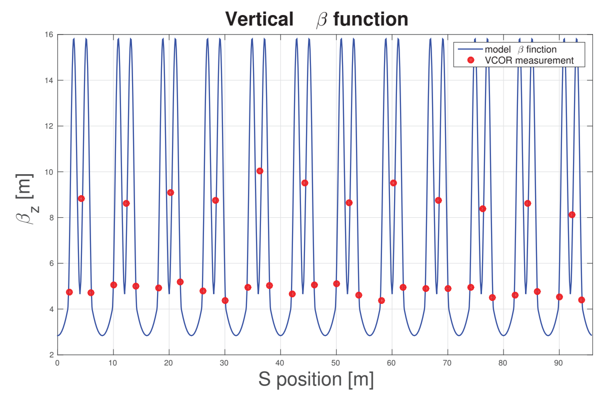

Figure 5: Vertical β function measured in HCM and VCM corrector magnets locations.

to compute and correct various linear optics functions like beta function.

The idea is to adjust the quadrupole strength in the model lattice to fit a model orbit response matrix to the measured one by minimizing the function:

$$\chi^2 = \sum_{i,j} \frac{\left(R_{i,j}^{meas} - R_{i,j}^{model}(\Delta k)\right)^2}{\sigma_i^2} \quad (5)$$

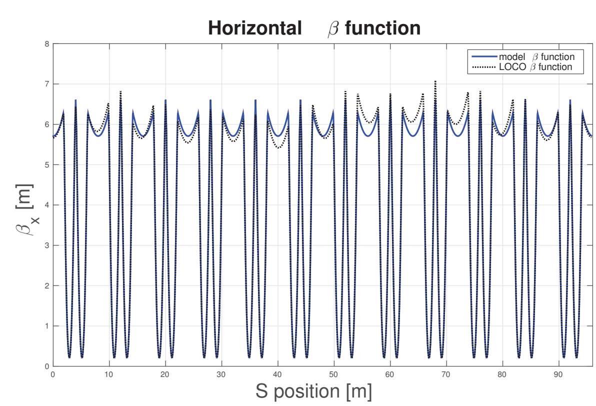

Figure 6: Horizontal β function obtained using LOCO algorithms.

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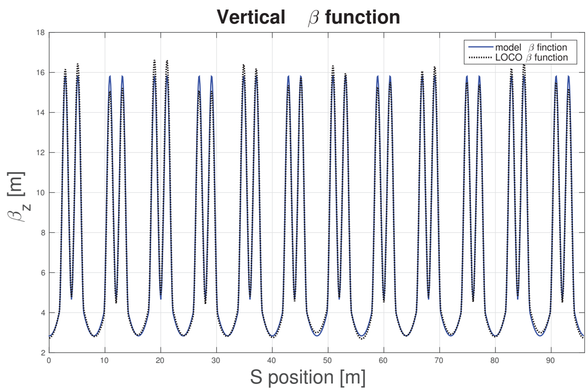

Figure 7: Vertical β function obtained using LOCO algorithms.

Figures 6 and 7 presents the results of beta function calculations using LOCO algorithms for horizontal and vertical planes, respectively. Maximal beta beating in horizontal plane is 16.45% whereas for the vertical plane the beating is 11.73%.

CONCLUSIONS

Three different beta function measuring methods were presented. First method uses betatron tune shift induced by a quadrupole excitation. Due to using unipolar current shunting to achieve a local quadrupole kick, significant hysteresis issues has been introduced to the measurement that resulted in a beta beating growth. Second method computes beta function from the orbit response to a local distortion. Bipolar power supplies for each corrector magnet allowed to obtain more reliable and repeatable results than the first method. Third commonly used method is LOCO calculations. The results obtained from LOCO are in good agreement with ORM calculations. Summary of obtained beta beating are presented in table 1:

Table 1: Beta Beating Comparison

Method	Hor. beating	Vert. beating
QUAD	26.84%	33.52%
ORM	13.14%	23.49%
LOCO	16.45%	11.73%

The results indicates that strong focus should be put to the quadrupole scan optimization to reduce measurement errors and to allow for better comparison of presented methods. Nevertheless all presented methods can be used to improve the overall measurement reliability. The beta beating need to be minimised. This can be done by fine shunting of the individual magnets what is planned in the near future.

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