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LATTICE CORRECTION USING LOCO FOR THE THOMX STORAGE RING*

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Abstract

ThomX is a compact Compton based X-ray source under construction at LAL in Orsay (France). The ThomX accelerator facility is composed by a 50-70 MeV linac driven by 3 GHz RF gun, a transfer line and a 18 meters long Storage Ring (SR). The Compton backscattering at each revolution between the 1 nC electron bunch and the ~25 mJ laser pulses stacked in the Fabry-Perot cavity results in the production of $\sim 10^{13}$ photons per second with energies in the X-ray regime. This high flux of the X-rays strongly depends on the quality (beam sizes) of the electron beam at the interaction point. To guarantee this, a good knowledge and quality of the linear lattice of the ThomX SR are required. Nowadays, LOCO (Linear Optics from Closed Orbits) is a well-known and widely used algorithm to measure and restore the linear optics of the SRs and ensure the designed performances. Comparing the measured and model orbit response matrices, the linear lattice can be restored by retuning the quadrupole gradients. In this paper, we report on the LOCO analysis of the ThomX SR taking into account simulated misalignment, calibration and field errors.

INTRODUCTION

ThomX is a demonstrator proposed by a collaboration of French institutions and one company to build an accelerator based compact X-ray (up to 90 keV) source in Orsay [1]. The main goal of the project is to deliver a stable and a high energy X-ray flux generated by the Compton backscattering process. Low energy, compactness and lack of the operation experience make such type of the machine very difficult to operate and, especially, to commission. At present, the ThomX machine is under construction. Layout of the ThomX accelerator facility including the Photoinjector, Transfer Line, Storage Ring (SR) and Extraction Line is shown on Figure 1.

First, to ensure a high flux X-ray production, linear optics of the ThomX SR has to be measured and controlled. Broken symmetry of the optics due to the field, calibration and misalignment errors usually leads to the resonant excitation which can strongly affect the beam dynamics and so the X-ray generation in the ring. Therefore, it is very important to identify and correct the linear optics (quadrupole gradient) errors in the ThomX SR.

In this framework, the analysis of the machine optics is usually performed by using the trajectories or closed orbit information organized in terms of the Orbit Response Matrices (ORM).

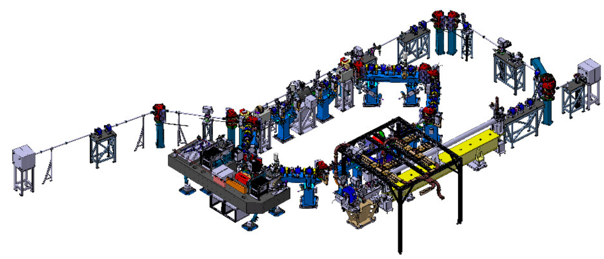

Figure 1: Layout of the ThomX facility.

THOMX STORAGE RING

ThomX SR design is based on a Double Bend Achromat (DBA) optics with a two-fold symmetry including eight 45° dipoles, 24 quadrupoles and 12 sextupoles (see Figure 2). This design accommodates two long straight sections and two short sections between the dipoles where potentially two interaction points can be located. Some of the ThomX SR parameters are listed in Table 1.

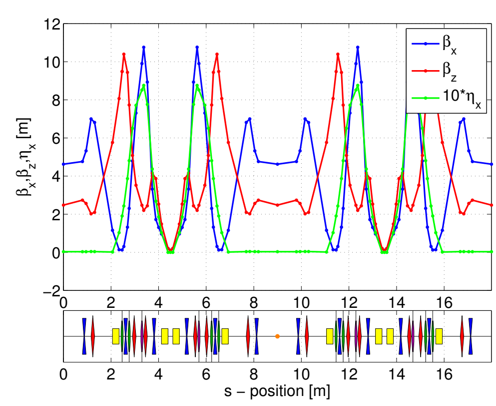

Figure 2: ThomX storage ring nominal optics: horizontal beta function (blue), vertical beta function (red), and horizontal dispersion (green).

The SR has 12 Beam Position Monitors (BPMs) and 12 correctors integrated in the sextupoles for both the horizontal and the vertical planes. The 24 quadrupoles are divided in 6 families and foreseen to have individual power supplies.

The Linear Optics from Closed Orbit (LOCO) code [2] is widely used to correct errors in the linear optics of the storage rings and transport lines. This paper will describe

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Table 1: ThomX Storage Ring Parameters

Parameter	Value	Units
Beam energy	50 – 70	MeV
Bunch charge	1	nC
Bunch length (rms)	20 – 30	ps
Circumference	18	m
Revolution Frequency	16.7	MHz
Current	16.7	mA
RF frequency / Harmonics	500 / 30	MHz
Momentum compaction	0.0125 – 0.025	
Betatron tunes	3.17 / 1.64	
Natural chromaticity	- 3.3 / -7	
Damping time, trans. / long.	1 / 0.5	s
Repetition frequency	50	Hz
Beam size at IP (rms)	70	μ m

the first attempt to simulate the process of the ThomX SR optics correction via ORM analysis.

LOCO ALGORITHM

LOCO is a program analysing the measured ORM and matching the machine model while properly taking into account several parameters such as the BPM and corrector calibration errors and couplings, quadrupole strengths and roll, corrector energy shifts, etc.. The numerical algorithms have been extensively described elsewhere [3]. It is based on the χ^2 function minimization which is given by:

$$\chi^2 = \sum_{i,j} \frac{(M_{ij}^{mod} - M_{ij}^{meas})^2}{\sigma_i^2}$$

where M_{ij} are the ORMs and σ_i is the measured BPM noise level. Finding the best fit optics model requires minimizing the χ^2 function by varying the model parameters the ORM depends on.

FITTING RESULTS WITH LOCO

Data Preparation

The ThomX high level control system will be based on the Matlab Middle Layer [4] together with the Accelerator Toolbox (AT) [5] as a machine simulator. Therefore, all the simulations have been performed by using these softwares with the LOCO code integrated in Matlab [6].

To perform the linear lattice correction, the LOCO requires the measured ORM, the measured dispersion function and the BPM noise measurements. In the case of the ThomX SR, the ORM has 576 elements: 12 BPMs (dualplane) and 12 correctors (dualplane) producing 576 data points.

Moreover, the measured dispersion can be included as additional column to the ORM which provides additional information for the fitting, improves the convergence and allows to avoid the intrinsic degeneracy of the BPM and corrector calibration factors. In this case, the ThomX ORM contains 600 elements. However, if the coupling between horizontal and vertical planes is absent, the off-diagonal sub-matrices of the ORM are zero and, therefore, only 300 data points are used by the LOCO routine.

The nominal fitting parameters used in the ORM lattice modeling are the quadrupole strengths, the BPM and corrector gains which gives a total of 72 parameters.

In order to perform the linear lattice correction, the following errors have been introduced and applied to the nominal lattice of the ThomX SR: 1% error of the quadrupole strength, 5% error of the BPMs and correctors gains and BPMs rms noise level at the level of 1 μm .

The LOCO fitting algorithm is then applied to the simulated errors-free ORM generated by the AT and simulated data set including the effects of the quadrupole field errors, BPMs and correctors calibration errors and BPMs noise.

Fit Results And Discussion

As described before, the simulated ORM is function of 24 known random BPMs gains, 24 known random corrector calibration factors and 24 known random quadrupole gradients. Therefore, by applying the LOCO, one should retrieve the introduced known errors. The simultaneous fit of all the parameters was performed with original Gauss-Newton method (with an appropriate SVD cut of 1e-6). In this case where only the beta function is to be corrected, the BPMs and correctors tilts (couplings) and the off-diagonal ORM elements are not included in the fit.

Starting with a model having distributed errors, it was possible to establish a nominal lattice of the ThomX SR and find the calibration and field errors (see Figures 3 and Figure 4) to restore symmetry of the machine. The betatron tune restored by the fit is 3.1701 (H) and 1.6399 (V) very close to the nominal model values (see Table 1). The normalized χ^2 is 0.003 which indicates a very good agreement between the fitting model and measured ORMs with respect to the BPMs noise level (which is in our case with simulated noise/errors-free data is certainly over-estimated).

As a second step, 8 ghost skew quadrupoles (two per arc) have been introduced in the sextupoles to investigate a possibility of linear coupling and vertical dispersion correction. The correction of the betatron coupling (and vertical dispersion) is based on the off-diagonal ORM and therefore this time it has to be included in the fit procedure. In order to simulate the vertical dispersion and betatron coupling a tilt of 1 mrad rms has been applied to all quadrupoles. Then, the LOCO was used to find the skew quadrupole strengths to remove the coupling and vertical dispersion from the lattice. The correction of the vertical dispersion is illustrated on Figure 5 where the required strength of the skew quadrupole predicted by the LOCO is at the order of 0.1% of the ring quadrupole strength (the normalized χ^2 for this fit is 0.14).

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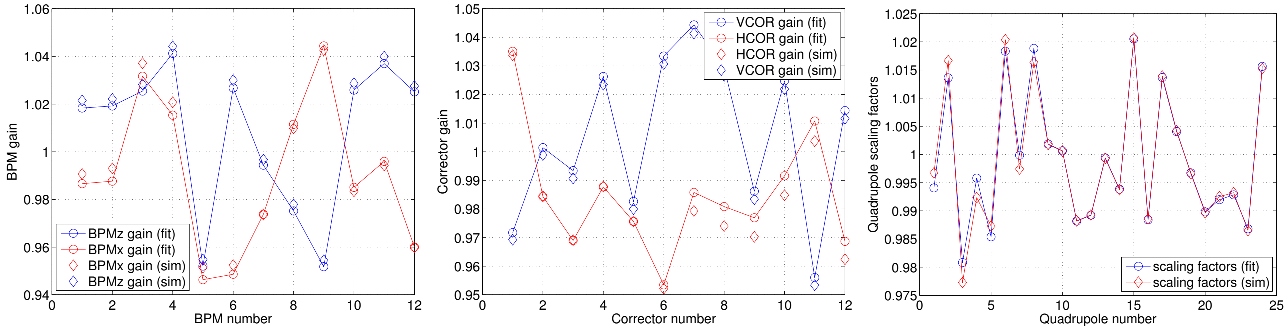

Figure 3: LOCO fitting results: comparison of the BPM gains, correctors gains (i.e. corrector kicks as a fraction of the intended kicks) and the quadrupole strength scaling factors with the corresponding values applied as the errors to the model.

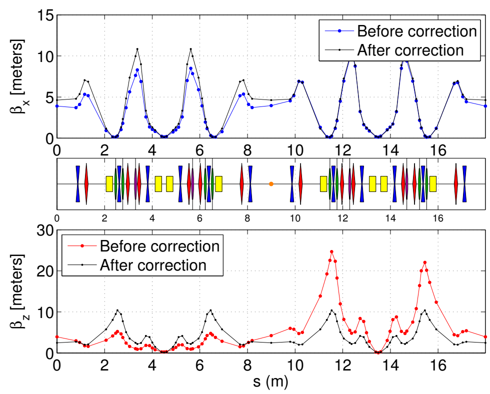

Figure 4: Beta functions of the initial (with simulated errors) and calibrated to the nominal ThomX SR lattice models.

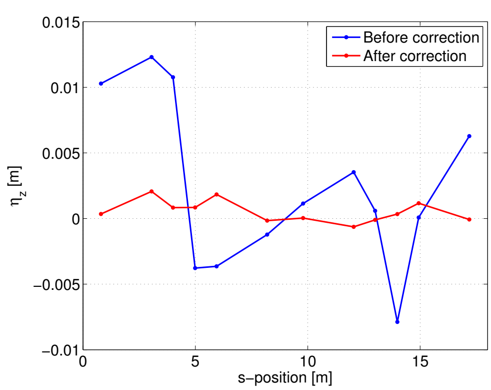

Figure 5: Vertical dispersion of the initial (with simulated quadrupoles tilt) and corrected lattice.

Possible Issues During The Real ORM Measurement

In the ThomX SR the electron beam is stored only for 20 ms and then extracted as compared to the usual damped storage rings operation where the beam is stored for several hours. The short storage time can be a difficulty for the ORM and dispersion measurement because several different beam injections must be used during the ORM measurement. In this case, the closed orbit change due to the corrector kick during the ORM measurement will affect/change the steering and the momentum at the injection. This specificities may generate large betatron or synchrotron oscillations for the next injection and lead eventually to the miss-measurements or beam loss. Therefore, this problem which is not encountered in the damped SRs where ORM measurements and LOCO analysis are continuously used will be addressed in the case of the ThomX SR.

CONCLUSIONS

The possibility of finding the gradient field and calibration errors from the analysis of the orbit response to the corrector kicks has been evaluated. The correction of the betatron coupling and vertical dispersion by introducing the additional (not foreseen by the baseline design) skew quadrupoles has been tested. This first study indicates that under the conditions which have been simulated, it is possible to apply the LOCO algorithm and restore the ThomX SR lattice symmetry, get the correct tunes and predict appropriate settings for the skew quadrupoles to reduce coupling and correct for the vertical dispersion. The further investigations and studies of the influence of the several parameters such as the dispersion and fitting parameters weights, type/value of the SVD cut, minimization methods, etc. should be performed.

In addition, dedicated routines to measure the ORM data according to the limited 20 ms storage without damping will have to be develop.

Although the nominal design does not include the skew quadrupoles the vertical dispersion must be well controlled in the interaction point to ensure the appropriate X-ray generation. A control of the vertical dispersion in this case can be realised by the two nearest correctors. However, depending on the results obtained during the ThomX commissioning, integration of the skew quadrupoles in the SR as a future upgrade option can be envisaged.

REFERENCES

[1] A. Variola, A. Loulergue, F. Zomer, *"ThomX Conceptual Design Report"*, LAL RT 9, 28 (2010).

[2] J. Safranek, *"Experimental determination of storage ring optics using orbit response measurements"*, Nuclear Instruments and Methods in Physics Research Section A, Volume 388, Issues 1–2, 21 March 1997, Pages 27-36.

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[3] See contributions by J. Safranek, X. Huang, L. Nadolski, M. Spencer in ICFA Beam Dynamics Newsletter, No. 44, Edited by A. Ghodke and W. Chou, December 2007.

[4] J. Corbett, G. Portmann, A. Terebilo, *"Accelerator control middle layer"*, Particle Accelerator Conference, 2003, Proceedings of the. Vol. 4. IEEE, 2003.

[5] A. Terebilo, *"Accelerator Toolbox for Matlab"*, SLAC-PUB8732, May 2001.

[6] J. Safranek et al., *"Matlab-based LOCO"*, EPAC, vol. 2, pp. 1184-1186, 2002.