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PROGRESSES OF THE THOMX HIGH LEVEL CONTROL APPLICATIONS BASED ON MATLAB MIDDLE LAYER *

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Abstract

The Compton back-scattering based compact X-ray source ThomX is under construction in LAL/IN2P3, CNRS, France. This machine will serve as a demonstrator in producing X-ray with a flux up to 10^{13} photons/second for imaging and cultural heritage recovery. The high level applications of the ThomX machine for the future commissioning and operations are being developed using Matlab Middle Layer (MML) which has a worldwide use in many accelerators. In this article, we report the nearest progresses of high level applications of the ThomX machine. For example, the orbit correction of the transfer line; the betatron tune corrections, the betatron function and the chromaticity measurements in the ThomX ring.

INTRODUCTION

Besides to serve as large facilities of the TeVs energy range and of the Kms size range for the high energy particle and nuclear physics, another trend in the accelerator fields is the compact and low cost machines, such as the Compton back-scattering based X-ray source ThomX, which is under construction on the campus of the Paris University in Orsay, France [1].

The ThomX machine is composed of a laser based RF photon gun, a warm Linac, a ring of a circumference 18 m and a beam energy 50 MeV where an electron beam collides with a laser beam, a Fabry-Perot optical cavity to amplify the laser beam, an extraction line to extract the beam every 20 ms, and an X-ray beam line for the users [2].

With the ongoing engineering constructions, the high level applications of the ThomX machine are being developed for the future commissioning and operation. These applications are used to control and measure beam properties in the transfer line (TL) between the Linac and the ring, and the ring. The applications are mainly involved in

- the basic machine configurations of the TL and the ring. For example, the switch between different machine operational modes; the magnets cycling, etc;
- measurements and corrections of the transverse and longitudinal optics, such as betatron tunes, chromaticities, dispersion functions, betatron functions, etc;
- nonlinear beam dynamics and beam instabilities studies to improve the injection efficiency and beam lifetime, then finally improve the X-ray luminosity, etc;
- optical matching between the TL and the ring; orbit measurements and corrections in the TL and the ring; emittance and bunch length measurements, etc.

In the ThomX machine control system, the set and read back values of the hardwares are directly controlled by the low level control system TANGO [3]. The high level applications, which are Matlab scripts, connect to TANGO through the Matlab Middle Layer [4, 5].

MATLAB MIDDLE LAYER

To benefit from the powerful features of the Matlab, such as the built-in libraries, mathematical optimization and graphic toolboxes, Matlab Middle Layer (MML) was first introduced by the accelerator physicists in ALS (Berkeley) in the 1990s. Due to its great utilities in the machine control and operation, MML has been continually developed and used in accelerators worldwide, such as SPEAR3 (SLAC), SOLEIL in France, ALBA in Spain.

Together with other Matlab based packages for the accelerators, such as Accelerator Toolbox (AT) [6] for the machine simulation, and Linear Optics from Closed Orbits (LOCO) [7] for optics calibrations, MML can be used to do on-line machine controls and measurements, and also the off-line machine simulations to study the machine properties. Using MML, the accelerator physicists can focus on the physics of the accelerators, rather than the complicated control system of the machine hardwares.

THOMX HIGH LEVEL APPLICATIONS

Progress of the Simulation Toolbox AT

The accelerator simulation toolbox AT is originally converted from the simulation code TRACY [8]. Hence AT is a code to study the beam dynamics using particle tracking, and the core part is a 4-th order symplectic integration algorithm for the particle tracking.

The ThomX machine is a nonlinear dominated machine, the dipole fringe field effect is nontrivial to the calculation of the chromaticities using the particle tracking. As a result, the physics model of the second order dipole fringe field was updated in AT using the model developed in the reference [9]. The chromatities obtained from the particle tracking in AT are consistent to the values from other simulation codes like MADX.

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TL Orbit Correction

The ThomX TL lattice consists of 7 quadrupoles, 4 main dipoles, one small dipole at the end of the TL to facilitate the injection into the ring, 8 BPMs and 8 correctors half of which in the vertical and half in the horizontal planes. In the case of the Transfer Line, MML is used in the "Transport" mode. For ThomX, the TL orbit correction is important since it has direct impacts on the stored beam emittances.

The ThomX TL orbit correction is implemented using a common procedure namely: (1) BPMs value reading, (2) orbit response matrix calculation, (3) SVD algorithm to calculate corrector values, (4) Apply these values on the correctors. A graphic panel has been developed to correct the TL orbit, this panel is not in the final state and is planned to be improved. The TL orbit correction application has been tested on the simulator AT by introducing a fictitious orbit error and it works properly (Fig. 1). This application will be tested again on the real machine with the connection with TANGO.

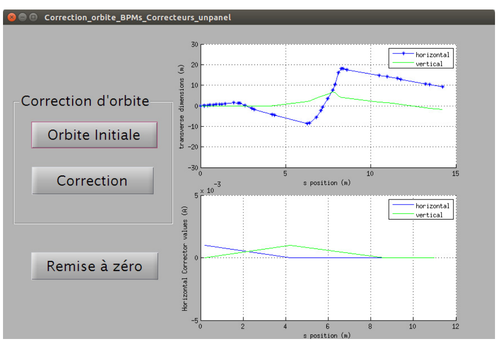

Figure 1: Panel of the ThomX TL Orbit correction.

Betatron Tunes Corrections

To correct the working tunes to the expected values, a tune response matrix A (a_{11}, a_{12}, a_{21},a_{22}) linking the tune shifts ($\Delta\nu_x$, $\Delta\nu_y$) and the strengths of one pair of focusing and defocusing quadrupoles (ΔK_f, ΔK_d) is measured and saved to the local disk,

$$\begin{bmatrix} \Delta\nu_x \\ \Delta\nu_y \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \times \begin{bmatrix} \Delta K_f \\ \Delta K_d \end{bmatrix} \quad (1)$$

Then this archived tune response matrix is used to calculate the quadrupole strength shifts based on the expected tune variations. The tune response matrix can be measured using MML, and it can be called only once to correct betatron tunes to the target values for the beams in the medium and large accelerators.

However, for the compact ThomX ring having a small circumference of 18 m and a beam energy 50 MeV, the tune response matrix A is nonlinear, and its components depend on the expected tune shifts. To overcome this limitation, a linear tune response matrix between a fixed small tune change and the quadrupole strengths is measured and archived, and this matrix is called iteratively to find the proper quadrupole strength shifts, and then the tunes are corrected step-by-step to the target values.

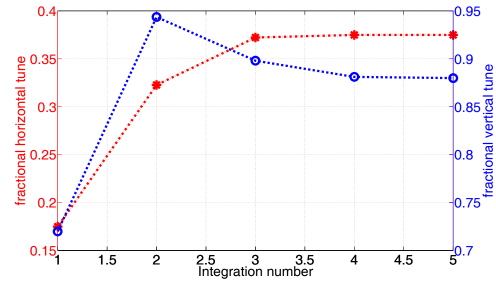

Figure 2: Betatron tune corrections in the ThomX ring based on the simulator AT. The start fractional horizontal and vertical tunes are respectively 0.175 and 0.720, the target tunes are respectively 0.375 and 0.880.

Fig. 2 shows one example of the tune correction of the ThomX ring based on the simulator AT. The horizontal tune shift is 0.2, and the vertical tune shift is 0.16. Through iteratively calling a linear tune response matrix, both the horizontal and vertical betatron tunes are corrected to the target values with an accuracy less than 10^{-5} after 5 steps.

Betatron Function Measurement

Another important machine parameter for the transverse beam dynamics is the betatron function $\beta_{x,y}$, which is related to the quadrupole excitation,

$$\begin{aligned} \beta_{x,y} &= \pm\frac{2}{\Delta K}\cot(2\pi\nu_{x,y})\left(1-\cos(2\pi\Delta\nu_{x,y})\right) \\ &\pm\frac{2}{\Delta K}\sin(2\pi\Delta\nu_{x,y}) \end{aligned} \quad (2)$$

where ΔK is the quadrupole strength excitation, $\nu_{x,y}$ are the betatron tunes, $\Delta\nu_{x,y}$ are the tune variations. However, if the tune change $\Delta\nu_{x,y}$ is small and the betatron tune $\nu_{x,y}$ is far away from the half and integer resonances,

$$\Delta\nu_{x,y} \ll 1, \quad \cos(2\pi\nu_{x,y}) \ll 1, \quad (3)$$

then Eq. (2) can be simplified to

$$\beta_{x,y} \approx \pm 4\pi\frac{\Delta\nu_{x,y}}{\Delta K}, \quad (4)$$

then the betatron functions can be measured using the linear dependence of the tune shift on the quadrupole excitation.

To verify the two conditions (Eq. (3)) of the betatron function measurement (Eq. (4)), the valid change range of the quadrupole strength is investigated (Fig. 3). With the quadrupole excitation less than 0.2 [m^{-2}], the measured betatron functions using Eq. (4) is trustable. Besides, the resolution of the BPMs limits the minimum measurable tune as 0.001 in the ThomX machine. As a result, the quadrupole strength change ΔK should be in the range 0.05 [m^{-2}] $\leqslant \Delta K \leqslant$ 0.2 [m^{-2}] to properly measure the betatron functions in the ThomX ring.

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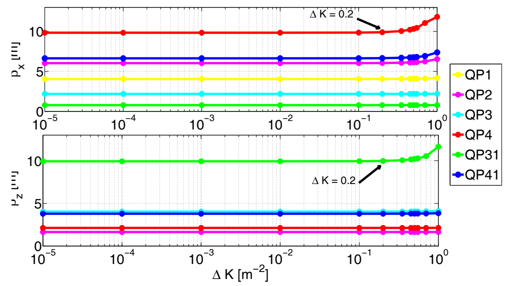

Figure 3: Betatron functions measurement of the ThomX ring with different set of quadrupole excitations. There are 8 quadrupole families in the ThomX ring.

Figure 4 shows the measurement of the betatron functions in the ThomX ring using Eq. (4), the quadrupole excitation is 0.01 [m^{-2}]. The tiny discrepancy between the measured betatron functions and the simulated values is due to the approximation of the thin lens model of the quadrupoles in Eq. (4).

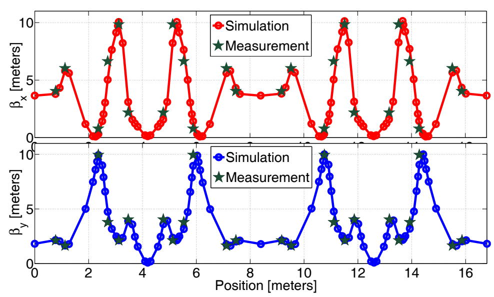

Figure 4: Measurement of the betatron functions of the ThomX ring using Eq. (4). The measurement is based on the simulator AT.

Chromaticity Measurement

The chromaticity $\xi_{x,y}$ is determined by the betatron tune shift of the off-momentum particle with respect to the tune of the on-momentum particle,

$$\Delta\nu_{x,y} = \xi_{1x,y}\left(\frac{\Delta p}{p_0}\right) + \xi_{2x,y}\left(\frac{\Delta p}{p_0}\right)^2 + \ldots \qquad (5)$$

where $\xi_{1x,y}$ is the linear chromaticity; $\xi_{2x,y}$ is the second order chromaticity; $\Delta p/p_0$ is the relative momentum shift with respect to the design momentum, which is linear proportional to the relative RF frequency variation $\Delta f_{RF}/f_{RF}$,

$$\frac{\Delta p}{p_0} \approx -\frac{1}{\alpha_c}\frac{\Delta f_{RF}}{f_{RF}}, \qquad (6)$$

where α_c is the linear momentum compaction factor. As a result, during the machine operations, the relative momentum change $\Delta p/p_0$ can be obtained by changing the RF frequency. Based on Eq. (5) and Eq. (6), the horizontal and vertical chromaticities can be measured.

Figure 5 shows one example to measure the chromaticities of the nominal lattice of the ThomX ring. The measured linear horizontal and vertical chromaticities are close to the nominal values which are both zero. The nonlinear chromaticities can also be measured using this method, which may be important to the future commissioning and operation of the ThomX ring.

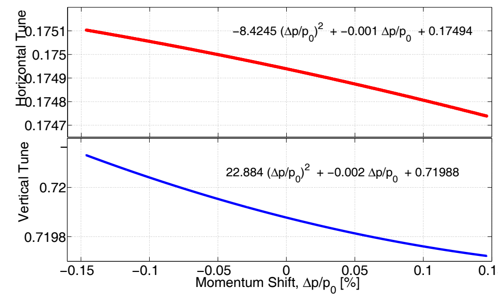

Figure 5: Measurement of the horizontal and vertical chromaticities of the ThomX ring using Eq. (5). The nominal horizontal and vertical chromaticities are both zero. The measurement is based on the simulator AT.

CONCLUSION

The compact Compton back-scattering based X-ray source ThomX machine is under constructions in LAL (Orsay) in France. Its high level physics control applications are being developed for the machine control and measurements using MML. This article reports several important applications, the nonlinear dipole fringe field model is updated in the simulator AT; the TL orbit correction is implemented based on a graphic interface; the betatron tune can be iteratively corrected using the tune response matrix; the betatron functions are measured using the quadrupole excitation; the linear and nonlinear chromaticities are measured using the tune shifts with the RF frequency. For the general progresses of the ThomX machine, the readers can refer to the articles of co-authors in the same conference proceedings.

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