STATUS OF THE PREPARATION TO THE COMMISSIONING OF THE THOMX STORAGE RING*

I. Chaikovska†, C. Bruni, S. Chancé, A. Gamelin, H. Monard
Laboratoire de l'Accélérateur Linéaire, CNRS, Université Paris-Sud XI, Orsay, France
A. Loulergue
SOLEIL, Gif-sur-Yvette, France

Abstract

ThomX is a compact Compton based X-ray source under construction at LAL in Orsay (France). The ThomX facility is composed by a 50-70 MeV linac, a transfer line and a 18 meters long storage ring. Compton scattering between the 50 MeV electron bunch of 1 nC and the 30 mJ laser pulses stacked in the Fabry-Perot cavity results in the production of photons with energies (up to 90 keV) with a maximum flux of 10^{13} photons per second. The ThomX construction will start shortly aiming to be completed in the middle of 2017. The preparation to the storage ring commissioning as far as a control system and beam physics applications are concerned is progressing gradually in order to prepare and test all the tools well ahead the start of the machine. The storage ring commissioning will face with many challenges providing the low energy, compactness, the nonlinear beam dynamics, the limited beam storage and need for the precision and stabilization in the Interaction Region. Several techniques used at the Synchrotron Light Sources should be modified/adapted to meet all the specificity of the ThomX. This is a report on preparation of the ThomX storage ring commissioning, its status, planning, main challenges and expectations.

INTRODUCTION

ThomX is a demonstrator proposed by a collaboration of French institutions and one industrial partner 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 Compton scattering process. In order to achieve the requested performance (10^{11} –10^{13} photons per second), both electron beam and laser pulses will be stacked respectively in a storage ring and in a high gain Fabry-Perot cavity. The X-rays will be produced at a 17 MHz rate and then transported to the users. In this context, the application fields that will be explored in the baseline ThomX program mainly concern medical science and cultural heritage preservation [2].

FACILITY OVERVIEW

Accelerator Facility

The ThomX accelerator complex, as shown in Fig. 1, consists of a 50 MeV linac (with an upgrade option of 70 MeV), a Transfer Line (TL) and a 18 meters long Storage Ring (SR) coupled to the extraction line going towards a beam dump. The 50 Hz ThomX injector composed by a high brightness electron 2.5 cells RF gun and a LIL-type S-band acceleration section are described elsewhere in these proceedings [3,4]. After the linac the beam is transported to the SR by 14 meters TL. The TL is based on the same magnetic elements family as the SR. Several beam diagnostics used to measure the beam characteristics from the linac including beam size, bunch length, beam emittance and energy spread are installed on the TL. This beam diagnostics together with the shaping of the beam by the scrapers will be used for the efficient injection to the SR taking into account injection envelop matching and orbit steering. The fast injection and extraction are ensured by a septum and two fast kickers implying single-turn on-axis injection. The SR is designed to store a current of about 17 mA (1 nC) in the single-bunch mode. More details on the ThomX SR are given in the following Section.

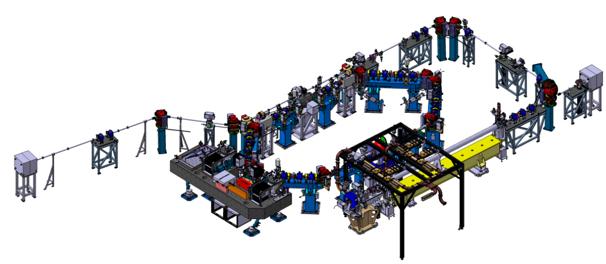

Figure 1: Layout of the ThomX facility.

ThomX accelerator complex will be integrated in a new research platform IGLEX (old IGLOO building in the Orsay Campus). The construction phase was launched in the end of 2015 covering the refurbishing of the old accelerator building and experimental hall along with the infrastructure works. The building will be ready by the end of 2016. The final assembly and the hardware testing phase is scheduled for the beginning of 2017. From then on, the commissioning of the injector, TL and SR will start respectively.

Low and High Level Control of the Accelerator

The ThomX control system is based on TANGO, initially developed at the ESRF and nowadays employed at SOLEIL, ALBA and other labs. It is highly distributed relying mainly on the Profibus and Ethernet as a fieldbus. The dedicated software development was started since a while. A MATLAB interface to the TANGO control system, so-called,

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† chaikovs@lal.in2p3.fr

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Matlab Middle Layer (MML) [5] is used to develop the High Level Applications to perform the accelerator measurements and physics studies. Although many tools are already included in the MML software such as orbit correction, LOCO optics correction program, betatron function and dispersion measurement, etc., several tools are under test and development now to meet the specificity of the ThomX machine [6]. Different tests of the control system are ongoing aiming the final configuration and installation during the assembly and hardware testing phase.

DESCRIPTION OF THE THOMX STORAGE RING

ThomX SR employs a Double Bend Achromat optics with a two-fold symmetry. Figure 2 shows the optical functions along the ring.

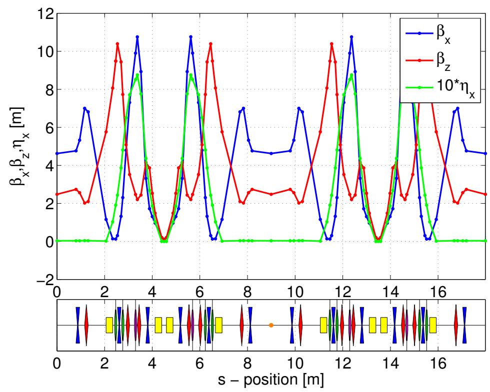

Figure 2: ThomX storage ring nominal optics: horizontal beta function (blue), vertical beta function (red), and horizontal dispersion (green).

There are eight 45° dipoles and 24 quadrupoles. The dipoles are all connected in series and the quadrupoles have the separate power supplies. The SR also has 12 sextupoles for chromaticity corrections and 12 correctors integrated in the sextupoles for both the horizontal and the vertical planes to correct the orbit. The sextupoles are arranged in 3 families with each family powered by a separate power supply. The correctors are powered with separate bipolar convertors. The pulsed magnets are controlled individually. Fig. 3 shows a schematic layout of the ThomX SR and the design parameters are listed in Table 1. This design is based on the very dense integration and accommodates two long straight sections and two short sections between the dipoles where potentially two interaction points can be located.

The stability of the electron beam is of great importance for the Compton based X-ray sources. Since ThomX is a nonlinear dynamics dominated machine, the operation and its commissioning is a big challenge owing to high particle density and low energy operation, mismatched beam injection, absence of the synchrotron damping, strong affect of intrabeam and Compton scattering and other collective effects including the ion instabilities, ring impedance, etc.. In this context, more information on the impedance in the

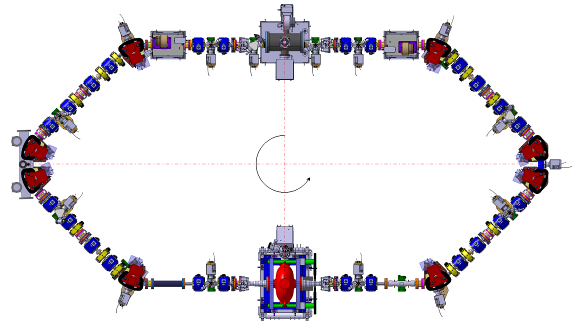

Figure 3: Layout of the ThomX Storage Ring.

Table 1: ThomX Storage Ring Design 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

ThomX SR [7] and ion instabilities [8] is given elsewhere. Moreover, broken symmetry of the optics can be responsible for the resonant excitation which can strongly affect the beam dynamics. Therefore, the analysis and correction of the SR optics taking into account simulated misalignment, calibration and field errors has been worked out [9].

Large ring acceptance is essential for efficient beam injection and maintaining particle losses at the acceptable level. In general, the momentum acceptance of the ring is limited by the RF acceptance and dynamic aperture which usually shrinks with momentum deviation due to chromatic and nonlinear effects (dynamic acceptance). The ThomX SR RF acceptance is ± 10%. Complete tracking simulations show that a major limitation on the dynamic momentum acceptance comes from the sextupoles used to correct the chromaticity and the sextupole component of the dipole field. The on-momentum dynamic aperture is about 30 times the rms transverse beam size of the injected beam and remains about the same for off-momentum particles (up to ±2%) taking into account magnet multipoles errors. In such a way, the ThomX SR momentum acceptance is mainly dominated

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by the pipe acceptance and considered to be large enough to sustain the maximum momentum spread of 0.6% attained at the end of the injection cycle.

Subsystem Status and Installation

Installation While waiting for the accelerator building and infrastructure to be ready, we are now in the process of construction and testing of the different subsystems. In order to optimize the assembly of the accelerator and reduce the installation work in the accelerator hall, different components will be preinstalled and prealigned in advance. The quadrupole and sextupole magnets together with the vacuum chamber and the hardware will be mounted on 8 girders with a maximum error of 50 μm. However, the dipoles will be equipped with the additional support tools allowing readjusting of its position relative to the girders given the large effect of the dipole misalignments on the closed orbit. The expected final total alignment errors are about 100 μm in each plane. Eventually, the preassembled girders will be transported to the accelerator building. The rest of the components dedicated to the injection, extraction and the RF system will be installed directly in the accelerator hall.

Vacuum Chamber The SR vacuum chamber is made of stainless-steel and has elliptical shape with the aperture of 40 mm in horizontal by 28 mm in vertical plane. This choice is made given the beam dynamics studies accounting several instability sources and the magnet bore radius. Average vacuum pressure will be maintained by ion pumps distributed along the ring at the level of 10^{-8} Pa.

Diagnostics As shown in Fig. 2 the ThomX SR has very dense integration allowing the primary beam diagnostics being only the Beam Position Monitors (BPM). There are in total 12 button BPMs in the ring whose data acquisition software allow the recording of turn-by-turn data. Other secondary diagnostics are the synchrotron radiation monitor and the beam loss monitor.

RF and Feedbacks Given the absence of synchrotron damping, beam instabilities and the injection mismatch the longitudinal and transverse feedback systems are indispensable for the beam stability. Longitudinal feedback is ensured by a 500 MHz ELETTRA-type cavity powered by a 40 kW SOLEIL-type solid state amplifier allowing the damping of the longitudinal oscillation during 20 μs (about 300 turns). The RF system will be commissioned in situ. The transverse feedback is made of a dedicated stripline installed at one of the long straight sections to provide 5 μs damping time.

Magnets The magnets of the SR have been fabricated and the measurements of the multipole errors being finished. Detailed description of the magnet status is presented at this conference [10]. The results of the magnetic measurements show that the field components are well within the tolerances imposed by the beam dynamics requirements. To achieve good performance, the dipole magnets will be distributed along the ring according to their field errors. Such assignment of the magnets to a given place, so-called sorting, results in the minimisation of the closed orbit distortion (see Fig. 4).

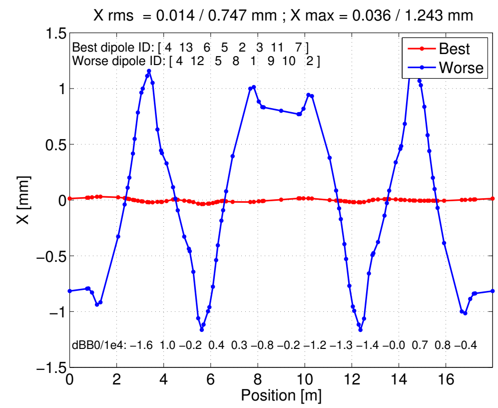

Figure 4: Dipole sorting procedure on the ThomX SR assuming Gaussian error distribution with $(dB/B)_{rms}=1/10^4$. Best and worse case of the closed orbit distortion.

GUIDELINE FOR COMMISSIONING

A three months commissioning time is foreseen for the ThomX SR after the injector and the TL are commissioned. Detailed plans for the SR commissioning are being developed. Since some components are common to both TL and SR we can benefit from the experience gained during the TL commissioning. During the installation, all the available equipment will be verified (including the magnet polarity, magnet cycling, power supplies, cabling, timing system, electronics etc..) and validated together with its control systems. The final test of the function of accelerator hardware and software will be performed with the beam.

In order to decouple several beam dynamics effects, the commissioning will start with lower bunch charge (200 pC or less) and lower injection frequency (a few Hz) allowing the increase of the beam lifetime and decrease the impact of the collective effects. When the closed orbit is established, the first-turns analysis (tune, chromaticity and orbit measurements and correction) will be carried out relying on the BPM signal as the main diagnostics tool. Once the RF system is powered, the beam can be stored for bigger number of turns providing more precise information about the beam orbit. Consequently, the more precise beam studies including injection optimisation, the optics measurements, beam extraction can be undertaken. Finally, the beam tuning and the underlying beam studies owing the electron-photon Compton scattering will be performed to find the optimum alignment of the electron and laser beams which maximizes the X-ray flux. According to the present planning, the first X-ray beam delivered to the users is expected in 2018.

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