STATUS OF THOMX STORAGE-RING MAGNETS*

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Abstract

The THOMX facility is a compact X-Ray source based on the Compton back scattering aiming at a flux of 10^{11} to 10^{13} ph/s in the range of energy from 40 to 90 keV. Due to the compactness and the expected stability of this machine, high requirements are set for all magnets in terms of design and manufacturing. First, the design optimization of the magnets is presented, leading to high performance in terms of harmonics. Issues regarding the cross-talk between quadrupole and sextupole fields are then discussed.

INTRODUCTION

Nowadays, intense X-Rays beams are produced using Bremsstrahlung, synchrotron radiation or Compton backscattering. Three approaches have been developed to produce a high flux of X-rays from Compton Back Scattering. These are based on either a high repetition rate linac [1], a CW superconducting linac [2] or a compact storage ring [3, 4]. Thanks to the development of high power femtosecond lasers and improvement of optical resonators in the last 15 years, it is now possible to generate hard X-rays by electron beams with comparatively low energies [5] by the latter method. It is in this context that THOMX facility project has been launched.

Indeed, THOMX facility will produce a flux of X-rays with a tuneable energy cut-off by using both electron bunches and laser pulses, stacked respectively in a storage ring and in a high gain Fabry-Perot cavity.

The most challenging aspects of this kind of facility are the laser storage cavity, essential to obtain sufficient laser pulse power and repetition rate, as well as the electron storage ring since it explores a new domain of beam dynamics [6]: low energy, no synchrotron damping, mismatched injection, Compton recoil induced energy spread [7], Intra Beam Scattering [8,9], residual gas scattering [9], ions instabilities together with the ring impedance and high electron bunch density [10, 11, 12].

To ensure a reasonable large dynamic aperture leading to an efficient injection and a large electron beam lifetime, very tight specifications have been put to the magnetic elements. All the accelerator magnets have been designed by using the OPERA-3D/Tosca program from Cobham [13].

This article will first present the ring magnets by defining the beam dynamic specifications leading to constraints over magnetic design, and then by showing magnetic simulation results leading to manufacturing choices. The second part will consist on magnet cross-talk simulation results.

GENERAL DESCRIPTION

The storage ring has a circumference of 18 meters and consists of 44 magnetic elements, including 8 C-shaped bending magnets, 24 quadrupoles and 12 sextupoles containing 12 two-plane correctors which features are summarized in Table 1. For each of these magnet families, a spare magnet has been added.

Table 1: Specifications of storage ring magnets.

Item	Dipole	Quad.	Sextu.
Quantity	8	24	12
Yoke Length	276.5 mm	140 mm	60 mm
Field Strength	0.7 T	5 T/m	$40 T/m^2$
Aperture	42 mm	41 mm	44 mm
GFR	+/-20 mm	+/-20 mm	+/-20 mm

GFR stands for Good Field Region

MAGNETS

Ring Dipole

A special endeavour has been done for the design of poles, in particular, for the deepness and width of the entrance/output chamfer design. It has been optimized to maintain the magnetic face with an angle of 22.5° both at the entrance and the exit for radial trajectory between +/20 mm and to limit its error. Indeed, the magnetic length error *Δ(Bl)/Bl* in the bending magnets distorts the horizontal orbit and consequently the dynamic aperture (due to optical distortion in sextupoles) [14]. Due to the compactness of the ring, the C-shape dipole has been preferred to facilitate the installation of the beam vacuum chamber and its pumping as well as to accommodate the Fabry-Perot cavity at the laser-electron collision point location (Fig. 1).

The main parameters of ring dipoles are summarized in the Tables 2, 3 and Fig. 2.

Table 2: Main parameters for THOMX dipole

Parameters	Value
Maximum dipolar field	0.63T
Integrated field	184.59 mT.m
Gap	42 mm
Bending radius	352 mm
Ampere turns per pole	13000

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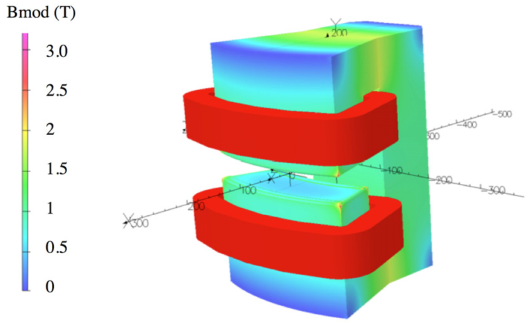

Figure 1: Simulated dipole.

Table 3: Integrated multipolar components at x = 20 mm with 200Amps, relatively to the main component.

Integrated components	**Value**
B_2	$-3.5\ 10^{-3}$
B_3	$-1.0\ 10^{-3}$
B_4	$-2.4\ 10^{-4}$
B_5	$-1.2\ 10^{-3}$

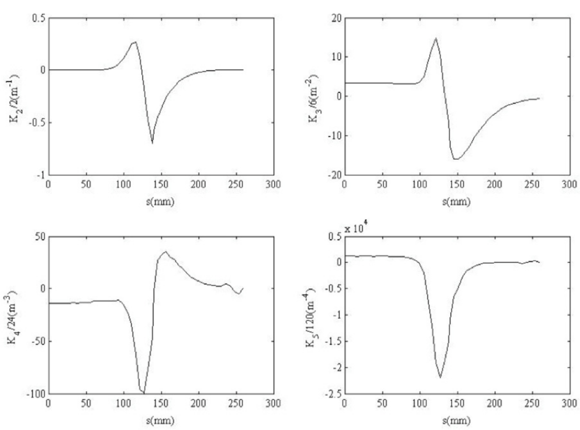

Figure 2: Multipole components along direction s.

A resistive magnet in a solid yoke technology with hollow copper conductor has been chosen for the manufacturing of THOMX dipole (Fig. 3).

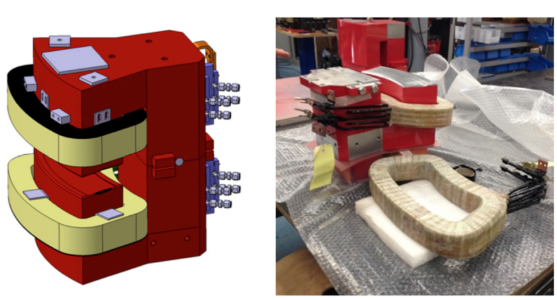

Figure 3: a) Drawn and b) Manufactured dipole.

Quadrupoles

A special endeavour has also been done to optimize the profile and the end chamfer of the quadrupole (Fig. 4), leading to achieve very small multipolar components and to keep a large dynamic aperture, as well as a large injection efficiency and beam lifetime [14, 15].

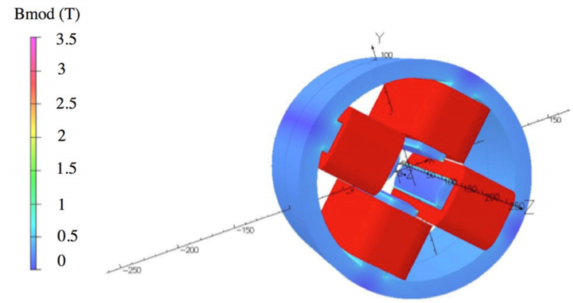

Figure 4: Simulated Quadrupole.

Furthermore, the lateral chamfer has been set at 2*2mm in order to facilitate the insertion of the coil around the pole and to minimize harmonic contents.

Table 4 shows the impact of the dimensions of the end pole chamfer on the B_6 component. OPERA 3D/TOSCA was used to estimate the field integrated along the magnet trajectory and individual multipole components were evaluated by Fourier analysis on a cylinder.

Table 4: Harmonic contents (Hc) at R_{ref} =18 mm with 10 Amps for different sizes of End pole chamfer (Epc).

Harmonic contents	Epc **0*0 mm**	Epc **1x1mm**	Epc **2.6x2.6mm**
B_6	-34	-21	2.4
B_{10}	1	-4,5	-6.4
B_{14}	-10	-8.2	-9.1

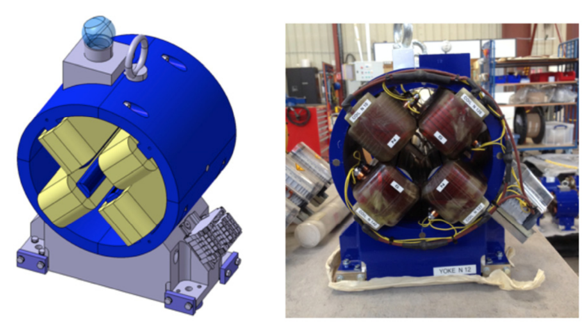

Figure 5: a) Drawn and b) Manufactured quadrupole.

Finally, the chosen end pole chamfer size is 2.6*2.6 mm and the normalized harmonics B_n/B_2 in the third column are given for a main magnetic field B_2 of 0.0128 T/m.

The manufacturing of the THOMX quadrupole (Fig. 5) is also achieved in a solid yoke technology, air cooled, with plain enamelled copper conductor. It operates at a maximum gradient of 5 $T.m^{-1}$ with a 41 mm bore diameter necessary to install the vacuum chamber.

Sextupoles

Sextupole magnets (Fig. 6) have been designed by applying the ideal pole shape and by optimizing the end pole chamfer to minimize multipolar components. Indeed, the error in sextupole strength doesn't affect the optics, to

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first order, however it distorts the chromaticity and non-linear optical optimization, which result at the end in destructing the on-momentum and off-momentum dynamic apertures [14].

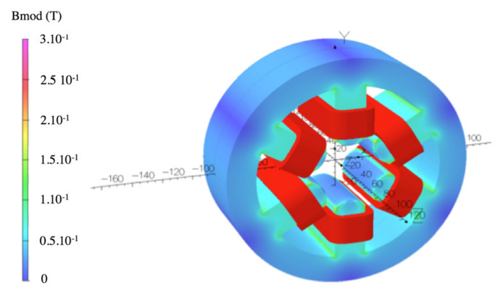

Figure 6: Simulated sextupole.

Harmonic contents $B_n/B3$ has been calculated from Fourier analysis on a cylinder, as Quadrupole, with B_3 of 7.87 10^{-4} T.m at R_{ref}=18 mm (Table 6).

Table 5: Hc at R_{ref}=18 mm with 10Amps.

Harmonic contents	Simulated results
B_9	-9.7 10^{-4}
B_{15}	6.7 10^{-4}
B_{21}	9.1 10^{-4}

As quadrupole, THOMX sextupole (Fig.6) is also resistive magnet manufactured in a solid magnet technology, air cooled. It operates at maximum sextupolar strength of 40 T/m² with a 44 mm bore.

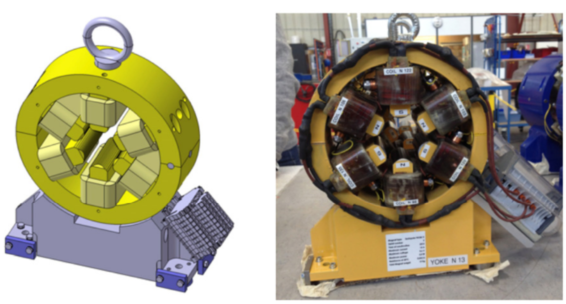

Figure 6: a) Drawn and b) Manufactured sextupole.

In order to save space, the dipolar vertical and horizontal correctors for closed orbit correction have been inserted as auxiliary coils inside the sextupole [16].

CROSS TALK SIMULATIONS

A drawback from the compact lattice is the fringe field mixing between quadrupoles and sextupoles, in particular in the arc region where sextupole yoke are located as close as 50 mm from quadrupole yoke.

Simulations of the sextupole effect on quadrupole and inversely have been done to estimate the impact. Results of three cases for quadrupole are summarized in the tables 7 and 8:

- Case 1: the quadrupole magnet is alone in the space
- Case 2: the quadrupole and the sextupole are in the space and only quadrupole magnet is powered
- Case 3: Both magnets are powered

Table 6: Hc in 10^{-4} at R_{ref} =18 mm and at nominal intensity – 10 A – for the quadrupole in the three cases of cross-talk.

Harmonic contents	Quad alone	Quad ON Sextu OFF	Quad ON Sextu ON
B_4	0.00	-1.25	-1.25
B_6	2.32	2.28	2.28
B_{10}	-6.38	-6.48	-6.48
B_{14}	-9.15	-9.19	-9.19
B_{18}	-3.65	-3.66	-3.66

From simulation results, sextupole doesn't affect the allowed harmonic contents of the quadrupole but its mere presence generates a small octupolar component. In the same way of the quadrupole, three cases have been simulated to estimate the impact of the quadrupole over the sextupole:

- Case 1: the sextupole magnet is alone in the space.
- Case 2: the quadrupole and the sextupole are in the space and only sextupole magnet is powered.
- Case 3: Both magnets are powered.

Table 7: Hc in 10^{-4} at R_{ref} =18 mm and at nominal intensity – 10 A – for the sextupole in the three cases of cross-talk.

Harmonic contents	Quad alone	Quad ON Sextu OFF	Quad ON Sextu ON
B_1	0.00	-2.94	-3.38
B_5	0.00	-0.99	-1.99
B_9	-19.00	-19.08	-19.31
B_{15}	-4.08	- 4.09	- 4.09
B_{21}	-0.17	- 0.17	-0.11

Cross-talk simulations have shown that quadrupole doesn't affect allowed harmonic contents of the sextupole, but as in the previous case, the presence of the quadrupole at 50mm generates small dipolar and decapolar components which increase by powering the quadrupole.

CONCLUSION

The magnets for THOMX, a compact X-Ray source based on the Compton back scattering, were optimized in such a way that their sizes were as small as possible to fulfill a ring circumference of 18m while allowing for a flexible and reliable operation.

Special design endeavours for quadrupoles and sextupoles were done to achieve harmonic contents less than 1.10^{-3} while minimizing the distance between them to 50 mm thanks to the studies of cross-talk.

Regarding dipole magnet design, it has been optimized to maintain the magnetic face with an angle of 22.5 ° both at the entrance and the exit for radial trajectory and to achieve multipolar components less than 5.10^{-3}.

At present, all magnets have been manufactured and magnetic measurements are on going at ALBA, SOLEIL and LAL.

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