DESIGN OF THE TRANSVERSE FEEDBACK KICKER FOR ThomX

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Abstract

ThomX is a Compton back-scattering source project in the range of the hard X rays to be installed in 2017. The machine is composed of an injector Linac and a storage ring where an electron bunch collides with a laser pulse accumulated in a FabryPerot resonator. The final goal is to provide an X-rays average flux of 1013 ph/s. To keep up with this flux, it is required to install a transverse feedback system to suppress instabilities generated by injection position jitter sources, resistive wall impedance or collective effects. This paper describes the design and simulation studies of the stripline kicker that will be used for the transverse feedback system.

Introduction

ThomX [1] is a demonstrator for a Compton back-scattering source in the hard X-ray range to be installed in Orsay, France, in 2017 [2]. A single electron bunch will be accelerated every 20 ms by a 50 MeV LINAC and stored in a 16 m circumference storage ring to interact with a high energy laser (fig. 1).

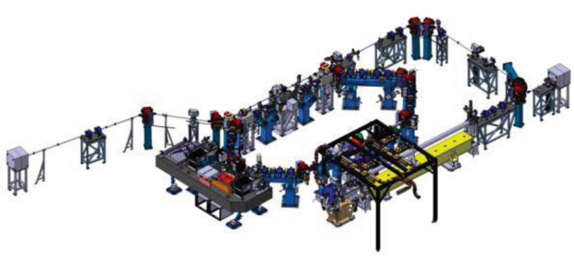

Figure 1: Layout of the ThomX facility.

By operating at low energy (50 MeV) the natural damping effect of the synchrotron radiation is weak and the beam stability becomes a crucial matter. The computed instability growth time and the corresponding kicker strength requirement for the different types of instabilities are listed in table 1. The results indicate that for Thom-X, the most critical effect comes from the injection orbit jitter inducing emittance growth at a growth rate of ~5 µs once the bunch stored in the ring.

Table 1: Instabilities Estimate for ThomX Ring

source	Growing time	Kicker strength $\Delta x'$
Beam pipe Geometries	160µs	> 10nrad
Resistive Wall	600µs	> 2 nrad
Ions	< 100 µs	> 20nrad
Injection Jitter	5 µs	2 µrad

ThomX Transverse Feedback

To cope with these instabilities, it was decided to use a digital transverse feedback system, composed of a wideband detector button beam position monitor (BPM) a RF front-end, a FPGA based processor, a power amplifier and a stripline kicker (fig. 2). The system is capable of detecting a coherent transverse motion and applying a counter kick to damp it, bunch by bunch and turn by turn, with one (or even 2) bunches.

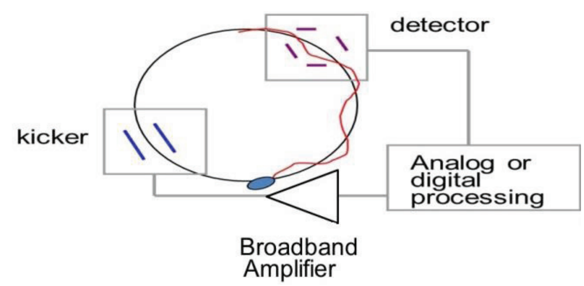

Figure 2: Digital feedback system.

Stripline Kicker Impedance Matching

The stripline kicker has 4 electrodes connected to electrical feedthrough at both ends. The electrodes are 300 mm long that corresponds to λ/2 of RF frequency (500 MHz). To maximize the transmission power, we must adapt the electrode impedance with the external transmission impedance lines (amplifier and cables are 50 ohm).

The formula to calculate the characteristic impedance Z for the different modes is the following [3, 4]:

$$Z = \frac{V^2}{2*E*c} \qquad (1)$$

where c is the speed of light, V is the electric potential between stripline electrode and vacuum pipe, and E is the electric field. We use the Poisson electromagnetics 2D software [5] (fig. 3) to calculate the electric field for different dipole, quadrupole and sum mode (table 2).

Table 2: The Potential Applied to each Electrode to Calculate Electric Field

Field mode	E1	E2	E3	E4
Sum	+V	+V	+V	+V
V Dipole	+V	-V	-V	+V
H Dipole	+V	+V	-V	-V
Quadrupole	+V	-V	+V	-V

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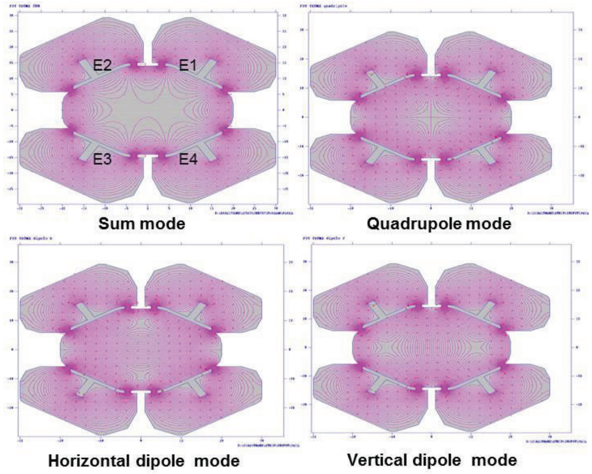

Figure 3: Electric field result in the stripline kicker.

The Impedance of different modes are in (table 3).

Table 3: Characteristic Impedance of Different Modes

	Sum	V Dipole	H Dipole	Quadru-pole
Z	54,86Ω	50,07Ω	48,86Ω	47,39Ω

The impedance Zch is calculate with following formula

$$Zch=\sqrt{Zsum * Zquadrupole}=\sqrt{ZVdipole * ZHdipole} \quad (2)$$

Stripline shape has been optimized to have Zch is equal to 51Ω in one case (sum and quadrupole) and 49.5 in the other (dipole).

Shunt Impedance

The shunt impedance Z_{sh} is given by the following formula [6]

$$Z_{sh}= 2 * Z_{ch}\left(\frac{g\perp * c}{2\pi f * R}\right)^2 sin^2\left(\frac{2\pi f * L}{c}\right) \quad (3)$$

where Zch is the characteristic impedance, L the stripline length, R is the inner radius c is the speed of light and f frequency. With 2D electrostatic model we determine the transverse geometry factor

$$g\perp = |E_{(x=0;y=0)}| * R \quad (4)$$

where E is the electric field obtained applying unit potential on two diagonal electrodes and R is inner electrodes radius. The transverse geometry factor is about 0.65 for ThomX stripline.

The shunt impedance Zsh is representative of the stripline efficiency. Higher is the shunt impedance, the better the efficiency of the kicker. At 250MHz, the shunt impedance is 6.8kΩ (fig. 4).

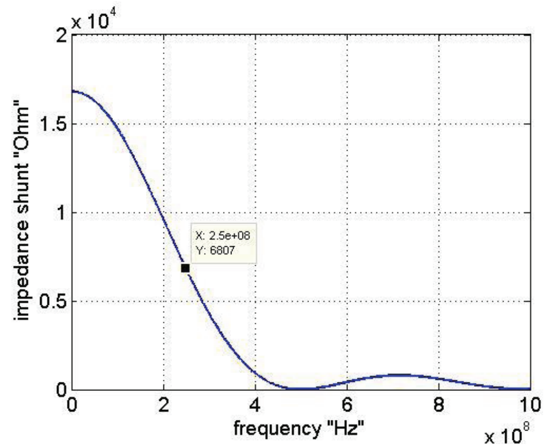

Figure 4: Stripline shunt impedance versus frequency.

3D model Design and Simulation

Starting from Poisson 2D model, the 3D model was built (fig. 5) with Ansys HFSS [7].

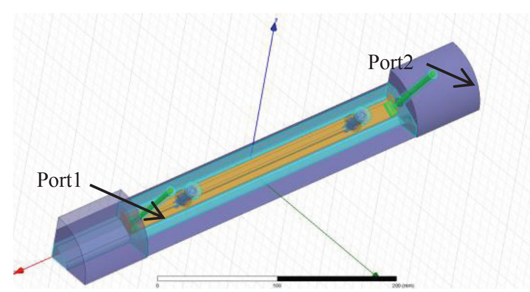

Figure 5: 3D stripline model.

ANSYS HFSS Frequency Domain Solver is used to minimize and calculate scattering parameters. The stripline kicker has a geometrical symmetry. To reduce the memory usage and the computation time, we simulate a quarter of the structure.

The S11 reflection coefficient represents how much power is reflected from the port (fig. 6).

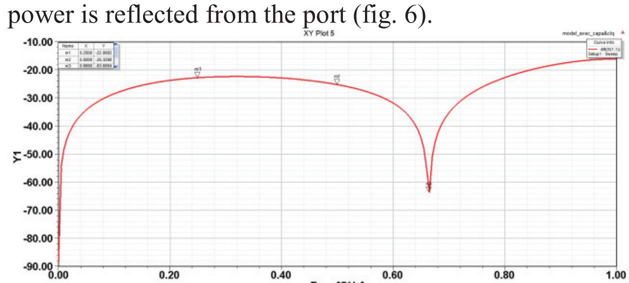

Figure 6: S11 parameter is below -22 dBm on the range of interest DC-250 MHz.

The S21 transmission coefficient represents how much power is transmitted from the Port1 to Port2 (fig. 7)

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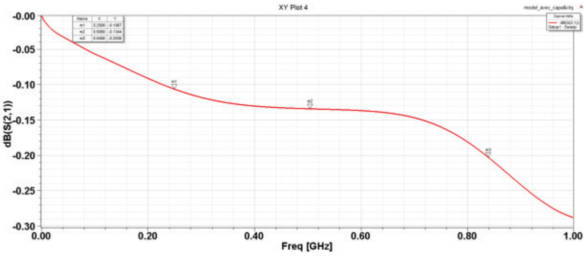

Figure 7: S21 parameter.

The feedback system must have a bandwidth from DC to 250 MHz. We must optimize reflection and transmission parameters on this range. The S11 value should be minimized to avoid power reflection at the input port, to avoid any damage on the amplifier driver. In our case the S11 has a value lower than -20 dB over the entire bandwidth of interest. The simulation takes into account an ideal vacuum feedthrough and coper foil used for electrodes expansion during the baking operation.

Wake Impedance Simulation

To achieve ThomX expected performances and determine the possible sources of beam instability, the simulation of the total machine impedance are being done [8]. The kicker is potentially an important source of impedance mismatch for the storage ring, so we need to estimate its impact and try to find how minimizing it.

Longitudinal impedance has been optimized adding (as it had been done for SOLEIL striplines [9]) 0.5 mm capacitive gaps at each side of the electrodes (fig. 8&9). This capacitive gap, combined with the inductance of the feedthroughs and metal foil, and 50 ohms impedance of electrodes, creates a low pass filter. The cutoff frequency of this filter depends on the height of the capacitive section.

Wakefield simulations are performed with the wakefield solver of CST Particle Studio [10].

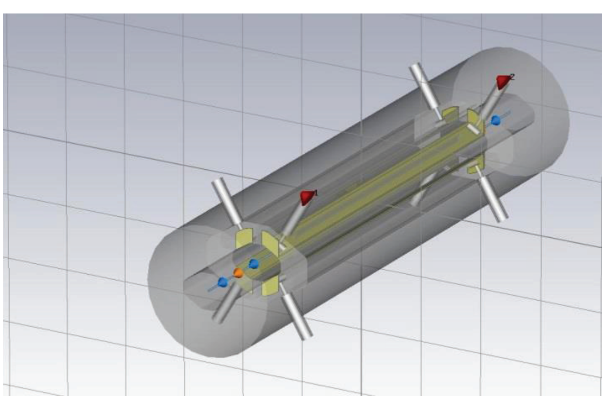

Figure 8: The CST model.

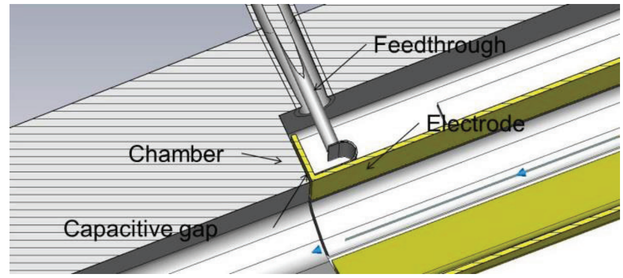

Figure 9: Capacitive gap between electrode and chamber body.

To assess the impact of the capacitive gap, the real part of the longitudinal impedance is extracted. Without this capacity, stripline impedance simulation shows peaks in the 3 to 4 GHz range (fig. 10). Those peaks are attenuated by introducing a capacity gap of 5 mm height, and completely damped with a capacity of 10 mm height. But in this case we observe significant peaks in high frequency 13.5 GHz.

Complementary simulations are being done to select the best capacitive gap according to the beam characteristics.

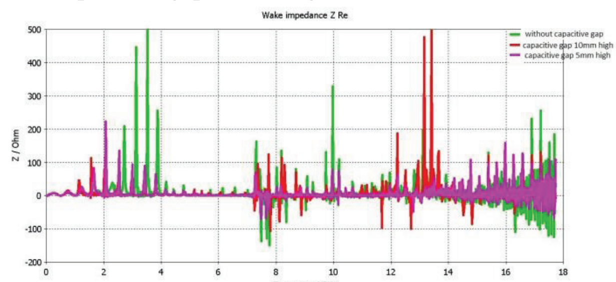

Figure 10: Real part of longitudinal impedance: green without capacity, magenta for a 5 mm height capacity and red for a 10 mm height capacity.

Mechanical Design

Electrodes and stripline body are made of AISI 316 LN stainless steel. The four electrodes are 300 mm long, 1mm thick with one rib in the middle on the external side to avoid any distortion. They are positioned at 30° to the horizontal with respect to the beam axis. Their shape reproduces the ThomX vacuum chamber inside geometry (fig.11) to minimize variation of chamber cross section seen by the beam and thus the stripline impedance.

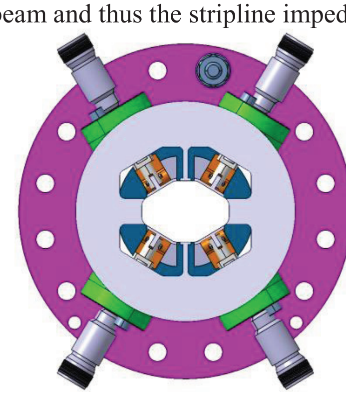

Figure 11: stripline cross-section.

The electrodes are fixed and mechanically aligned through ceramic rods for electric isolation. They are electrically connected to UHV feedthrough at both ends

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through flexible copper sheets to avoid any damage during baking process (fig.12).

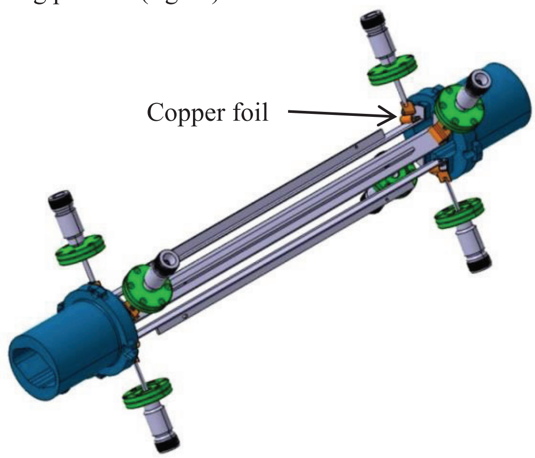

Figure 12: Electrical connections at both ends of the electrodes are made through a flexible copper sheet to avoid damage during baking process.

Feedthroughs are mounted on flanges, and all parts are screwed together, so that the stripline can be fully dismounted for future needs (fig.13).

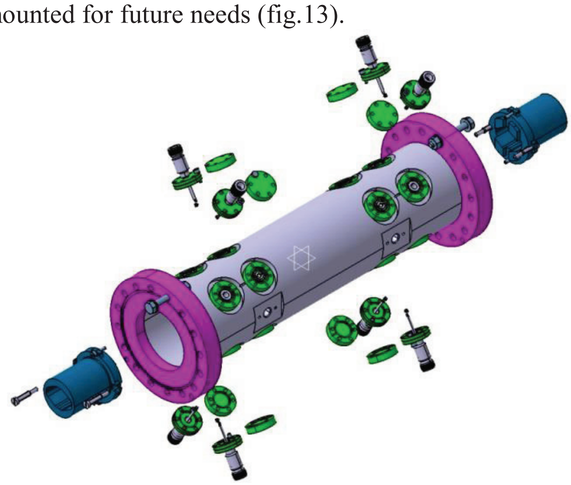

Figure 13: General view of the stripline.

CONCLUSION

The stripline design is in its final phase. Production should start in the next months, so that the stripline will be ready for ThomX installation in spring 2017. Before installation, electromagnetic measurements on a wire test bench [8] will be performed to compare theoretical and experimental results.

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