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).

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

<table>
<thead>
<tr>
<th>source</th>
<th>Growing time</th>
<th>Kicker strength Δx'</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam pipe Geometries</td>
<td>160 μs</td>
<td>&gt; 10 nrad</td>
</tr>
<tr>
<td>Resistive Wall</td>
<td>600 μs</td>
<td>&gt; 2 nrad</td>
</tr>
<tr>
<td>Ions</td>
<td>&lt; 100 μs</td>
<td>&gt; 20 nrad</td>
</tr>
<tr>
<td>Injection Jitter</td>
<td>5 μs</td>
<td>2 μrad</td>
</tr>
</tbody>
</table>

ThomX Transverse Feedback

To cope with these instabilities, it was decided to use a digital transverse feedback system, composed of a wide-band 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.

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]:

\[ Z = \frac{V^2}{2E c} \]  

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

<table>
<thead>
<tr>
<th>Field mode</th>
<th>E1</th>
<th>E2</th>
<th>E3</th>
<th>E4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sum</td>
<td>+V</td>
<td>+V</td>
<td>+V</td>
<td>+V</td>
</tr>
<tr>
<td>V Dipole</td>
<td>+V</td>
<td>-V</td>
<td>-V</td>
<td>+V</td>
</tr>
<tr>
<td>H Dipole</td>
<td>+V</td>
<td>+V</td>
<td>-V</td>
<td>-V</td>
</tr>
<tr>
<td>Quadrupole</td>
<td>+V</td>
<td>-V</td>
<td>+V</td>
<td>-V</td>
</tr>
</tbody>
</table>
The Impedance of different modes are in (table 3).

Table 3: Characteristic Impedance of Different Modes

<table>
<thead>
<tr>
<th>Mode</th>
<th>Impedance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sum</td>
<td>54.86Ω</td>
</tr>
<tr>
<td>V Dipole</td>
<td>50.07Ω</td>
</tr>
<tr>
<td>H Dipole</td>
<td>48.86Ω</td>
</tr>
<tr>
<td>Quadrupole</td>
<td>47.39Ω</td>
</tr>
</tbody>
</table>

The impedance $Z_{ch}$ is calculate with following formula:

$$Z_{ch} = \sqrt{Z_{sum} \cdot Z_{quadrupole}} = \sqrt{Z_{Vdipole} \cdot Z_{Hdipole}}$$  \hspace{1cm} (2)

Stripline shape has been optimized to have $Z_{ch}$ 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]

$$Z_{sh} = 2 \cdot Z_{ch} \left( \frac{g_{\perp} \cdot c}{2 \pi f \cdot R} \right)^2 \sin^2 \left( \frac{2 \pi f \cdot L}{c} \right)$$  \hspace{1cm} (3)

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

$$g_{\perp} = |E_{(x=0,y=0)}| R$$  \hspace{1cm} (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 $Z_{sh}$ 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).

**3D model Design and Simulation**

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

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 4: Stripline shunt impedance versus frequency.](image1)

![Figure 5: 3D stripline model.](image2)

![Figure 6: S11 parameter is below -22 dBm on the range of interest DC-250 MHz.](image3)

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

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

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

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.

REFERENCES