Transverse impedance of crystal goniometer

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- Collaboration with University of Sapienza (Rome)
- Understand and improve the discrepancies between simulations and measurements
- Danilo performed simulations of longitudinal impedance
- With the issues of 11T dipoles, crystals are now the baseline of HL-LHC with ions
- Need a fast approval of the system for Run 3, based on version 2
- Need transverse impedance for ions, and we decided to do it ourselves with high priority
Need to remodel

- The model could not be digested correctly by CST
- Required remodeling to remove many unnecessary details and model issues
Longitudinal impedance
longitudinal impedance (crystal in parking position – 54 mm)

→ Similar impedance spectrum
longitudinal impedance (crystal at 14 mm)

→ Impedance spectrum is quite different
→ Same order of magnitude for frequency range and shunt impedance
longitudinal impedance (crystal at 2 mm)

→ Impedance spectrum is quite different
→ Same order of magnitude for frequency range and shunt impedance
Increasing mesh cells around the beam

\[ \text{Im}(Z/n) \approx 1 \text{ mOhm (i.e. } \approx 1\% \text{ of the total LHC low frequency until 500 MHz)} \text{ for 1 crystal} \]

\[ \rightarrow 1 \text{ crystal per plane per beam} \]

\[ \rightarrow 2\% \text{ of total LHC impedance when all crystals fully inserted} \]
Using the crystal properties measured by Danilo and Mauro

- Measured by cavity perturbation measurements between 2 and 4 GHz
- Significant difference between placing the crystal in one direction or another
Longitudinal imaginary impedance

More losses on the main crystal mode
Longitudinal imaginary impedance

- Frequency shift of 2.5 MHz and reduction of the crystal mode by a factor 2.4
Longitudinal imaginary low frequency impedance

→ No significant change with crystal properties
Longitudinal imaginary low frequency impedance

- Significant contribution of the goniometer to the longitudinal impedance of LHC
- Contribution divided by 5 when crystal in parking position
Transverse impedance
54 mm (parking position): are there transverse modes?

Several transverse modes below 1 GHz (600 MHz, 800 MHz, 940 MHz), but shunt impedance small compared to large constant term.
Transverse modes?

→ All major vertical modes are already longitudinal modes
Transverse impedance (very noisy, requires convergence)

- 2 mm
  - $Z_x = 15 \text{ Ohm/mm} = 15 \text{ kOhm/m}$
  - $Z_y = 13 \text{ Ohm/mm} = 13 \text{ kOhm/m}$

- 14 mm
  - $Z_x = 11 \text{ Ohm/5mm} = 2 \text{ kOhm/m}$
  - $Z_y = 5 \text{ Ohm/5mm} = 1 \text{ kOhm/m}$

- 54 mm
  - $Z_x = 5 \text{ Ohm/5mm} = 1 \text{ kOhm/mm}$
  - $Z_y = 5 \text{ Ohm/5mm} = 1 \text{ kOhm/mm}$

→ These are small contributions
(≤ 0.1% of the transverse impedance assuming standard beta functions)
Results with version 3

→ Reused version 2 and added the crystal holder from version 3
Crystal version 3 at 4 mm
Crystal version 3 @ 4 mm vs crystal version 2 @ 2 mm

Similar longitudinal impedance contributions, need to compare with version 3 at 2 mm (simulations ongoing)

Conclusions similar to version 2 for the transverse impedance
Power loss for v3 at 4 mm (from Francesco Giordano)

• Protons:
  - Fill5979 max power loss: 545.97 W, average power loss: 183.18 W
  - HL2760b max power loss: 2150.43 W, average power loss: 710.47 W
  - 8b4eHL max power loss: 1209.78 W, average power loss: 482.96 W

• Ions
  - HL: max power loss: 1.89 W, average power loss: 1.10 W

To be confirmed for crystals at 2 mm
Imaginary longitudinal impedance

Crystal version 3 @ 4 mm vs crystal version 2 @ 2 mm

- Same order of magnitude for v2 and v3, to be confirmed with ongoing simulations with v3 at 2 mm
- Crystals cost ~1 mOhm per device
Horizontal driving impedance (4 mm from crystal with displacement of 2 mm)

- No identified major transverse mode
- At low frequency $\text{Im}(Z_x) \sim 11 \text{ kOhm/m}$
Vertical driving impedance (4 mm from crystal with displacement of 2 mm)

→ No identified major transverse mode
→ At low frequency
\[ \text{Im}(Z_y) \approx 14 \text{ kOhm/m} \]
Outlook

• Longitudinal impedance contribution is significant compared to LHC impedance model (1 mOhm/goniometer)

• Transverse contribution appears less significant for beta functions of IR7, to be confirmed with more simulations

• Could we get an assessment of the crystal parameters closer to the frequency range of interest?
Silicon lossy (CST default model)

Silicon fit from measured data