MKP-L impedance mitigation and expectations for MKP-S in the CERN-SPS

HB 2023

C. Zannini, M. Barnes, M. Beck, M. Diaz, L. Ducimetière, G. Rumolo, D. Standen, P. Trubacova (CERN, Geneva, Switzerland)

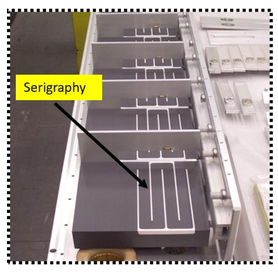
Abstract

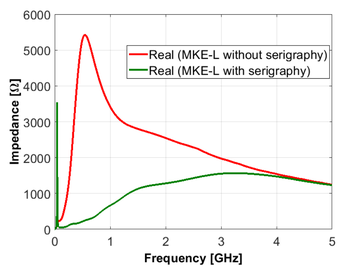
Beam coupling impedance mitigation is key in preventing **intensity limitations** due to beam stability issues, heating and sparking. In this framework, a very good example is the optimization of the SPS kickers beam-coupling impedance for **beam-induced heating mitigation**. After the optimization of the SPS extraction kickers, the **SPS injection kickers** became the next bottleneck for high intensity operation. This system is composed of three **MKP-S** tanks and one MKP-L tank. To accommodate LIU beam intensities, it was necessary to mitigate the beam induced heating of the **MKP-L**, using a shielding concept briefly reviewed in this paper. Moreover, temperature data from the 2023 run are analyzed to qualify the accuracy of the models and assess the effectiveness of the impedance mitigation. Finally, the expected limitations from the MKP-S, foreseen to become the next bottleneck in terms of beam induced heating, are discussed.

Context

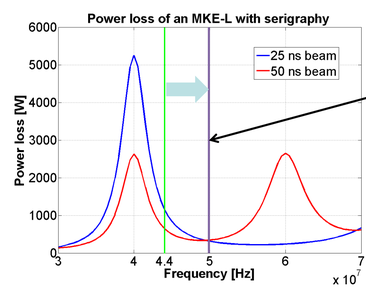
The beam coupling impedance characterizes the interaction between the particle beam and an accelerator device. During the traversal through the accelerator, the particle beam will induce electromagnetic fields which will affect the motion of the beam itself. This mechanism is studied to understand, predict and prevent beam instability behaviour. However, **beam induced EM fields** also **cause heating of the accelerator device** itself. In the case of a ferrite kicker magnet, the **heating resulting from the beam induced power loss could raise the ferrite temperature to its Curie temperature, with risk of device damage or malfunction.**

The original design of the SPS extraction kickers (MKEs) had to be modified





It is preferable to address potential beam induced heating issues in the design phase. However, due to the more relaxed performance constraints, decades ago, beam coupling impedance effects were not systematically taken into consideration when designing new accelerator components.

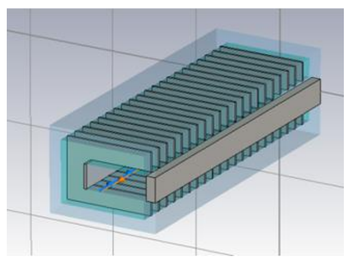


40% more margin on bunch intensity

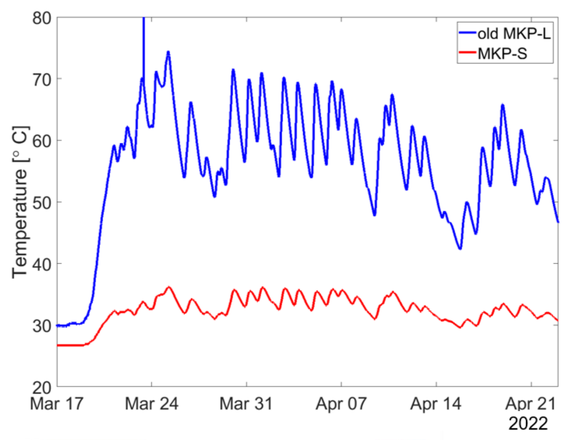
Essential to accommodate HL-LHC intensities

MKP-L beam induced heating mitigation

The MKP kicker modules have C-shaped ferrite cores sandwiched between high voltage (HV) plates. Plates connected to ground are interleaved between the HV plates: the HV and ground plates form a capacitor to ground. One C-core, together with its HV and ground capacitance plates, is named a cell. The kicker module is divided into 22 cells, each 31 mm long.



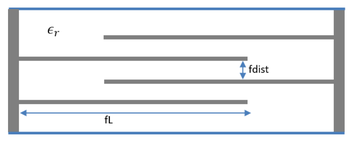
The SPS injection kicker system is composed of four tanks (three MKP-S and one MKP-L tank). **The MKP-L**, due to the wider aperture, **has a higher impedance** than the MKP-S **at lower frequency**. **This causes a stronger interaction with the beam spectrum and hence higher beam induced heating.**



After the optimization of the SPS extraction kickers, **the MKP-L became the bottleneck for CERN-SPS beam induced heating**

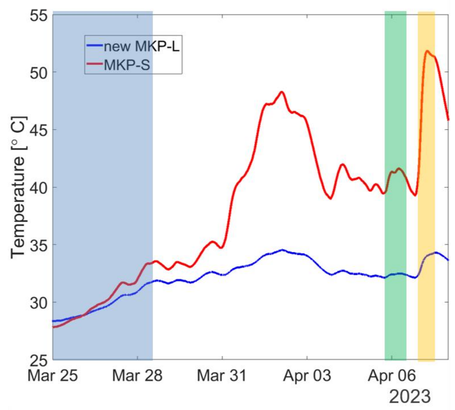
$$\Delta W = (f_0 e N_{beam})^2 \sum_{p=-\infty}^{p=\infty} \left[\left| \overline{\Lambda}(p\omega_0) \right|^2 \mathrm{Re}\left[Z_{\parallel}(p\omega_0) \right] \right]$$

Based on the SPS extraction kicker experience, a design with silver fingers was developed. Due to the shorter length of the MKP-L ferrite cells, 31~mm in comparison with 235 mm, applying the fingers directly on an MKP-L ferrite, as done for the MKEs, was not a viable solution.



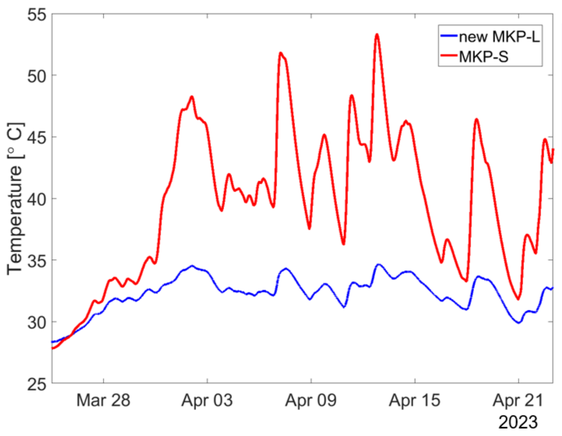
Ceramic chamber with serigraphy

Significant reduction of the broadband impedance: however, **resonances** are introduced **in the low frequency range**. **Design optimized**, **with the HV constraints** in mind, **to place impedance resonance as far as possible from high amplitude spectrum lines** comparing measurements and simulations

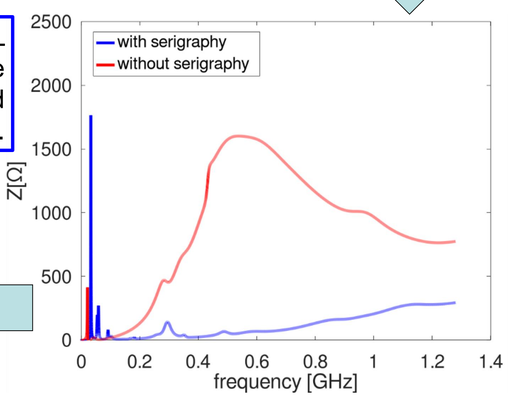


Beam type	$(\frac{\Delta W_{MKP-S}}{\Delta W_{MKP-L}})_{sim}$	$(\frac{\Delta T_{MKP-S}}{\Delta T_{MKP-L}})_{meas}$
flat bottom scrubbing	1.5	1.6
long flat top scrubbing	5.5	6.9
8b4e long flat top	5.2	6.3

In agreement with the expectations, the heating ratio between MKP-S and MKP-L significantly increases during flat top scrubbing due to the reduction of the bunch length.



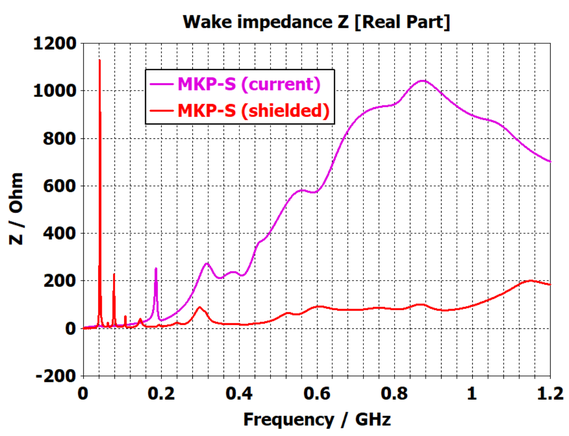
The low impedance MKP-L has been installed in the SPS during the Year-End Technical Stop 2022--2023.



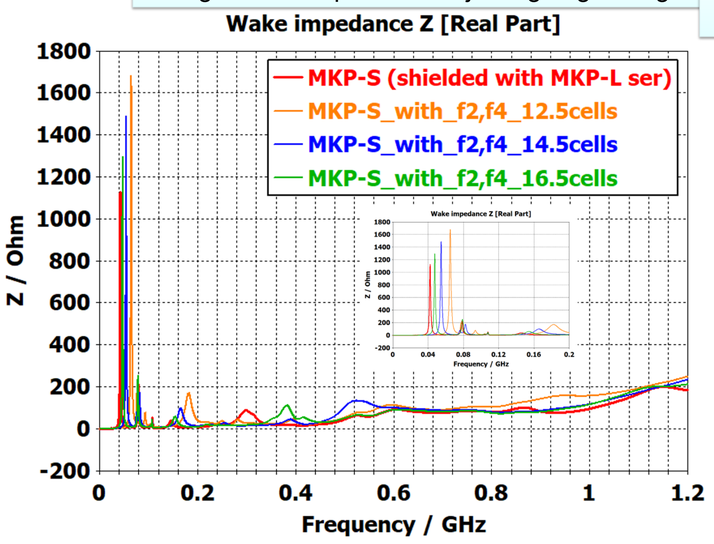
Expectations for the MKP-S

With the MKP-L now exhibiting significantly lower heating, the MKP-S kicker emerges as the device pacing the scrubbing and maybe operation in terms of beam-induced heating within the SPS kickers.

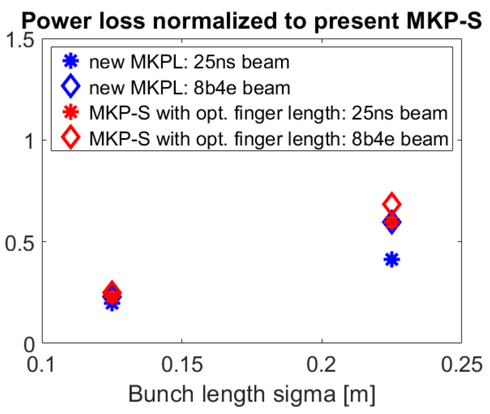
MKP-L shielding concept on the MKP-S



Design can be optimized adjusting finger length



In contrast to the MKP-L case, this **optimization requires shortening the serigraphy**, which is not expected to be detrimental to the high-voltage requirements.



Due to the relatively small horizontal aperture of the MKP-S, the **beam-induced power loss** strongly depends on the beam's position and **diminishes when the beam is moved towards the ground conductor**.

If compatible with aperture requirements, this would represent a relatively straightforward solution for reducing power loss.

Preliminary data suggests that introducing a beam **offset of 10 mm** can result in a substantial **30% reduction in MKP-S power loss**

Summary

The SPS ferrite kickers are the main limitation in terms of beam induced heating. **After the optimization of the extraction kickers, the bottleneck was represented by the injection kickers.** Due to the aperture dimensions, the **MKP-L** has more beam induced heating than the MKP-S. **To accommodate HL-LHC beam intensities, it was necessary to mitigate the beam induced heating** of this kicker. **In good agreement with the expectations, the 2023 temperature data of the new MKP-L confirm the effectiveness of the mitigation solution.** Simulations suggest that the **MKP-L shielding** concept will be effective also **for the MKP-S**. Alternatively, one could introduce a **horizontal beam offset** of at least 10 mm towards the ground conductor. Both solutions would need to be compatible with aperture requirements and would facilitate scrubbing runs and operation in the coming years. Water cooling of the MKP-S side plates is also being considered.