Beam Coupling Impedance of the New Beam Screen of the LHC Injection Kicker Magnets

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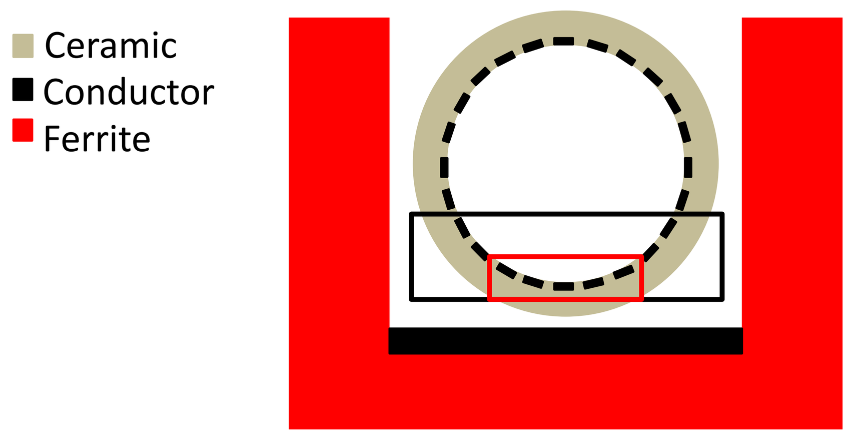
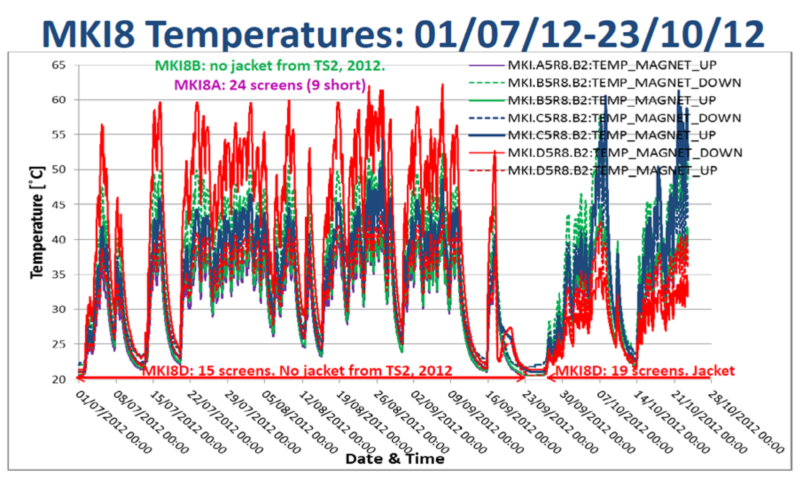
Summary

The LHC injection kicker magnets experienced significant beam induced heating of the ferrite yoke, with high beam currents circulating for many hours, during operation of the LHC in 2011 and 2012. The causes of this beam coupling impedance were studied in depth and an improved beam screen implemented to reduce the impedance. Results of measurements and simulations of the new beam screen design are presented in this paper: these are used to predict power loss for operation after long shutdown 1 and for proposed HL-LHC operational parameters.

Background

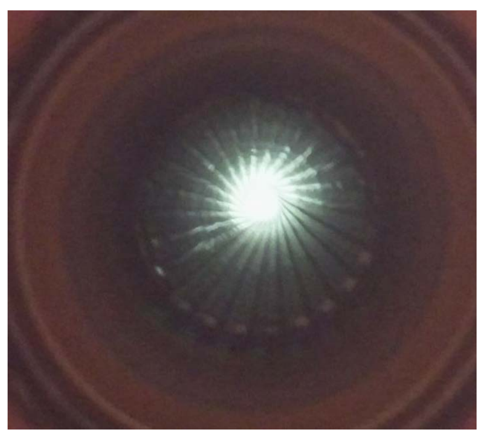
The LHC Injection Kicker Magnets (MKIs) saw high temperatures during the 2012 run of the LHC due to high current beams driving strong longitudinal wakefields in the device. The MKIs contain a beam screen, inserted into the ferrite aperture, consisting of a ceramic cylinder supporting metal wires running the length of the kicker magnet to give a good conducting path for the beam image currents





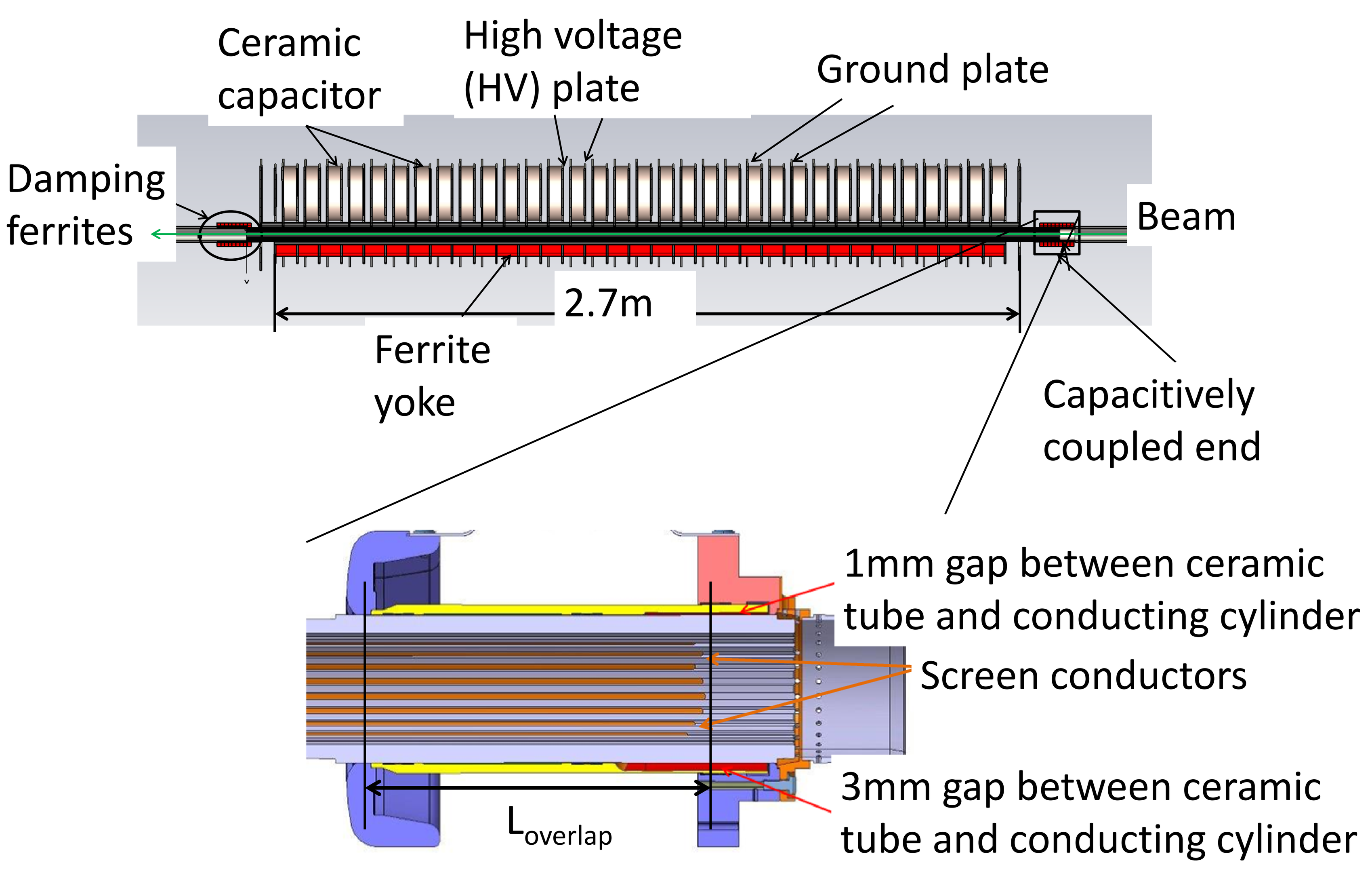
Cross-section of beam screen and ferrite yoke, showing the screen conductors on the internal face of the ceramic tube. Due to poor high voltage performance 9 conductors (in the black box) were originally removed to prevent electrical breakdown during pulsing.

One MKI in particular showed higher temperatures than the others – MKI8D (the solid red line above). This was replaced in September 2012 during, technical stop 3 (TS3), with a beam screen with 19 conductors (in the red box above-left), which was predicted to have a much lower power loss due to improved screening of the ferrite yoke from the beam. This magnet had the lowest temperature after TS3.



MKI8D was found to have a 90° twist in its ceramic screen. This cause a significant portion of it's ferrite yoke to be directly exposed to the beam, resulting a very high beam coupling impedance

Beam Screen



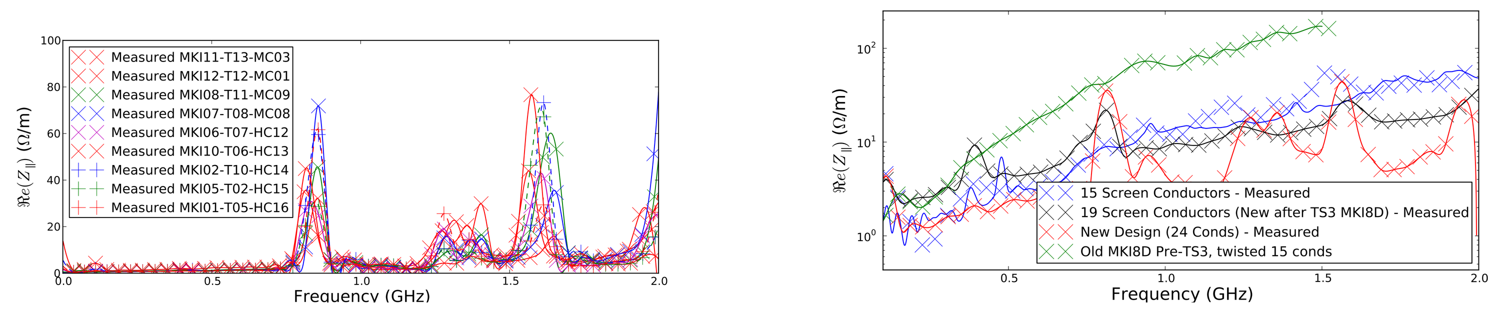
- The new screen design [1], being installed in the MKIs during long shutdown 1 (LS1), has been designed to permit the inclusion of 24 screen conductors in the ceramic tube, whilst lowering the surface electric field on the ceramic tube during kicker pulsing to reduce the change of surface flashover.
- The capacitively coupled end is significantly changed:
  - The external metallization is replaced by an external metal tube which steps away from the ceramic tube near the ends of the screen conductors. This reduces the surface electric field on the ceramic tube significantly. Tapering the length of the conductors also helps this reduction.
  - This allows 24 screen conductors to be placed back in the beam screen, greatly improving the screening of the ferrite yoke from the beam.

References

1. M.J. Barnes *et al.*, *Upgrade of the LHC Injection Kicker Magnets*, IPAC2013, MOPWA030
2. M.J. Barnes *et al.*, *Cooling of the LHC Injection Kicker Magnet Ferrite Yoke: Measurements and Future Proposals*, MOPME075, These proceedings
3. Hugo Day, PhD Thesis, June 2013

Impedance Measurements of New Design

- The beam coupling impedance for all MKIs with the new beam screen design is measured before bake out and HV conditioning to ensure consistency between magnets and to foresee any possible problems with regards to heating.
- Measurements are typically done using the coaxial resonant method due to it's sensivity to low impedances.



(a) (b)

Impedance measurements of (a) all MKIs with the new design using the resonant coaxial wire method and (b) MKIs with 15, 19 and 24 screen conductors, and the MKI8D pre TS3 (experienced high temperatures)

Beam parameters for power loss calculations

Running Mode	N_b 10^{11}	$n_{bunches}$	bunch length (ns)	Bunch separation (ns)
Pre-LS1	1.6	1380	1.2	50
Post-LS1	1.15	2808	1.0	25
HL-LHC 25ns	2.2	1380	1.0	25
HL-LHC 50ns	3.5	2808	1.0	50

The power loss expected in the MKIs for the magnets measured so far. All power losses are given in W/m.

Screen Design	Pre-LS1	Post-LS1	HL-LHC 50ns	HL-LHC 25ns
New Design (24 conductors)	20-35	34-52	151-240	125-191
15 screen conductors	68	117	538	432
Old MKI8D (twisted, 15 conds)	168	N/A	N/A	N/A
19 screen conductors	52	76	N/A	N/A

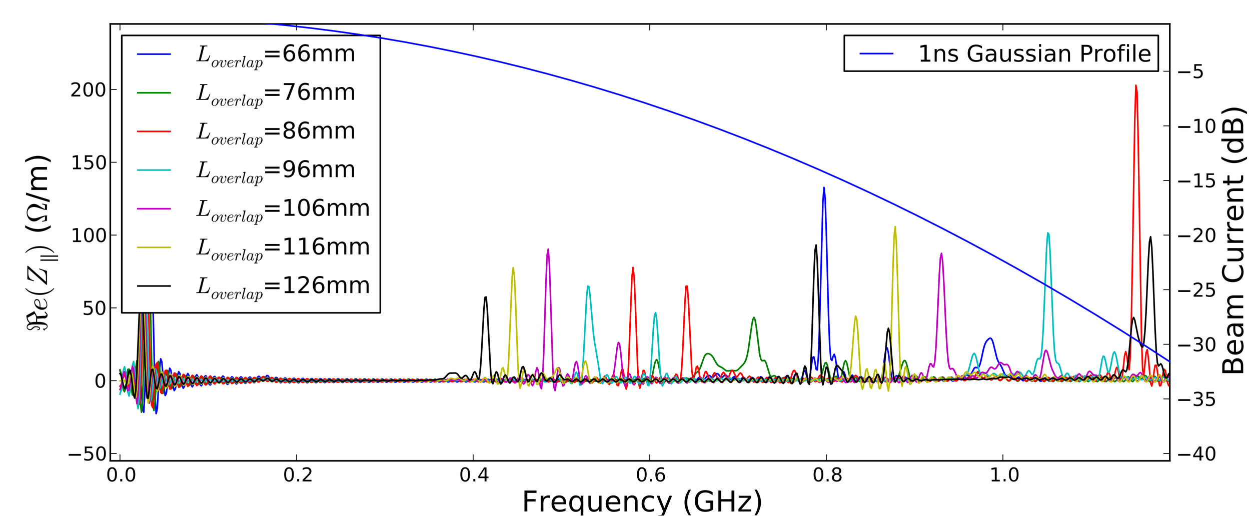
- The new design with 24 conductors gives a decrease of some 20-50% for post-LS1 parameters compared to the magnets with 15 screen conductors pre-LS1 - a great success! It is predicted that beam-induced heating should no longer be a problem in the MKIs for nominal LHC parameters.

Future Developments

- The table above shows that for the proposed beam parameters for HL-LHC, the power loss calculated for the MKIs will be as high under these parameters as the power loss in the MKI8D pre-TS3.
- Given the high temperatures observed in MKI8D, it is necessary to either reduce the power loss or improve the evacuation of heat from the ferrite yoke.
  - The cooling of the MKIs is dominated by radiative heat transfer to the vacuum tank. However the tank is highly polished giving a low thermal emissivity, particularly of the vacuum tank. Studies into how to improve the heat transfer are underway [2].
- To reduce the power loss either two paths may be considered:
  - A different type of beam screen.
  - Modify the existing design to reduce the interaction with the beam current.
- Previous work [3] has shown that the resonant frequency of the beam impedance is determined by the length of the overlap between the screen conductors and the external metal cylinder, given by

$$\mathbf{f_{res}} = \frac{\mathbf{nc}}{2\sqrt{\epsilon_r}\,(\mathbf{L_{overlap}} + \delta_{\mathbf{fringe}})} \tag{1}$$

  where $\mathbf{n}$ is an integer, $\mathbf{c}$ the speed of light, ϵ_r is the relative permitivitty of the ceramic tube, $\mathbf{L_{overlap}}$ the length of overlap between the screen conductors and the external cylinder and $\delta_{\mathbf{fringe}}$ the influence of the fringe fields on the effective length.
- If the overlap can be shortened the resonant frequency will increase, pushing the resonances into a region where the beam current spectrum is smaller in magnitude. Initial simulations with different lengths of overlap are plotted with profile of a 1ns Gaussian bunch below - They show that the resonant frequency increases as the overlap is decreased - as expected. Further studies are underway to better evaluate this possibility.



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