LHC INJECTION KICKER MAGNETS - AN OVERVIEW OF HEATING AND BEAM SCREEN CHANGES IN LHC-MKI8D

H. Day, M. Barnes, B. Salvant, F. Caspers, E. Metral

October 9, 2012

CONTENTS

WHAT IS A KICKER MAGNET AND WHY DO WE CARE?

- Kickers are normal conducting magnets used to give temporary momentum kicks to the beam
- Injection kickers are specifically used to match the trajectory of particles being injected to the stable beam path (see Fig. 3)

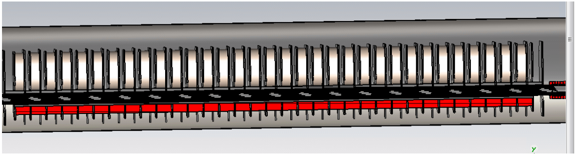
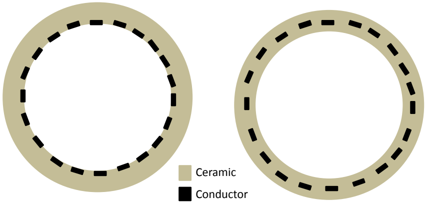


FIGURE 1: A cross section of the LHC-MKI. Red indicates the ferrites yoke, the surrounding structure the transmission line structure of the magnet.

LHC-MKI BEAM SCREEN BEFORE TS3

- All MKIs were installed with the same beam screen (tapered screen conductors, see Fig. 6).
- Originally this was intended to house 24 screen conductors, but due to repeated instances of electrical breakdown during firing of the kicker (due to induced voltage) between the conductors, those experiencing the highest induced field were removed (9 conductors closest to the HV busbar)



Open slots – Screen Conductors in recessed slots in ceramic

Enclosed slots – Screen Conductors 1.2mm below the surface

HEATING OBSERVED IN THE LHC-MKIS

- The LHC-MKIs have been observed to heat substantially during LHC physics fills - This has been traced back to beam-induced heating by the beam interacting with the longitudinal impedance of the LHC-MKIs

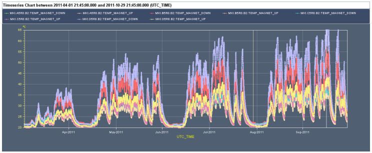


FIGURE 2: Examples of heating of the injection kickers at point 8 during 2011 operation. The highest temperature is MKI8d.

- To solve - Can we improve the shielding of the ferrite in the MKIs by adding more conductors back to the screen?

TAPERING OF SCREEN CONDUCTORS

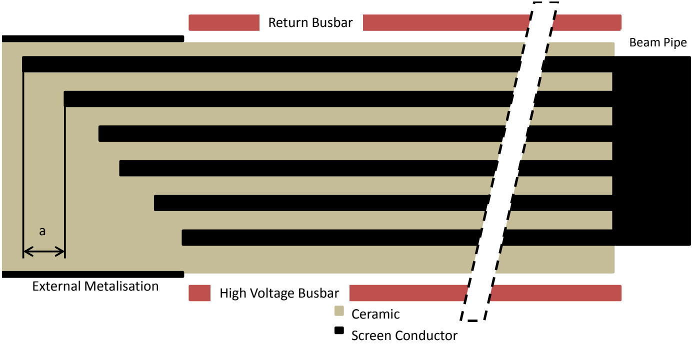


FIGURE 3: The beam screen layout. The screen conductors taper in length from longest near the return conductor to shortest near the high voltage conductor. At one end of the beam screen the screen conductors are electrically connected to the beam pipe, and at the other they are capactively coupled to a layer of metalisation on the external side of the beam screen.

ALTERNATING THE LENGTH OF SCREEN CONDUCTORS

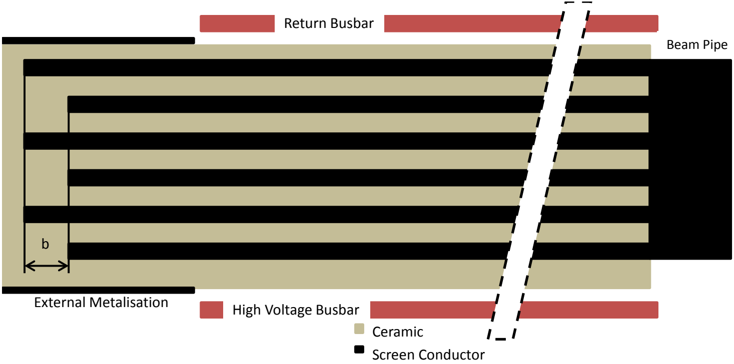


FIGURE 4: The beam screen layout made by alternating the screen conductor lengths between a "long" and a "short" conductor length, seperated by distance b.

SIMULATIONS AND MEASUREMENTS OF IMPEDANCE

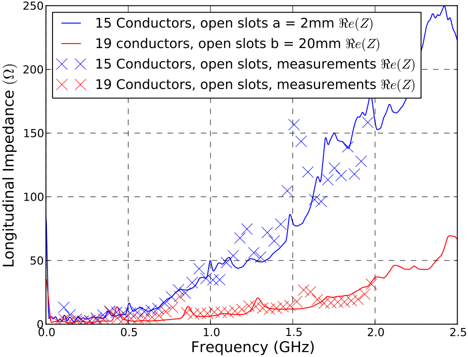


FIGURE 5: The measured and simulated real component of the longitudinal beam impedance of the LHC-MKI with 15 screen conductors (all MKIs prior to TS3) and 19 screen conductors (MKI8d post TS3).

Beam parameters

- 25ns - $N_b = 1.15^{11}$, $n_{bunches} = 2808$. For 1.3e11ppb, scale by 1.3
- 50ns - $N_b = 1.45^{11}$, $n_{bunches} = 1380$. For 1.7e11ppb, scale by 1.4

TABLE 1: Power Loss Estimates* - All values in Watts. Bunch length defined by $4\sigma_z$ value

	25ns		50ns	
	1ns	1.2ns	1ns	1.2ns
24 cond, o slots	51-55	49-52	24-27	21-24
19 cond, o slots, b=10mm	55-71	47-58	36-48	30-38
15 cond, o slots	153-226	119-147	97-153	66-96

* Note: Ranges are given due to considerations of different bunch profiles. Gaussian gives the lowest, cos^2 the highest. Reducing the impedance at low frequencies helps a lot for Gaussian profiles, not for any others.

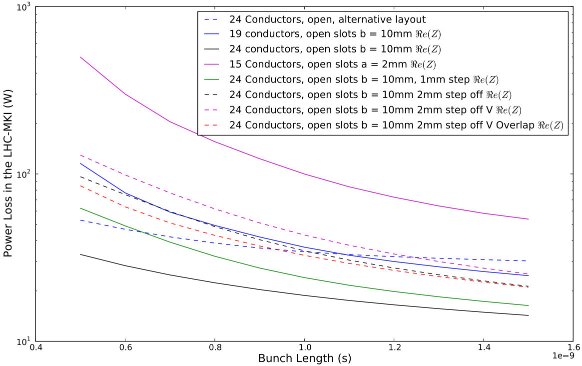
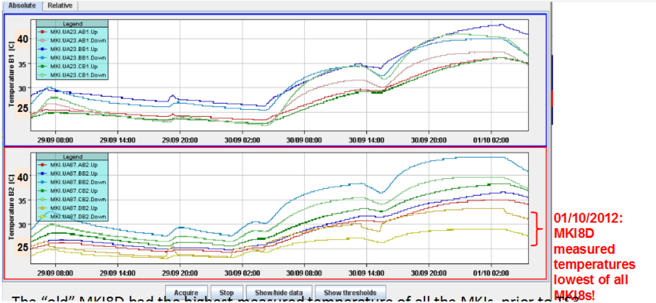


Figure 6: The change in the power loss in the MKI with bunch length for a number of different screen designs. Here we assume a 50ns nominal beam (1.45e11ppb, 1380 bunches) and a $\cos^2$ bunch profile.

Summary



01/10/2012: MKI8D measured temperatures lowest of all MKI8s!

The "old" MKI8D had the highest measured temperature of all the MKIs, prior to TS3

Figure 7: Examples of heating of the injection kickers at point 8 after TS3 operation. The lowest temperature is MKI8d.

Summary Contd.

- The altered shielding appears to be working very effectively!
- The simulation tools that we have are quite capable of simulating very complex structures, in this case before the device has been made (simulations for 19 conductors were made before the measurements)
- Work is ongoing to further improve the shielding for both post-LS1 and beyond (See MKI Strategy Meeting minutes)
- Thanks and any queries, questions, quibles, quests or quails?

More Beam-Induced Heating Resources

- "Beam Induced Heating", B. Salvant, LHC Beam Operation Workshop, Evian, 2011
- "Beam-induced heating/bunch length/RF and lessons for 2012", E. Metral, LHC Performance Workshop, Chamonix, 2012

METHODS OF HEATING ESTIMATES

- We have two ways of estimating heating
  - We can assume a single spectral line falls on each cavity mode

$$P_{loss} = \left(N_b e n_{bunch} f_{rev}\right)^2 R_s 10^{\frac{P(\omega)_{dB}}{10}} \qquad (1)$$

where n_{bunch} the number of bunches, N_b the bunch population, e the electron charge, f_{rev} the revolution frequency,, R_s is the shunt impedance, ω the mode frequency, $P\left(\omega\right)_{dB}$ is the power spectrum. For a gaussian bunch profile

$$10^{-\frac{P(\omega)_{dB}}{10}} = exp\left(-\left(\frac{\omega\sigma_z}{c}\right)^2\right) \qquad (2)$$

σ_z the RMS bunch sigma, c the speed of light

- We can calculate the broadband impedance from all resonances and convolve with a calculated/measured bunch spectrum and sum across a given frequency range

$$P_{loss} = I^2 R = 2\left(N_b e n_{bunch} f_{rev}\right)^2 \left[\sum_{k=1}^{\infty} Z\left(k\omega_0\right) P\left(k\omega_0\right)\right] \qquad (3)$$

  where P_{loss} is the total power lost, n_{bunch} the number of bunches, N_b the bunch population, e the electron charge, f_{rev} the revolution frequency, ω_0 is the angluar frequency interval of spectral data, Z the real longitudinal impedance and P the power spectrum.

- We can also take measured multibunch spectra and simply convolute the spectrum with the impedance (Thanks to Themis and Phillipe for the spectral measurements)