BEAM COUPLING IMPEDANCE OF THE NEW BEAM SCREEN OF THE LHC INJECTION KICKER MAGNETS

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Abstract

The LHC injection kicker magnets (MKIs) experienced strong heating during the first operational run, identified as being caused by power loss due to wakefields induced by stored beam. Studies of the beam coupling impedance of the beam screen, a series of conductors embedded in a ceramic tube placed in the ferrite yoke to screen the ferrite from the beam, resulted in new design offering improved screening: this is predicted to reduce the heating to acceptable levels for operation with 25ns beam during run 2 of the LHC. However higher beam intensities proposed for HL-LHC operation are predicted to again cause strong heating to occur. Further studies have been carried out to reduce the beam induced power loss by optimising the beam screen design, some key results and findings of which are presented here.

INTRODUCTION

The injection kicker magnets (MKIs) are fast pulsed transmission line kicker magnets, which have a ceramic tube inserted into the ferrite yoke: this supports a number of screen conductors, designed to provide a good conducting path for the image currents of the circulating beam. One end of the screen is directly connected to the beam pipe whilst the other is capacitively coupled to the beam pipe in order to preserve the fast field rise time of the magnet. Beam-induced heating due to high stored beam current lead to high temperatures being observed in devices in the LHC, including the MKIs [1]. In the MKI this lead to problems as the temperature of the ferrite yoke rises above it's Curie temperature necessitating 2-3 hours waiting time between fills. Substantial work has been done reduce the power deposited by reducing the beam coupling impedance of the device - a revised beam screen was implemented on all magnets during long shutdown 1 (LS1) which is predicted to reduce the power loss to a degree where excessive heating will not be a problem with nominal LHC beam parameters [cite LHC impedance 2014].

The planned high luminousity upgrade of the LHC (called HL-LHC) will involve a doubling of the beam current in the LHC under current nominal parameters [cite] - this is predicted to lead to again a four fold increase in the power loss to all devices in the LHC unless counter-measures are taken. To this end further improvements to the beam screen have been studied in order to reduce the power loss into the magnet whilst continuing to ensure good high voltage (HV) performance during pulsing and good field quality for operation.

Building on this success a new design has been proposed to satisfy competing needs of low rates of electrical breakdown, during magnet pulsing, and a low beam coupling impedance to reduce the power lost into the structure by wakefields; in addition to meeting strict requirements for magnet operation for field rise time and flat top ripple [3].

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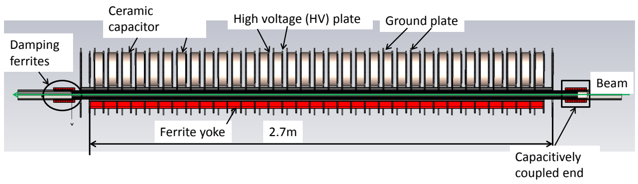

Figure 1: Structure of the injection kicker magnets.

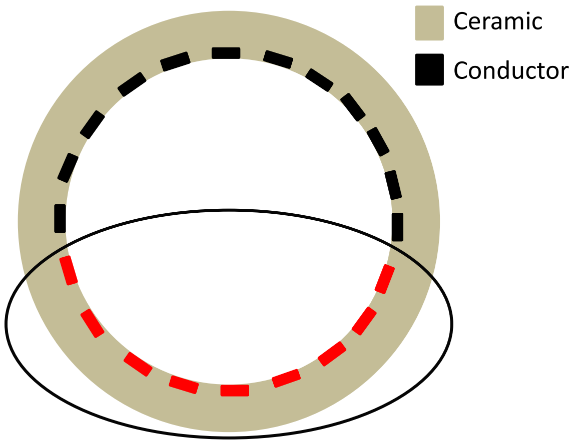

Figure 2: Cross-section of the beam screen of the MKI. Conductors circled in red weren't in place prior to long-shutdown 1

CHANGES TO BEAM SCREEN DESIGN

Past work on the beam screen of the MKI has focused on improving the screening of the ferrite yoke from the beam by increasing the number of screen conductors in the beam screen to the full compliment of 24 - during the first run of the LHC only 15 screen conductors were in place, positioned closest to the return busbar (see Fig. 2), due to issues with surface flashover during magnet pulsing [cite relevant schnitzel].

A revised beam screen was designed that reduced the electric field strength during magnet pulsing sufficiently to allow 24 conductors to be inserted into the screen for post-LS1 [cite MKI upgrade], shown in Fig. 3. This is predicted to see a substantial reduction in the power loss in the MKIs post LS1, by a factor of almost 2 (see Table **??**), even account-

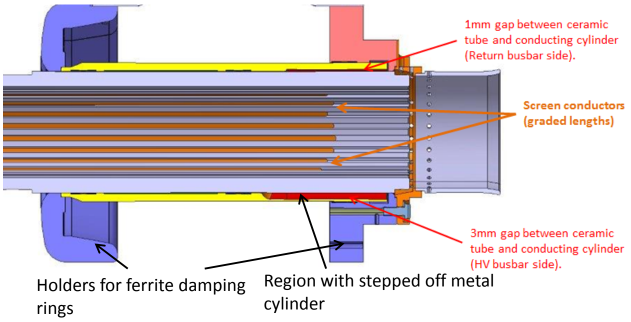

Figure 3: Cross-section of the beam screen of the MKI. Conductors circled in red weren't in place prior to long-shutdown 1

ing for the increased beam current with the change to 25ns bunch separation. However this is not expected to be sufficient for HL-LHC operation, which will see a much higher beam current than nominal LHC operation (see Table 1) and is predicted to see power losses comparable to that which caused a faulty magnet to heat beyond it's point during early operation of the LHC [cite ol' 8D], thus necessitating further modifications.

Previous work had showed [cite relevant] that the beam coupling impedance the MKI with a well shielded ferrite yoke is resonant in nature, with the frequency of the resonances determined by the length of the overlap between the screen conductors on the internal face of the ceramic tube and the metal cylinder on the outside at the capacitively-coupled end of the tube, giving the form

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

where n is an integer, ϵ_r the relative permitivitty of the ceramic tube, $L_{overlap}$ the length of the overlap between the screen conductors and the external cylinder and δ_{fringe} the influence of the fringe fields on the effective length. For the post-LS1 design, $L_{overlap} = 117mm$ If we consider the general formula for power loss;

$$P_{loss} = 2\left(f_0 e M N_b\right)^2 \sum_{n=-\infty}^{\infty} \left|\lambda\left(pM\omega_0\right)\right|^2 \Re e\left[Z_{\parallel}\left(pM\omega_0\right)\right] \tag{2}$$

where f_0 is the revolution frequncy, $\omega_0 = 2\pi f_0$, e is the charge of an electron, N_b is the number of particles per bunch, M is the number of bunches in the machine, $\lambda(\omega)$ is the beam current spectrum, and $\Re e(Z_{\parallel}(\omega))$ is the real component of the longitudinal beam coupling impedance; we can see that we can reduce the power loss by changing the beam profile (in this case limited as the beam profile is determined by the requirements for the physics experiments) or the beam impedance profile may be modified. Due to the approximately gaussian roll off of the beam current spectrum

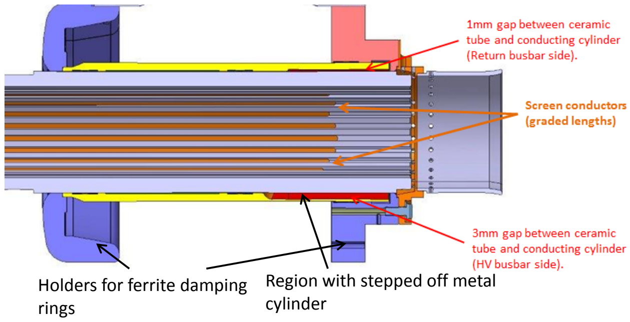

Figure 4: Cross-section of the proposed beam screen for the MKI under HL-LHC conditions.

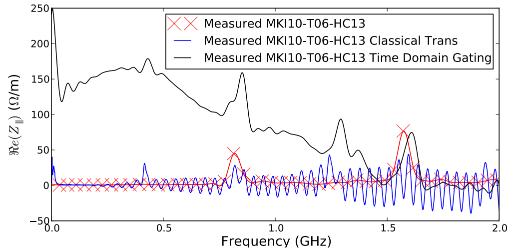

Figure 5: The beam coupling impedance measurements for a magnet using either time domain gating only, or a matched resistor network in comparison to resonant coaxial wire measurements.

at higher frequencies it can be seen that shortening $L_{pverlap}$ would result in the resonant frequency increasing. This approach was thus chosen due to the relative simplicity of the change (no major redesign of the magnet would be foreseen in this case) and the system being well proven for both HV and beam impedance factors.

IMPEDANCE MEASUREMENTS

POWER LOSS

$$P_{loss} = 2\left(f_0 e M N_b\right)^2 \sum_{n=-\infty}^{\infty} \left|\lambda\left(pM\omega_0\right)\right|^2 \Re e\left[Z_{\parallel}\left(pM\omega_0\right)\right] \tag{3}$$

Table 1: Beam Parameters for different LHC operational modes

Mode	τ_{sep} (ns)	N_b (10^{11})	M	t_b (ns)
Pre-LS1	50	1.6	1380	1.2
Post-LS1	25	1.15	2808	1.0
HL-LHC, 50ns	50	3.5	1380	1.0
HL-LHC, 25ns	25	2.2	2808	1.0

Table 2: Power Loss for different beam screen arrangements with different beam parameters (see Tab. 1) in W/m.

Mode	24 screen cond.	15 screen cond.
Pre-LS1	20-35	68
Post-LS1	34-52	117
HL-LHC, 50ns	151-240	538
HL-LHC, 25ns	125-191	432

FUTURE PLANS

SUMMARY

REFERENCES

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[8] `http://www.cst.com`.