Estimation of beam induced heat load in SIS100 kicker magnets

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Introduction

In the operation of synchrotrons with high intensity beams electromagnetic parasitic loss causes heating of components. Especially the recent incidences at the LHC [1] gave rise to investigate this phenomenon for SIS100. The components most susceptible to beam induced heat load in SIS100 are the kicker magnets. Their ferrite yokes are strongly lossy especially at higher frequencies.

Heat Load Computation

The total beam induced heat power can be calculated from the longitudinal coupling impedance (CI) and the beam power spectrum. Since the CI is broadband for those lossy components, the effects of different bunches are uncorrelated and therefore the total power is linear in the number of bunches. Nonetheless, the charge and the number of particles per bunch enters squared:

$$P = \frac{1}{2\pi} q^2 N_{ppb}^2 \omega_0^2 \sum_{k=-\infty}^{\infty} e^{-\sigma_t^2 k^2 \omega_0^2} Re\{\underline{Z}_{\parallel}(k\omega_0)\} \quad (1)$$

Here, $\omega_0/2\pi$ is the revolution frequency and σ_t is the RMS length of a Gaussian bunch. Subsequently, the scenario with the highest heat load in SIS100 is the high intensity (2e13) single proton bunch at top energy with $\sigma_t = 12.5$ns. The power in Eq. 1 is the instantaneous one. For the computation of temperature it has to be averaged over a SIS100 cycle. The crucial quantity in Eq. 1 is the CI. For structures like the kickers it can only be obtained numerically [2] or by bench measurements.

Impedance Computation

The heat load for a SIS100 (to SIS300) transfer kicker magnet has been investigated exemplary, since it might also be operated in a (Nitrogen-) cryogenic environment.

The CI is determined numerically by a code explained in [2]. A 2D approach is used, which means that a slice of the 3D model is taken and end-effects are neglected. Further the beam is assumed to be ultra-relativistic. The ferrite yoke consists of the material Ferroxcube 8C11 [3] which is a soft ferrite with dispersive complex permeability.

As visible in Fig. 1 the longitudinal CI has been investigated for two magnet gap configurations. The resulting power is 7kW for an open gap and 48W if it is filled by a copper sheet. Note that these values are worst case steady state, i.e. they have to be weighted by the SIS100 cycle. If the copper sheets are used, skew cutaways as in SIS18 kickers are not necessary.

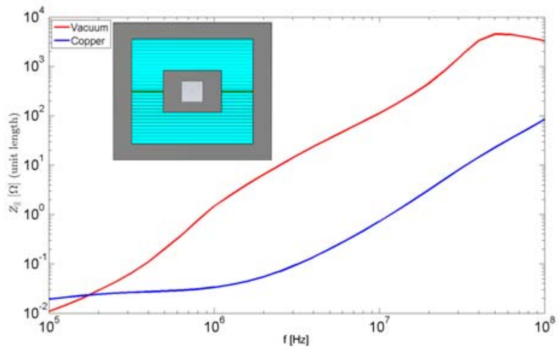

Figure 1: Longitudinal CI of a kicker magnet for vacuum or copper in the gaps (green). Each gap is 2.8mm wide.

Cooling and Temperature Equilibria

The heat conduction of Ferrite is quite good ($\lambda_{\text{Ferrite}} \approx 4\ \text{WK}^{-1}\text{m}^{-1}$) which allows to calculate a temperature of the ferrite independent of the position. Nonetheless, the thermal conduction off the ferrite is very poor since there is a small vacuum layer between the ferrite and its stand. Therefore the thermal interaction of the ferrite with its surrounding is dominated by radiation. From the Stefan-Boltzmann law one finds

$$T^4 = T_{rad}^4 + T_0^4 \approx \begin{cases} T_{rad}^4 & \text{if } T_{rad} \gg T_0 \\ T_0^4 & \text{if } T_{rad} \ll T_0 \end{cases} \quad (2)$$

$$T_{rad} = \sqrt[4]{\frac{P}{\sigma_{SB} C L K_\varepsilon}} \approx 200K \quad \text{for P} = 50\text{W}, \quad (3)$$

where the outer circumference is $C = 0.86$m, $L = 0.8$m and the average emissivity is assumed as $K_\varepsilon \approx 0.8$. Therefore cryogenic kickers are always at radiation temperature and warm kickers stay at room temperature for heat power below roughly 250W. This means that the impednace and heat load values for the improved design (with copper sheets) are acceptable.

References

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[3] Ferroxcube 8C11 Material Specification, 2002

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