IMPEDANCES IN SLOTTED-PIPE KICKER MAGNETS

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Abstract

Storage ring slotted-pipe kicker magnets based on the DELTA design are foreseen for the Metrology Light Source (MLS) of the Physikalisch-Technische Bundesanstalt currently under construction near the BESSY site. Although the slotted pipe maintains the cross-section of the storage ring vacuum chamber, image currents have to bypass the slots generating wakefields. Actually modes with substantial impedances have been revealed by simulations and verified by measurements of a kicker model for the MLS.

INTRODUCTION

Based on the DELTA storage ring kicker design [1] a first kicker model for MLS has been built to support the development of an appropriate high current pulse power supply. Unlike conventional designs, slotted-pipe kickers are fully integrated in the storage ring vacuum beam pipe. They are using the same cross-section with the aim to minimize their contribution to the total ring impedance. By symmetrically slitting the pipe along the beam axis a conductor on each side is formed. This current loop has a low inductivity which allows strong and short current pulses depending on the pulsed power source. Current pulses of opposite polarity are fed through two electrodes to induce the kicker magnetic field. In Fig. 1 a transparent view of the MLS kicker is depicted showing the essential details of the design.

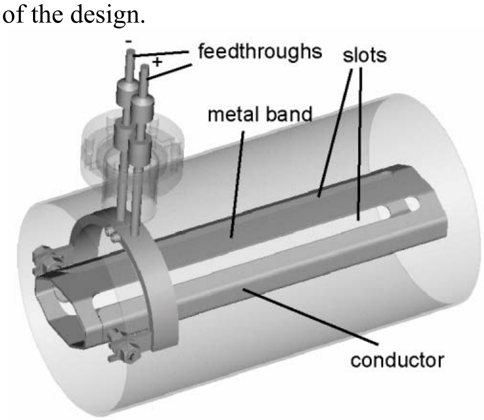

Figure 1: Transparent view of the MLS kicker showing the slotted pipe and electrodes inside the vacuum vessel.

The magnetic field distribution of the kicker is shown in Fig. 2 at a transverse cross-section as numerically computed with Microwave Studio (MWS) [2]. To measure the field homogeneity it has been probed at pulsed currents with an induction coil yielding the integral kicker strength. The measured data are plotted in Fig. 3 at different horizontal offsets together with the MWS simulation results. For the prototype kicker a spare stainless steel vacuum chamber was utilized. Unintentionally it exhibits a rectangular cooling tube welded along one conductor. This actually yields an asymmetry of the kicker field. The exact geometry of the tube was unknown, thus it has been implemented in the MWS model with some imprecision, which explains the somehow larger discrepancies of experimental and simulated fields closer to this tube.

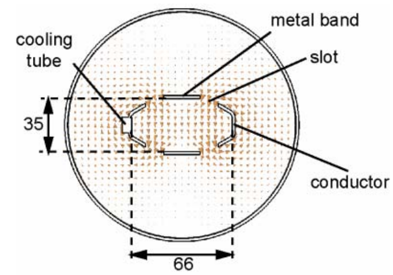

Figure 2: Cross-section of the MLS kicker model with the magnetic kicker field as simulated with MWS.

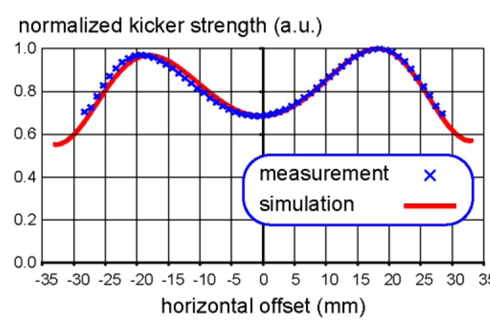

Figure 3: Measured and simulated magnetic kicker strength at different horizontal offsets.

MODE IMPEDANCES

Simulation Results

The slotted kicker exhibits metal bands at the top and bottom of the pipe carrying the dominating part of the image currents which travel with the beam.

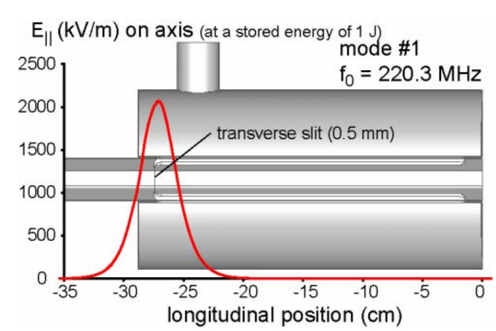

Figure 4: Computed on axis electric field of mode #1.

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Although the cross-section of the vacuum beam chamber is maintained by the kicker pipe, some part of the image current has to bypass the transverse slits. This generates wakefields which are partly composed of trapped modes resonating below the chamber cut-off. By using the 3D eigenmode solver of MWS, modes with remarkably high R/Q-factors -and consequently shunt impedances- have been revealed. Usually the first mode possesses the highest impedance. It is of hybrid nature with monopole and quadrupole field components. Fig. 4 illustrates the computed on axis electric field of this mode. It has been observed that a geometrical asymmetry -e.g. caused by a cooling tube- can strongly displace the mode field pattern. This is more clearly demonstrated in Fig. 5, where the R/Q-values of the first mode are plotted at different horizontal offsets. When omitting the cooling tube the asymmetry vanishes. Computations have also been carried out for the DELTA kicker which exhibits different dimensions, however principally feature the same field characteristics.

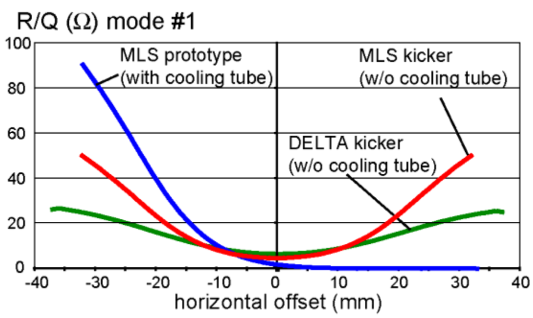

Figure 5: R/Q-factors of the first resonant mode in the MLS and DELTA kicker respectively computed at different horizontal offsets. Asymmetric fields can be induced by implementing a cooling tube.

For each kicker model R/Q-values of up to several ten Ohms have been found depending on the radial offset.

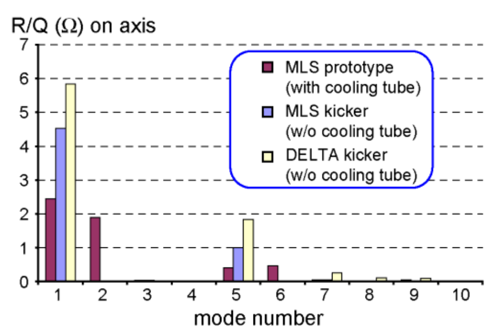

Figure 6: On axis R/Q-values of the first ten modes.

Consequently with quality factors $Q \sim 10^2$-10^3, true for a stainless steel kicker, longitudinal shunt impedances in the kΩ–regime can be induced. Due to the transverse field character, strong transverse impedances have to be taken into account as well. The on axis R/Q–values of the first ten modes are summarized in Fig. 6 revealing that a minor number of modes exist with significant impedances "seen" by the beam even passing the kicker axis. By introducing an asymmetry, e.g. a cooling tube, the on axis impedance of the most parasitic modes can be reduced to some extent as shown for the MLS kicker. However some impedance is taken over by the subsequent mode.

Measurement Results

To verify the simulation results shunt impedance measurements have been performed utilizing the existing MLS kicker prototype. The setup is shown in Fig. 7.

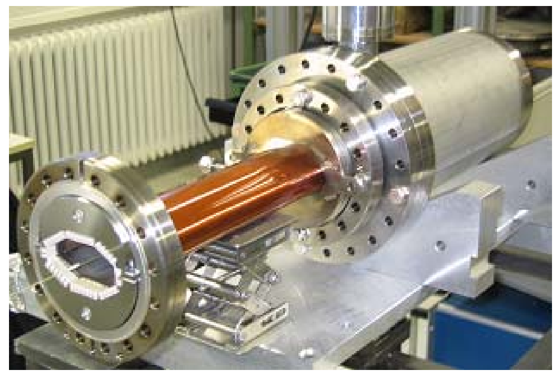

Figure 7: Setup showing the MLS kicker model with an additional vacuum chamber flanged on one side.

Impedances have been measured by applying the "two bead-pull measurement method". Hereby a needle („I") and a disc („II") shaped dielectric perturbation object has been pulled subsequently through the kicker to probe the electric field of the mode of interest. The "needle" (L = 10 mm, Ø = 3 mm) and "disc" (L = 0.75 mm, Ø = 11.3 mm) have been calibrated prior to the measurement in a pillbox resonator to account for the individual shape and permittivity, which are combined in the perturbation constant α. In an arbitrary field both objects more or less sample longitudinal and radial electric field components. Therefore both the longitudinal and transverse perturbation constants $\alpha_{\|}$ and $\alpha_{\perp}$ have been determined for each object exposed either parallel or perpendicular to the electric field of the TM_{010} pillbox mode. The bead-pull measurements have been carried out with a Vector Network Analyzer using two antenna probes to sample the perturbed phase shift $\Delta\varphi$ of the transmitted signal S_{21} at equidistant points z_i spaced by Δz. One then can analytically solve for the longitudinal $|E_{\|}|$ and radial fields $|E_{\perp}|$ at each position, i.e.

$$\frac{|E_{\|}|}{\sqrt{P_l}} = \sqrt{\frac{Q_0}{Q_L \omega_0} \frac{\left(\alpha_{\perp}^{II} \tan\Delta\varphi^{I} - \alpha_{\perp}^{I} \tan\Delta\varphi^{II}\right)}{\left(\alpha_{\|}^{I} \alpha_{\perp}^{II} - \alpha_{\perp}^{I} \alpha_{\|}^{II}\right)}} \tag{1}$$

$$\frac{|E_{\perp}|}{\sqrt{P_l}} = \sqrt{\frac{Q_0}{Q_L \omega_0} \frac{\left(\alpha_{\|}^{I} \tan\Delta\varphi^{II} - \alpha_{\|}^{II} \tan\Delta\varphi^{I}\right)}{\left(\alpha_{\|}^{I} \alpha_{\perp}^{II} - \alpha_{\perp}^{I} \alpha_{\|}^{II}\right)}}, \tag{2}$$

whereby ω_0 is the angular frequency of the measured mode and Q_0 and Q_l the unloaded and loaded quality factor respectively. The fields are normalized by the square root of the ohmic wall power loss P_l yielding material-independent values. Integrating along the kicker of length L finally results in the longitudinal shunt impedance (EU-definition):

$$R = \frac{\left(\Delta z \cdot \sum_{i=0}^{L/\Delta z} \left| E_{||}(z_i) \right| \right)^2}{2 \cdot \overline{P}_l}. \tag{3}$$

As an example Fig. 8 shows the $|E|/\sqrt{P_l}$–curves for the first mode measured along the kicker at a horizontal offset of 24 mm. The mode frequency has been found at f_0 = 213.4 MHz (MWS simulation: f_0 = 220.3 MHz). Both the needle and disc clearly probe longitudinal as well as radial field components (Fig. 9 top). Using just the "needle", the longitudinal shunt impedance would be overestimated. Therefore $|E_{||}|$ has to be resolved by means of eq. 1 to finally determine the impedance more accurately according to eq. 3. As can be seen in Fig. 8 (bottom) the measured field profiles $|E_{||}|/\sqrt{P_l}$ and $|E_{\perp}|/\sqrt{P_l}$ closely resemble the numerical findings although lower field levels have been detected.

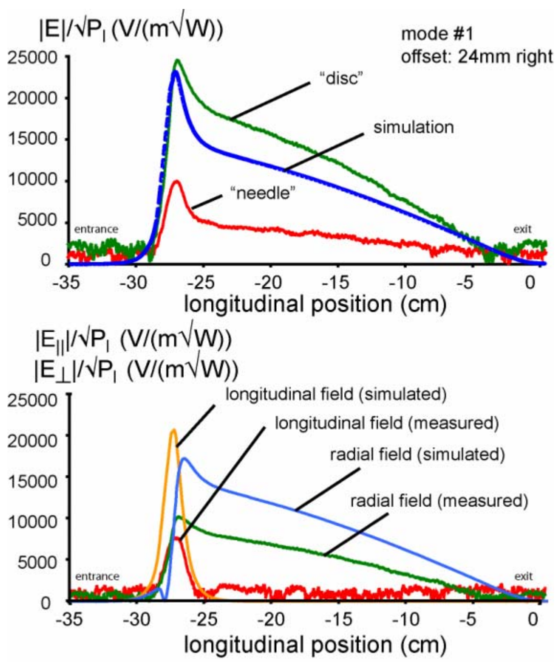

Figure 8: Measured and simulated fields $|E|/\sqrt{P_l}$ of the first mode in the MLS kicker at a horizontal offset of 24 mm towards cooling tube. At the top the absolute field values are shown, whereas the purely longitudinal and radial fields are shown at the bottom.

Eventually Fig. 9 shows the R/Q–values of the first two modes measured at different horizontal offsets. Results have been analyzed applying the "two bead-pull method" and using the data of the "needle" only, which could be placed much closer to the wall than the "disc". However these data include radial field components thus yielding an upper impedance margin only. The measured signals suffered from a strong sensibility on mechanical vibrations. Even at the rather low Q's of the kicker modes, the signal-to-noise ratio was not sufficient to yield accurate results for comparably low R/Q-values which had to be omitted. Nevertheless the principle asymmetric field behaviour has been clearly identified and still remarkably high impedances have been detected off axis albeit some higher values have been numerically computed.

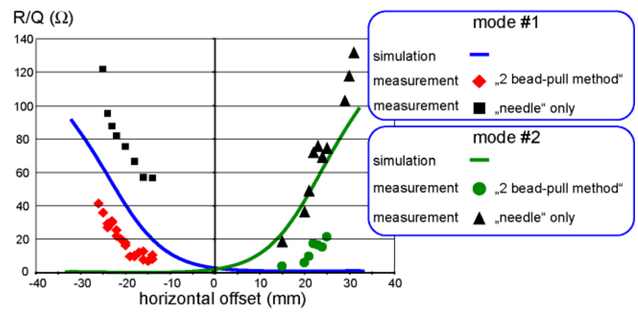

Figure 9: Measured R/Q-values of mode #1 (f_0 = 213.5 MHz) and mode #2 (f_0 = 221.7 MHz) respectively at different horizontal offsets. Simulated results are given for comparison.

CONCLUSION

A slotted pipe kicker for the MLS storage ring has been built based on the DELTA kicker design to develop a suitable high current pulse power supply. Both designs were subject of numerical analyses revealing modes with R/Q-values up to several ten Ohms depending on the radial offset. At Q's of several hundred this yields impedances in the kΩ-level. Impedance measurements have been performed for the MLS kicker verifying the findings. The parasitic modes thus can significantly add to the total ring impedance. To diminish the on axis impedance a geometrical asymmetry e.g. caused by a cooling tube may be introduced. Possible damping of the parasitic modes in situ by using UHV capable absorbing material has not been investigated yet. Albeit slotted-pipe kicker magnets present a higher impedance to the beam than expected, the impedances of conventional kicker magnets might be of the same order. Slotted-pipe kickers thus have been chosen for the MLS due to the straightforward and cost effective design.

REFERENCES

[1] G. Blokesch, M. Negrazius, K. Wille, "A Slotted-Pipe Kicker for High-Current Storage Rings", NIM A 338 (1994) 151-155.

[2] CST Microwave Studio V6, www.cst.de.