CALCULATION OF METALLIZATION RESISTIVITY AND THICKNESS FOR MEDAUSTRON KICKERS

M.J. Barnes (CERN, Geneva), T. Kramer, T. Stadlbauer (EBG MedAustron, Wr. Neustadt)

Abstract

The MedAustron facility, to be built in Wiener Neustadt (Austria), will provide protons and ions for both cancer therapy and research [1]. Different types of kicker magnets will be used in the facility. The kicker magnets are outside machine vacuum: each kicker magnet has a ceramic beam chamber whose inner surface is metalized. The resistivity and thickness of the metallization are chosen such that the induced eddy currents, resulting from the pulsed kicker magnetic field, do not unduly affect the rise/fall times or homogeneity of the magnetic field. A comparison of an analytical calculation and measurement is reported for the effect of metallization of a ceramic chamber in an existing kicker system at CERN. Conclusions concerning the metallization of the ceramic chambers for the MedAustron kicker magnets are presented.

INTRODUCTION

To get reliable results three different approaches have been used to identify the effects of coating thickness and resistivity on the field attenuation and field delay (time constant) of the kicker magnet field inside a vacuum chamber. 2D AC FEM simulations, including the magnet with coil and the metalized vacuum chamber, are compared with measurements and analytic solutions.

All studies presently consider only round chamber geometries. The 2D FEM simulations neglect end fields of the kicker magnet but correctly take into account the magnet geometry, conductors, and field uniformity.

The analytical calculations assume a spatially uniform field over the chamber but neglect the end effects in the kicker magnet [2].

ANALYTIC SOLUTIONS

The analytic calculations are based on the paper [2]:

-for $t \leq t_0$

$$B_i(t) = B_0\left(\frac{1}{\sqrt{1+(\omega\tau)^2}}\sin(\omega t-\varphi)+\frac{\omega\tau}{1+(\omega\tau)^2}e^{-\frac{t}{\tau}}\right)$$

where:

$\tau = \frac{\mu_0 \sigma a d}{2}$ time constant

a = radius of metallization of vacuum chamber

d = coating thickness

φ = phase delay

Field Delay

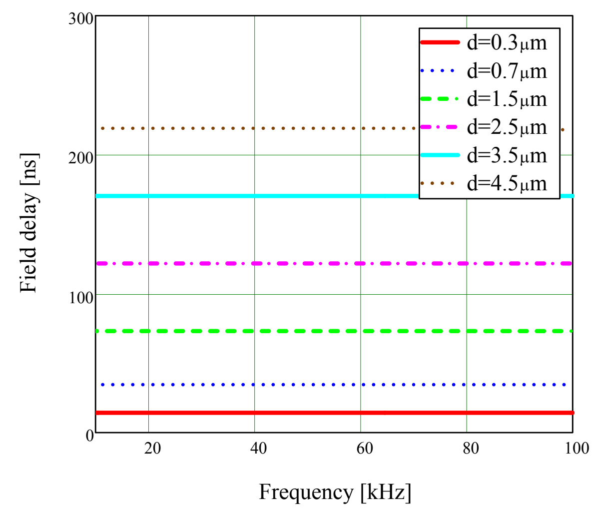

Figure 1: Field delay at peak of field for different titanium coating thicknesses (σ = 2.5E6 S/m, a = 31mm) versus frequency.

Figure 1 shows field delays calculated using the analytical equation: the delay can have an important impact on the kicker rise/fall time. The calculations show negligible field attenuation effects (not visible Fig. 1).

LHC MKD MEASUREMENTS

The impact of a metalized vacuum chamber is studied by means of measurement data from the LHC MKD magnet test stand.

Field Response

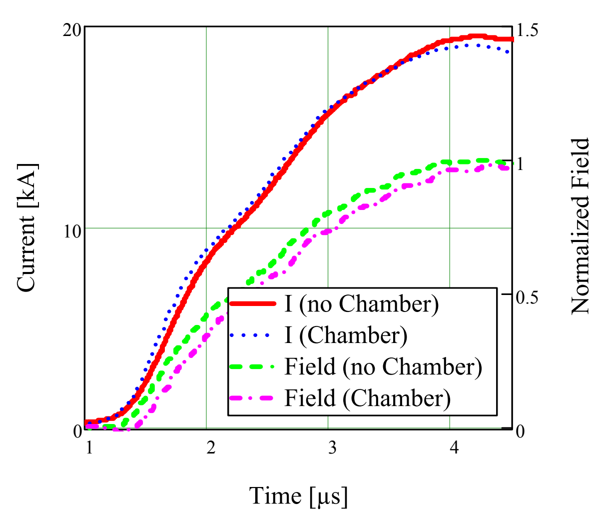

Figure 2: Measured field response of the LHC MKD magnet for 83 kHz sine wave drive current.

Figure 2 shows smoothed curves of the current and the field for a test setup with and without vacuum chamber. The measured field delay, with a coated vacuum chamber, is approximately 200 ns. The specified applied thickness of titanium (Ti) is 4.5 µm. An equivalent coating thickness of 2.34 µm is calculated from the measured DC resistance of the coating, the resistivity of titanium and the tube diameter. Fig. 2 shows that the metallization attenuates the magnetic field to approximately 0.98 of the un-metalized magnitude: the exact value is difficult to ascertain because the peak currents are not the same and also there is a small ripple on the measured field.

2D FEM SIMULATIONS

A magnet similar to the MKD, with a round metalized ceramic vacuum chamber, has been modelled using the Cobham Opera2D FEM software. Sine wave driven steady-state as well as transient simulations have been carried out. The FEM meshing was controlled to stay within an aspect ratio of 10:1, to achieve at least 3 layers inside the coating, and to stay within the maximum number of mesh elements permitted by the software. The effects of different excitation frequencies, coating thicknesses and coating conductivities upon field attenuation and field delay have been studied and are compared with analytic and measured results.

With an un-metalized chamber the predicted inhomogeneity at 90° is ±0.4% within the chamber. Fig. 3 shows that, for the metalized chamber, the corresponding field inhomogeneity is ±7%. Fig. 3 also shows that, due to skin and proximity effects, the current distribution in the vacuum chamber is not uniform.

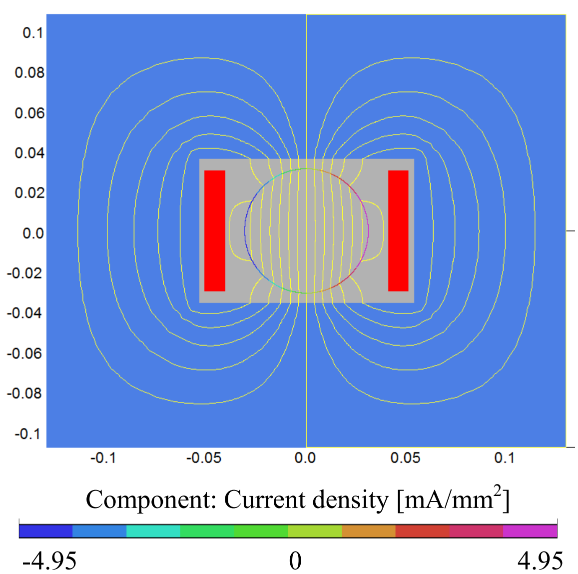

Figure 3: 2D FEM AC simulation model with vector potential lines (yellow) and coloured current density in the chamber coating at 83 kHz, phase of 90° and 4.5 µm titanium coating.

Field Delay and Attenuation, AC Simulation

To determine the impact of the metallization upon the field delay (Fig. 4) and field attenuation (Fig. 5), inside the metalized vacuum chamber, steady-state AC analyses were carried out over a wide frequency range.

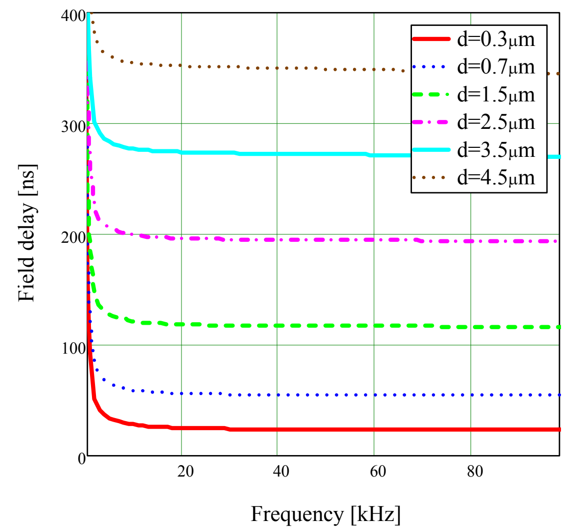

Figure 4: Field delay versus frequency for different titanium coating thicknesses.

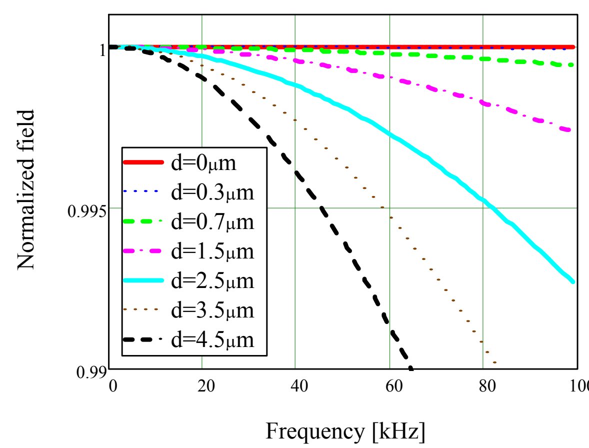

Figure 5: Field attenuation versus frequency for different coating thicknesses.

Figure 4 shows that the field delay initially reduces rapidly as frequency is increased to approximately 5 kHz: above 5 kHz the field delay is relatively constant.

The field attenuation (Fig. 5) is frequency dependent and strongly dependent upon the coating thickness. The effect of the conductivity of the coating has also been simulated: the same field attenuation is obtained by changing the coating thickness or the conductivity of the metallization, provided that the DC resistance (proportional to $1/\sigma d$) of the metallization is unaltered.

Field Response, Transient Simulation

The AC solutions are, by definition, at steady-state whereas a kicker is usually pulsed and therefore the field penetration through the metallization does not necessarily correspond to the steady-state solution [2]. Thus transient simulations have been carried out, with a driving current which corresponds to the single half-period of a 83.3 kHz sine wave. Fig. 6 shows the predicted flux density, at the centre of the ceramic chamber, for various coating thicknesses.

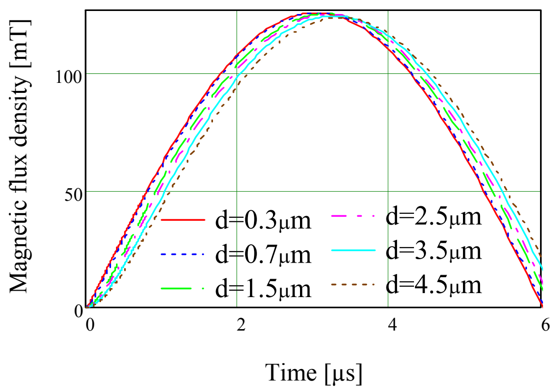

Figure 6: Field response, at the centre of the ceramic chamber, at 83.3 kHz for various coating thicknesses.

COMPARISON OF RESULTS

Field Delay for Analytical, Transient and AC Solutions

One of the most important parameters for field rise and fall time is the field delay and is thus compared in Fig. 7 for the three different solutions. The results of the transient and the steady-state AC simulations are in reasonable agreement: the measured delay, of 200 ns for the LHC MKD (see above), is in good agreement for a coating thickness of 2.34 µm. The analytical solution gives a smaller field delay (time constant) than both the predictions and measurement.

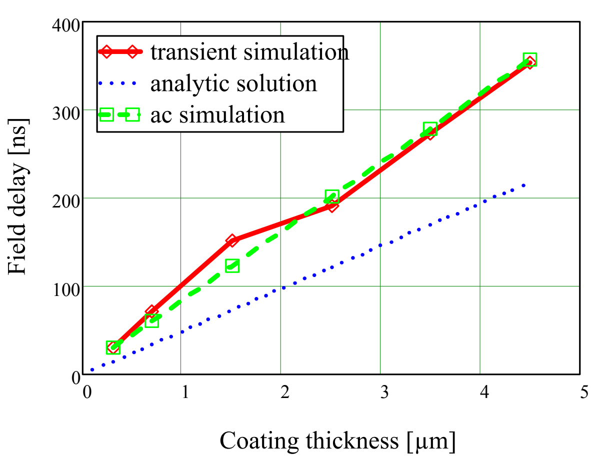

Figure 7: Field delay versus coating thickness, at 83.3 kHz, for analytical solution and both AC and transient simulations.

Field Attenuation for Analytical, Transient and AC Solutions

Figure 8 shows field attenuation for the three different solutions. The field attenuation is in reasonable agreement for the transient and steady-state AC simulations; the analytical solution gives significantly less attenuation. However, the analytical solution depends on the calculated inductance for the vacuum chamber and thus on the time constant [2]. Using the delay calculated from the simulations as the time constant in the analytical solution, the attenuation calculated from the analytical solution is in good agreement with the simulations. Thus further investigation of the time constant is planned to clarify the observed differences. For example, the ferrite yoke surrounding the vacuum chamber and the inhomogeneous field could have an impact on the chamber inductance.

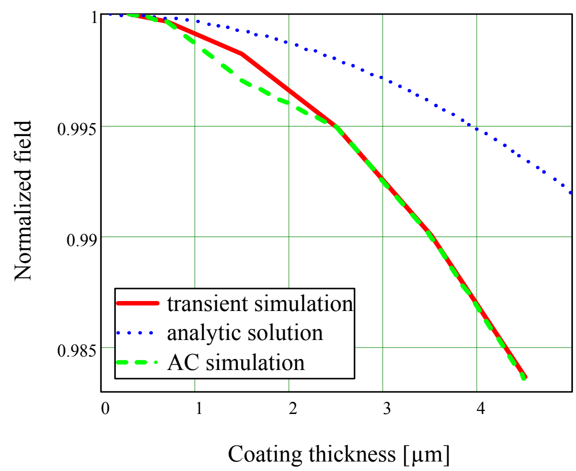

Figure 8: Comparison of field attenuation versus coating thicknesses at 83.3 kHz for analytical solution and both AC and transient simulations.

CONCLUSION

There is a good agreement between the measured field delay value for the LHC MKD system, with a 2.34 µm metalized vacuum chamber at 83.3 kHz, and the simulations (steady state and transient). The measured field attenuation is in the expected range, but predictions are considered more accurate. Differences between the analytical solution and simulations are attributable to the phase delay, which will be investigated further.

When venting the vacuum chamber after the Ti deposit, Ti tends to react with the vent gas, which in return will alter its resistance [3] and thus its time constant. Tests on prototype vacuum chambers are needed to validate the process and the achieved results.

Independently from these deviations it can be concluded that the field attenuation can be neglected for the MedAustron kickers as the power supply driving current can be adapted. On the other hand the field delay has a significant impact. Thus only a very thin coating is recommended (hundreds of nm), with a high resistivity.

REFERENCES

[1] M. Benedikt et al., MedAustron—Project overview and status, Eur. Phys. J. Plus (2011) 126: 69.

[2] S.H. Kim, APS, USA, "Calculation of pulsed kicker magnetic field attenuation inside beam chambers", January 8, 2001.

[3] J. Borburgh, private communication, August 2011.