OPTIMIZATION OF Ti COATING THICKNESS FOR INDUS-2 INJECTION KICKER CERAMIC CHAMBER

Abdurrahim, V. K. Jain, A.D. Ghodke and Gurnam Singh

IOAPDD Raja Ramanna Centre for Advanced Technology, Indore (M.P.), India

Abstract

In a synchrotron, kicker chambers are made with the ceramic in order to avoid the strong eddy currents, which would screen the kicker pulsed magnetic field acting on the beam. These ceramic chambers introduce the discontinuities in the path of beam image current and also develop an accumulation of static charges inside the chambers. To avoid these problems, ceramic chambers are coated with the thin layer of Titanium, thickness of which is a crucial parameter. In this paper, we present an optimization procedure of the coating thickness for Indus-2 injection kicker chamber based on the screening effect due to eddy currents and heating of the chamber due to image current. Optimization results show that 2µm coating thickness of Ti is sufficient to put inside the kicker chamber.

INTRODUCTION

To provide the conducting path to the image current along the ceramic chamber, a thin layer of Ti coating is put on the inner surface of the chamber. Ti metal has been chosen as the coating material[1] for its high melting point, high conductivity, high sputtering efficiency and good adhesion to the ceramic (alumina). The coating minimizes the beam impedance, helps in avoiding the accumulation of static charges on the ceramic but at the same time it also shields the pulsed kicker magnetic field. Therefore, the coating thickness has to be decided by taking the following points in consideration, (a) thin enough, to avoid the distortion in the kicker magnetic field pulse, (b) thick enough, to avoid excessive heating due to stored beam current, (c) thin enough, to avoid excessive heating due to eddy currents, (d) thick enough, to minimize the beam field leakage.

Indus-2 ceramic chamber and injection kicker pulse

The cross section of the ceramic chamber used in Indus-2 ring is racetrack. The chamber is made of the alumina, having a thickness of 8 mm and an aperture of H×V=101×46mm^2. Injection in Indus-2 is carried out with the half sinusoidal injection kicker pulse, which has the pulse duration of ~ 3µsec.

THE THICKNESS OPTIMIZATION

Pulsed kicker magnetic field attenuation

The eddy currents will decay exponentially from the time t1 with a time constant τ, which depends on the geometry of the chamber. Therefore, the kicker field seen by the beam (Bi(t)) can be calculated by subtracting the shielding field due to eddy currents from the actual kicker field (B(t)).

$$Bi(t) = B(t) - \int_0^t \frac{\partial B(t-t1)}{\partial t} \exp(-t1/\tau)\, dt1 \qquad \ldots(1)$$

For simplifying the calculations, the racetrack geometry of the ceramic chamber is assumed to be rectangular. For a kicker field of a half sinusoidal wave with a pulse width of $t_0 = \pi/\omega$, the above equation can be solved[2], which is given as

$$Bi(t) = B_0\left[\frac{1}{\sqrt{1+(\omega\tau)^2}}\sin(\omega t-\phi)+\frac{\omega\tau}{1+(\omega\tau)^2}e^{-t/\tau}\right] \qquad \ldots\ldots\ldots(2)$$

for $t \le t_0$ (half sine width)

$$Bi(t) = B_0\left[\frac{\omega\tau}{1+(\omega\tau)^2}\{1+e^{t_0/\tau}\}e^{-(t-t_0)/\tau}\right] \qquad \ldots\ldots\ldots (3)$$

for $t > t_0$ (half sine width)

where $\tau = \dfrac{2\mu_o\sigma w_f d}{\pi}$ [for the rectangular cross section]

σ: conductivity of the coating material, d: thickness of the coating, w_f: full width of the rectangular chamber.

Using the equations (2) & (3), the kicker field attenuation and the time delay seen by the beam for different coating thicknesses are calculated and shown in figure1. The numerical values of attenuation and time delays for different coating thicknesses are given in the Table-1

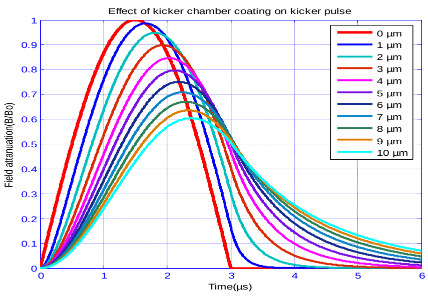

Figure 1: Kicker field attenuation for different coating thicknesses

Table-1: Kicker pulse attenuation and time delay due to different coating thicknesses

Coating Thickness (µm)	Time of the kicker peak field X (µs)	Time delay (shift of the kicker peak field) due to coating (ns) X(i)-X(1)	Kicker peak field attenuation (%)
0	1.5000	0	0.00
1	1.6620	162	1.42
2	1.8120	312	5.22
3	1.9320	432	10.18

Power deposited in the coating due to the stored beam current

If skin depth δ_s at bunch characteristic frequency is higher than the coating thickness then the beam image currents flowing through the coating are nearly uniform and the surface power density due to beam image current for a circular cross section cylinder is given by[3]

$$P_i = I_{total}^2 R_{sq} \frac{1}{n} \frac{1}{(2\pi a)^2} \frac{C_r}{2\sigma_l \sqrt{\pi}}$$

I_{total}: stored beam current, R_{sq} : surface resistance of the coating, n: number of bunches, a: radius of the circular pipe (half vertical gap of racetrack chamber), C_r : storage ring circumference, σ_l : r.m.s bunch length (~0.2 cm at 550MeV with 600kV cavity gap voltage).

For power density distribution around the racetrack perimeter and total power deposited in the coating, following results will be used. (a) According to Yokoya[4] and Piwinski[5], the total power for the racetrack shaped ceramics is equal to the total power of a circular chamber with radius equal to the half vertical gap of the racetrack chamber. (b) For the power density distribution variation along the perimeter, Piwinski's study for flat chamber is used. The calculation shows that in a two plates model, closed to racetrack ceramic chamber, the power density is peaked in middle and is ~2.5 times of the circular chamber[6]. Based on these, the power deposited in the chamber for various thicknesses of the Ti coating is calculated and shown in Table-2.

Table-2: Power deposited in the Indus-2 kicker ceramic chamber due to stored beam

S.No.	Thickness (μm)	Filled buckets / Current	Power density (W/m2)	Power deposited(W)
1.	2	All 291 buckets 300mA/ 400mA	86.1/152.98	4.5/7.9
		131 buckets 300mA/ 400mA	191.2/339.8	9.9/17.6
2.	1	All 291 buckets 300mA/ 400mA	172.10/ 305.96	8.9/15.8
		131 buckets 300mA/ 400mA	382/679.7	19.8/35.2
3.	0.5	All 291 buckets 300mA/ 400mA	344.21/611.9	17.8/31.7
		131 buckets 300mA/ 400mA	764.6/1359	39.6/70.3

Power deposited in the coating due to eddy current

The eddy current heating will also raise the temperature of the chamber. For a simplified rectangular chamber model, the power deposited by a sinusoidal field is estimated by the formula[3].

$$P_{eddy} = dL\sigma \frac{w^3}{3}\left(B_0^2 \frac{\pi^2}{2\Theta}\right)F_r$$

Where d: thickness of the coating, L: length of the coated ceramic, σ: conductivity of the coated material, w: half internal width of the ceramic, B_0: peak field of the kicker, θ: half sine pulse width, F_r: repetition rate of the kickers.

In Indus-2 kicker ceramic chamber, the power deposited due to eddy current is 0.12W for the Ti coating thickness of 1μm and 0.25W for the Ti thickness of 2μm.

Temperature distribution simulation

Above calculations show that the main source for heating the chamber is power deposited by the stored beam. Using the Piwinski's study for power density distribution along the chamber perimeter, thermal simulation is performed in 3D ANSYS code with air convection heat transfer coefficient of 5 W/m^2 and alumina thermal conductivity of 34.1W/mK at 25^{0}C room temperature. The simulations show that for 400mA filled in 291 buckets, the maximum temperature rises up to 86.6^{0}C, 56.8^{0}C and 41.9^{0}C for the coating thicknesses of 0.5 μm, 1 μm and 2 μm respectively. Temperature distribution in Indus-2 kicker ceramic chamber for 2 μm Titanium coating thickness is shown in figure 1. In the case of partial buckets (400mA filled in 131 buckets filling) filling, the maximum temperature for 2 μm coating thickness will be around 60^{0}C but for 1 μm coating thickness the maximum temperature will be higher than 87^{0}C and there will be requirement of forced cooling.

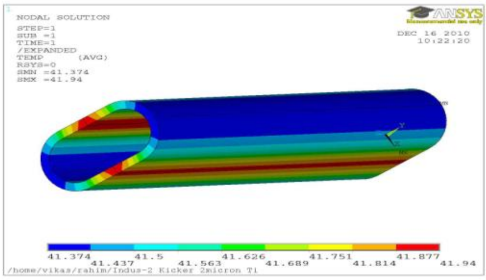

Figure 2: Temperature distribution in Indus-2 kicker ceramic chamber for 2 μm Titanium coating thickness.

CONCLUSION

Based on the above calculations and temperature distribution simulation, Titanium coating thickness of 2 μm is optimum to put inside the Indus-2 kicker ceramic chamber.

REFERENCES

[1] P. He, et al., "Metallization of ceramic vacuum chambers for SNS ring injection kicker magnets", Thin Solid Films 420 –421 (2002) 38–42.

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

[3] P. Lebasque et al., "Optimization of the coating thickness on the ceramic vacuum chambers of SOLEIL storage ring", EPAC-2006.

[4] K. Yokoya, "Resistive wall impedance of beam pipes of general cross section", Part. Acc., 41 (1993) 221.

[5] A. Piwinski, "Wake fields and ohmic losses in flat vacuum chambers", DESY HERA 92-04.

[6] R. Nagaoka, "Recent studies of geometric and resistive wall impedance at SOLEIL ", EPAC 2006.