OPTIMISATION OF THE COATING THICKNESS ON THE CERAMIC VACUUM CHAMBERS OF SOLEIL STORAGE RING

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Abstract

The SOLEIL storage ring vacuum chamber integrates four matched injection kicker magnets, two diagnostics kicker magnets and a beam shaker, which need ceramic chambers with an inner titanium coating. For each equipment (according with its field amplitude and its time or frequency domain), the coating thickness has been evaluated from the different points of view: field attenuation, beam deposited power, magnet excitation deposited power, and cooling efficiency. So we could determine the different coating thicknesses and tolerances needed according to the different magnetic field shapes. The realised ceramic chambers have adequate coating resistances, with in particular a low non-uniformity among the matched injection kicker magnets chambers.

INTRODUCTION

For all the fast pulsed elements, it is necessary to use ceramic vacuum chambers in order to avoid strong eddy currents which would prevent the excitation field penetrating to the beam. It is the case for the four injection kickers, the vertical and horizontal kickers for machine studies and the shaker for tune measurements.

A thin titanium coating is put on the inner side of the ceramics to minimize the impedance seen by the beam and avoid the accumulation of charge on the ceramics.

Coating thickness has to satisfy a compromise between:

- enough thin not to deform too much the excitation field shape,
- enough thin not to generate excessive thermal loss due to eddy currents,
- enough thick not to generate excessive thermal loss due to stored beam.

Ceramic chambers of SOLEIL have a racetrack cross-section, with an aperture of HxV= 80x25 mm and a mean alumina thickness of 7mm. Ceramic length is 728mm for the four injection kickers and the horizontal study kicker, and only 428mm for the vertical study kicker and the shaker.

The rise and fall times of the magnetic pulse depend of the applications.

Table 1: Pulsed equipments characteristics.

	Peak field	shape	Duration /frequency sweep	Rise/fall time
Injection Kickers	116 mT	½ sine	7 µs	
Study Kickers	30 mT (H) 18 mT (V)	trapezoid	1180 ns	450 ns
Shaker	130 µT. (H & V)	sine	420 kHz max	

DISTORTION OF THE FIELD PULSE

Eddy currents generated in the thin coating combat the penetration on the excitation field depending of the rising time and the coating thickness.

According to S.H. Kim calculations [1], we calculated the field penetrating (B_{int}) through the coating, using a rectangular geometry as simplified model of SOLEIL racetrack ceramic chambers:

- for t $\leq t_0$ (half-sine width) :

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

- for t$\geq t_0$:

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

With $\tau = \dfrac{2\mu_0\sigma w d}{\pi}$ (w = width of rectangular chamber).

Injection kickers

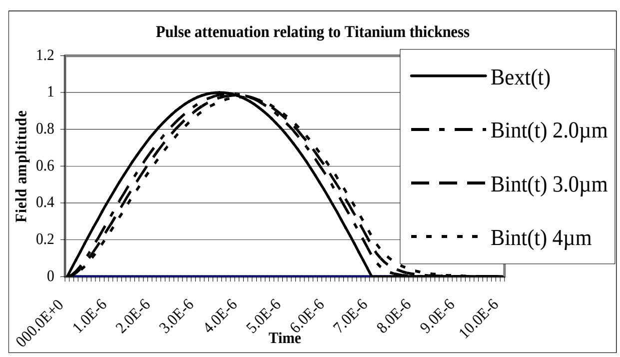

Figure 1: Pulse signal attenuation of the injection kicker versus the coating thickness.

Calculation of field pulse attenuation shows that with a moderate thickness like 2µm we have a significant delay (250ns) but only a small amplitude attenuation (0.66%).

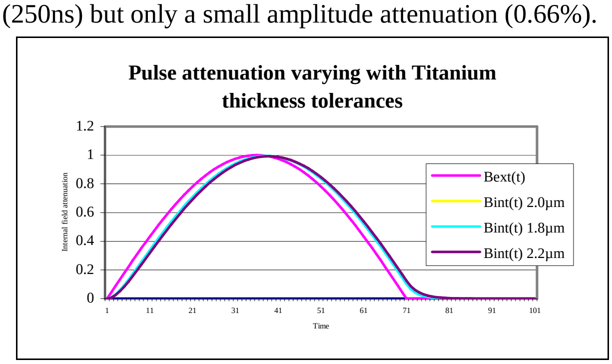

Figure 2: Effect of ±10% variation of coating thickness.

A tolerance of ±10% on the 2µm thickness will have a very small effect on the field amplitude in the ceramic chamber: ±0.12%.

Machine Study kickers

Machine study kicker magnets will be excited by trapezoid pulses, but the distortion of their transition time can be evaluated with **half-sine pulse** of corresponding width t_0= **643ns**.

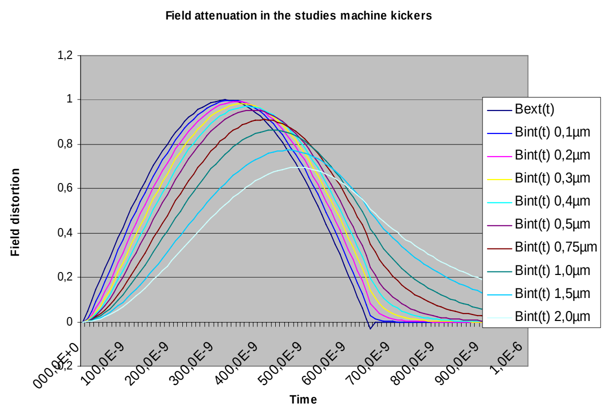

Figure 3: Pulse signal attenuation of the machine study kicker versus the coating thickness.

The distortion becomes unacceptable with more than 0.5µm thickness of Titanium coating, for these kickers which need fast transition pulses. With a 0.5µm thickness we have a delay of 64ns and an attenuation of 4.5%, when the delay is 25.6ns and the attenuation only 0.78% if we choose 0.2µm.

Shaker

The case of the shaker ceramic chamber is quite different. As the beam shaker is excited by permanent sinus wave (means without trigger), sweeping from 10 to 420 kHz, it's not concerned by the same distortion problems. The sine field attenuation can be compensated by the source amplifier

The main question concerns the beam power deposited on the chamber coating relating to its thickness, and the thermal cooling efficiency.

DEPOSITED POWER IN THE COATING DUE TO THE STORED BEAM

An extensive study was made at SOLEIL [2] on the impedance of ceramic chambers with metallic coating.
Some results are reported here:

- The ceramic makes the image current to flow uniformly across Titanium.
- According to Yokoya and Piwinski, 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 *b* = 12.5 mm.
- The surface density varies along the perimeter. Piwinski's study on a flat chamber was used.
- As the flat section of SOLEIL chamber extends to x = ± 27.5 mm, the use of the flat model may be justified.

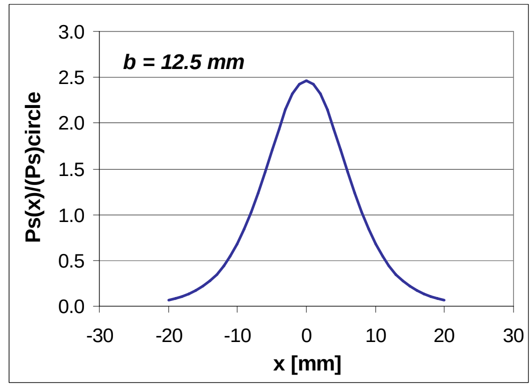

Figure 4: Transverse distribution of the ratio between the power density on a 2 plates model chamber and its density on a circular chamber.

This calculation shows that in a two plates model, closed to our racetrack ceramic chamber, the power density is peaked at 2.5 times the circular chamber value at x = 0.

The distribution of the power density on the surface has been calculated for each case for maximum current (600mA) in the storage ring.

$$p_i = I_{tot}^2 R_{sq} \frac{1}{n} \frac{1}{(2\pi r)^2} \frac{C_r}{2\sigma_l \sqrt{\pi}}$$

$$p_i = I_{tot}{}^2 R_{sq} \frac{1}{n} \frac{1}{(2\pi r)^2} \frac{1}{2\sigma_t f_{rev} \sqrt{\pi}}$$

with
I_{tot} : stored beam total current (A),
n : number of bunch,
σ_l : bunch length (m),
σ_t : bunch width (s) in 1 sigma,
C_r : Storage Ring length,
f_{rev} : revolution frequency (of beam in the SR) = 352 MHz/416,
R_{sq} : surfacic resistance of the coating.

In the multibunch mode: SOLEIL could be injected with 600 mA in 416 bunches of 12 ps sigma width.

So power density will be: p_i = 3895.3 W/m² * R_{sq}

In the few single bunch mode: SOLEIL could be injected with 120 mA in 8 bunches of 20 ps sigma width.

Which gives: p_i = 4861.4 W/m² * R_{sq}

The total power deposited in a ceramic chamber will be:

$P_{tot} = p_{i\_\max} * 2\pi r * L$, depending on its length.

As the few single bunch mode (temporal structure) reveal to be more restricting, we evaluate the total power deposit by the beam in this mode, according to the diverse coating thickness, on a 728mm long ceramic:

0.2µm ➔ 664 W; 0.5µm ➔ 266 W; 2 µm ➔ 66.4 W,

and thermal heating have been calculated in these cases.

DEPOSITED POWER IN THE COATING DUE TO FIELD EXCITATION

From a simplified rectangular chamber model, we could calculate the power deposited by a sine field:

$$P_{tot} = dL\sigma \frac{w^3}{3}\left(B_0^2 \frac{\pi^2}{2\theta}\right)F_r$$ with in this formula:

d : coating thickness,
σ : Titanium conductivity ($2\ 10^6$ S),
w : half internal width of ceramic (0,040 m),
L : length of the coated ceramic (0,728 m for the SR injection kicker),
B_0 : peak field in SR injection kicker (0,116 T),
θ : half sine pulse width ($7\ 10^{-6}$ s),
F_r : repetition frequency of kickers (50/17 Hz).

That gives in the case of the Storage Ring injection kickers, which are more powerful:

$$P_{tot} = dL * (1.190 \cdot 10^6) \text{ W/m}^2$$

depending on the thickness and length of the ceramic.

P_{tot} = 1.733 W for a 'long' ceramic chamber (L=728 mm), with d = 2 µm.

We can see that the power due to field excitation is small in comparison with the beam deposited power, even in the case of SR injection kicker which have longer pulses and stronger field. And it can be neglected for heating evaluation.

THERMAL CALCULATIONS

Each kicker magnet is equipped by an air cooling roughly uniformly distributed along the upper part of the vacuum chamber. First the air flowing geometry has been determined, according to the turbine characteristics and to the cooling path on the ceramic. Then thermal calculations were made with the 3D ANSYS code.

The figure 4 shows the results: the hottest point is limited to 90° for 0.5µm coating, while the temperature rises up to 195 ° for 0.2µm thickness which is unacceptable.

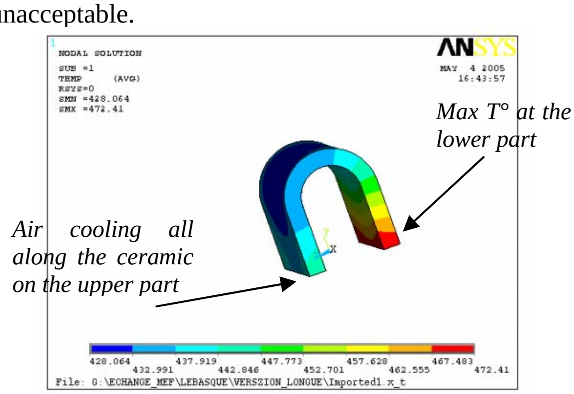

Figure 5: Thermal calculation of the ceramic vacuum chamber for 500mA and 0.2µm.

So the 0.2µm coating thickness could not be retained, and we chose a 0.5µm Titanium thickness for the Study kicker magnets.

Extrapolation results for the SR injection kicker magnets, which could support a 2µm coating without excessive distortion of the penetrating field, shows that they won't be overheating.

The shaker includes, around the same chamber, both horizontal and vertical coils. So it has a different geometry of the kickers, which made delicate to get an effective cooling. Thermal calculations shows that we needed to improve the cooling design, what was done afterwards. Now the shaker is in operation for a few months, without any problem of overheating.

RESULTS ON MANUFACTURED CERAMIC CHAMBERS

The ceramic chambers supplied by PMB, with very good alumina tube from Saint-Gobain-Ceramics, exhibit dimensions very well controlled, with geometrical tolerances inferior to our strict specifications.

The Titanium coating by PMB of these chambers have been realised with an important collaboration from us. So we could get Titanium coating very close to our specifications.

As usual the coating thicknesses were measured through the resistance of each chamber flange to flange. The resistance was measured frequently during the sputtering, in order to control the progressive deposit and to anticipate the end of deposit.

At the end of sputtering at 180°C, before cooling and putting in air, PMB could realised the deposit corresponding exactly to the foreseen resistance concerning the six ceramic chambers dedicated to the matched SR injection kickers. However after setting in air, the oxidation made some differences in the final resistance, but all ceramic chambers exhibit the same coatings between ± 7 % of measured resistance. This result for matching coating is better than the specification (±10%).

For the other ceramic chambers, we could get the demanded coating resistances, with a rather good precision, giving:

- 0.5µm thickness for the chambers dedicated to machine study kickers,
- 1µm thickness for the chambers dedicated to the shaker.

CONCLUSION

Detailed evaluation of pulse distortion, power deposit and thermal effect is of great interest, for fast pulsed or high frequency systems. It permits to determine precisely the appropriate compromises for each specific case.

REFERENCES

[1] S.H. Kim, APS, USA "Calculation of pulsed kicker magnetic field attenuation inside beam chambers", January 8, 2001.
[2] R. Nagaoka, SOLEIL, Saint-Aubin, France, contribution submitted to EPAC 2006, Edinburgh.