KICKER CHAMBER METALLIZATION INDUCED EFFECTS ON THE BEAM IN INDUS-1

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Abstract

Indus-1 has single turn beam injection using a fast kicker magnet. The ceramic chamber of this kicker has been metallized in order to carry the image currents and to avoid cracking of the chamber. Titanium has been chosen as a coating material due to its known properties as a coating material. The optimization of the coating thickness takes into account the distortion of the kicker pulse, propagation of the beam frequencies and power losses due to this coating. The growth rates of the transverse resistive wall instabilities driven due to the impedance offered by this coating have been estimated taking into consideration the frequency shift of the bunch power spectrum due to the chromaticity. For a chosen thickness of Titanium and slightly positive chromaticity, it is envisaged that there will be no problem due to the interaction of the beam with this coating.

1. INTRODUCTION

Indus-1 is a 450 MeV storage ring for the production of VUV radiation. The injection scheme used for Indus-1 is single turn stacking [1] The rise time of the kicker pulse is 1 μsec and fall time is 120 nsec. In order to avoid the shielding of fast varying magnetic field by a metallic pipe, a ceramic pipe is generally used for the kicker magnet. However, it is necessary to have a thin conductive coating inside this chamber to flow the image currents of the beam and to avoid the electrical discontinues of the chamber wall. The metallic coating also avoids building up of the static charges inside the ceramic chamber. Such coating inside the chamber manifests itself into shielding of the kicker magnetic field. It causes heating of the chamber walls due to eddy currents. These contradictory requirements make the optimisation of the coating thickness critical. The thickness of the coating has to be optimised by taking into consideration all these effects.

After investigating the effect of different coating materials and the required coating thickness, Titanium has been chosen as the coating material and studied its effect on the kicker pulse distortion. The impedance offered by this coating has been calculated. Coupling of this impedance to the power spectrum of the circulating bunches has been studied in order to decide the growth time of the transverse resistive wall instabilities.

2. DISTORTION OF THE KICKER PULSE

The effect of the metallic coating is to shift the peak & change in the amplitude of the kicker pulse. These effects can be compensated in actual operation by adjusting the timing and amplitude of the kicker field. The other effect is to change the rise and the decay slopes of the kicker field, which cannot be compensated by adjustments.

The rise time due to shielding arising from the eddy currents is governed by the time constant L/R where L and R are characteristic inductance and resistance of the metal coating. For a metal thickness 'd' and the electrical conductivity σ for a chamber with length 'l' and rectangular cross section $w \times h$ (d<<w), the time constant is defined as follows [2]

$$\tau_s \cong L/R \cong \mu_0 w\sigma d/\pi$$

To satisfy the condition, $\tau_s < k\ \tau_k$ where τ_k is the kicker rise/fall time and k is a numerical factor deciding the allowable distortion of the magnetic field. This gives rise to a condition

$$\sigma d < \pi k \tau_k / \mu_0 w$$

2.1 Impedance offered by the coating and power spectrum of the beam:

Assuming an electric permeability ε = 10 for the ceramic and considering the case of a pipe with height 'h', radius b=h/2 , length 'l' and ceramic thickness 'Δ' the coupling impedance at frequencies well below cut-off ~ $c/(2\pi\sqrt{\varepsilon} b)$ are given by [3]

$$Z_L(\omega) = \frac{Z_0 \omega l}{4\pi c} \frac{s(\omega) - i\zeta}{s(\omega)^2 + \zeta^2}$$

$$Z_T(\omega) = \frac{2c}{b^2} \frac{Z_L(\omega)}{\omega}$$

Where $\sqrt{s(\omega)}$ is the ratio between the geometric mean of pipe radius and the coating thickness and the skin depth $\delta_{Ti}(\omega)$ in the Titanium, having resistivity ρ_{Ti}

$$s(\omega) = b\, d/\delta^2_{Ti}(\omega)\ ;$$

$$\delta_{Ti}(\omega) = (2\rho_{Ti} / \mu_0\omega)^{1/2}\ \ \&\ \zeta = (b+\Delta)^2/[(b+\Delta)^2 - b^2]$$

The general expression for the coherent frequency shifts whose imaginary part gives the instability growth rate of a bunched beam. This essentially indicates that to the first order, the coherent frequency shift is proportional to the Impedance averaged over the power spectrum of the bunches.

The bunch mode frequencies $\omega_p=(pk_b + s + \nu_{\perp 0} + a\nu_{s0})\omega_0$, contains the harmonics of the revolution frequency, the betatron oscillation frequency and the synchrotron oscillation frequency, in addition, because the momentum dependence of the of betatron tune, the entire spectrum is shifted by chromatic frequency $\omega_\xi = \xi\omega_0/\eta$. Where ξ is the chromaticity, ω_0 revolution frequency and η is the frequency slippage factor of the ring. Although the mode spectrum is rather complicated, normally one has to worry about the rigid bunch mode a=0 and few lowest order a=1,a=2 etc head-tail modes due to their high growth rates.

The Effective Transverse Impedance for total bunch length L = $4\sigma_s$ is defined as

$$(Z_T)^{(s,a)}_{eff} = \frac{\sum_{p=-\infty}^{p=\infty} Z_T(\omega_p) h_{|a|}(\omega_p - \omega_\xi)}{\sum_{p=-\infty}^{p=\infty} h_{|a|}(\omega_p - \omega_\xi)}$$

Where $h_a(\omega)$ denotes the mode power spectrum and, for Gaussian bunches it is given by

$$h_a(\omega) = \frac{(\omega\sigma_\tau)^{2a}}{\Gamma(a + 1/2)} \exp\left[-(\omega\sigma_\tau)^2\right]$$

$$\Delta Q^{(s,a)}_T = \frac{-iI_b R}{|a|+1} \frac{\beta_{av}(Z_T)^{(s,a)}_{eff}}{2(E/e)L}$$

From the above equation, the imaginary part of effective impedance is responsible for real coherent tune shift and can lead to the collective instability owing to the mode coupling or to the loss of Landau damping. While the real part of the effective impedance is related to the instability rise time.

The Coherent effect includes the parasitic losses, associated with the real part of the longitudinal coupling impedance Z_L, and complex tune shifts of beam oscillation modes. For Gaussian bunches, with r.m.s. Bunch lengths $\sigma_S = c\sigma_\tau$, the power dissipated by the wall currents in impedance with resistive component $\mathrm{Re}[Z_L(\omega)]$ is

$$P = 2k_b I_b^2 \sum_{p=0}^{p=\infty} \mathrm{Re}[Z_L(p\omega_0)] \exp\left[-(p\omega_0\sigma_\tau)^2\right]$$

Where k_b is the number of bunches, I_b is the bunch current and ω_0 is the angular revolution frequency around the ring.

2.2 Power loss due to eddy current heating

The instantaneous power dissipated in a resistive loop of length 'l', width 'w', height 'h' and thickness 'd' is given by [4] $P = \dot{B}^2 \omega^2 lh / 2R_{sq}$, where $R_{sq}=\rho/d$, is the surface resistivity of the coating in Ω/square

Indus-1 kicker pulse can be expressed as,

$B=B_0 \sin(\omega t)$, $0 \le t \le t_0$ & $B = B_0 e^{-(t-t_0)/\tau}$, $t_0 \le t \le t_1$

The time-averaged power dissipated in the resistive loop of length 'l', width 'w' and height 'h' is given by [5]

$$P = fB_0^2 w^2 lh[\omega\pi/4 + (1 - e^{-2(t_1-t_0)/\tau})/2\tau]/2R_{sq}$$

3 CALCULATIONS AND RESULTS

The parameters of the injection kicker magnet

Deflection	15 mrad	
Peak current	2500 A	
Rise time	1 µs (sinusoidal)	
Fall time	120 nsec(exponential)	
Kicker magnet		Ceramic chamber
Type Window frame		Thickness 7 mm
Length	400 mm	405 mm
Width	90 mm	8.6 mm
Height	42 mm	26.5 mm

Allowing 10 % distortion in the kicker pulse fall time, k=0.1, the following table gives the thickness of the required materials:

Coating material	Resitivity at 20 ^{0}C	Thickness
Titanium	54.0×10^{-8} Ω-m	0.25 µm
Chromium	13.2×10^{-8} Ω-m	0.06 µm
Gold	2.2×10^{-8} Ω-m	0.01 µm
Copper	1.7×10^{-8} Ω-m	0.007 µm

As it is reported in the literature, Titanium is generally used as a coating material due to its high resistivity, high melting point and good adhesivity with ceramic. We have also chosen Titanium as a coating material for the ceramic chamber.

Circumference	18.96640 m
Energy	450 MeV
Bunch current	50 mA
Bunch length	0.114 m
Momentum compaction	0.142
Tune-x,z	1.88
Tune-z	1.22
Tune-s	$1.44\ 10^{-3}$
$\tau_{x,z,\varepsilon}$	15.7, 15.7, 7.8 msec
Coating material	Titanium

As shown in the Figure 2 & 3, changing chromaticity, which can significantly modify the coherent frequency which can control the interaction of bunch power spectrum with the impedance. Chromaticity of 0.5 is sufficient to landau damp all lower order including most severe a=1 rigid dipole bunched mode. With the chromaticity +7 the head tail mode up to a=4 are stable with the beam current of 100 mA, since they interacts with lower value impedance as shown in the Fig. 3.

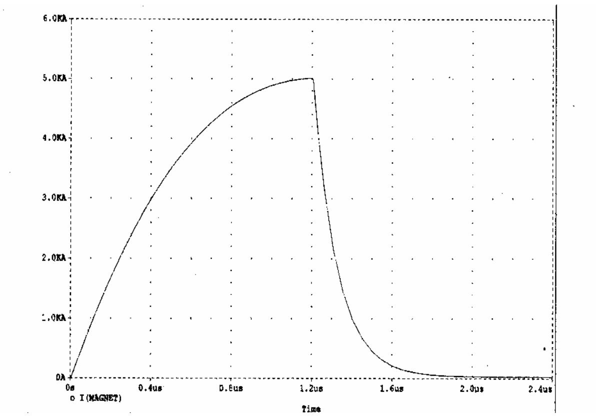

Fig 1 The injection kicker pulse for Indus-1

The estimated growth rate is shown in Table-1.

Table 1 Growth rates for few lowest order modes.

ξ	a	s	$\Delta\nu_z\ 10^{-5}$	τ(m sec)	Stability
-0.82	0	0	-1.78	1.27	Unstable
	1	0	-0.22	-3.84	Stable
0.1	0	0	1.85	-10.1	Stable
	1	0	0.17	28.0	LD
7.0	0	0	-0.16	-0.64	Stable
	1	0	-0.26	-1.11	Stable

The interaction of the beam with the impedance under different chromaticities are shown in Figure 2 & 3.

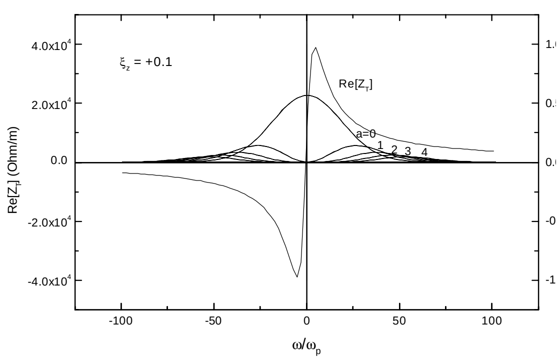

Figure 2: Interaction when ξ is slightly positive

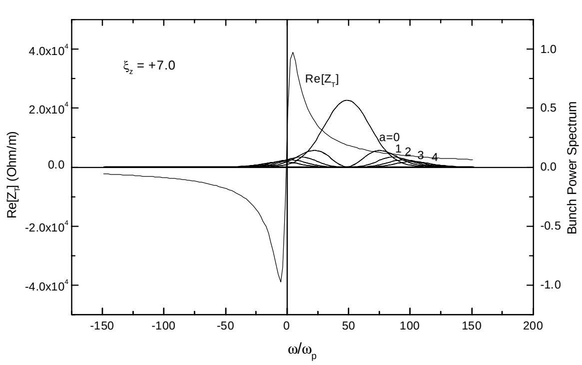

Figure 3: Interaction when ξ is highly positive

The total power loss due to eddy current and beam image current in the metallic coating is 1 Watt

4 COATING METHOD

The kicker magnet ceramic cavities are coated with thin films of titanium by using DC sputtering system [6]. In this process the cathode is made of the material of which coating has to be made the ceramic cavity is the substrate where the material has to be deposited is kept at ground potential when the electric field is set up between cathode and anode in the presence of argon gas the electrons ionises the neutral gas atoms and the ions and electrons are formed these newly formed electrons are further accelerated and causes more ionisation of the argon gas. These ions are bombarded on the cathode; if the energy of these ions is large enough a cathode will sputter. The sputtered cathode material gets deposited over the substrate. The thickness of the thin metallic film is monitored by in situ measurement of film electrical resistance. The measured value of DC resistance for titanium thickness of 0.25 μm is 4.8 Ω.

5 MAGNETIC FIELD MEASUREMENTS

Magnetic field measurements were done in the median plane to confirm the effect of metallisation on the magnetic filed uniformity. The field uniformity ($\Delta B/B$) without coating was 5 10^{-3} with coating it was 8 10^{-3}.After coating the decay time up to 10 % of the B_{peak} is changed from 137 nsec to 145 nsec.

6 CONCLUSIONS

A 0.25 μm thickness of titanium offers distortion less than 10 % of injection kicker pulse. It is enough to set a small positive chromaticity +0.1 to damp all the major modes of bunch oscillations due to radiation damping and there will not be any problem to store 100 mA design beam current in Indus-1. The power loss in the thin coating is negligible.

7 ACKNOWLEDGMENTS

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