IMPEDANCE OF CPMU IN SLS STORAGE RING

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Abstract

The longitudinal and transverse resistive impedances of CPMU (cryogenic permanent magnet undulators) of the SLS storage ring are evaluated. The study takes into account the walls frequency dependent conductivity and the electrical properties of the material at low temperature.

INTRODUCTION

Cryogenic permanent magnet undulator (CPMU) is developed and under construction in SPring-8 [1,2] and at ESRF [3] will operate at cryogenic temperatures much higher than that of existing superconducting undulators with low temperature superconducting coils. The low gap CPMU planned to be installed in SLS storage ring is under development in collaboration of PSI, SPring-8 and Diamond and is aimed to produce the 30keV energy photon beams at the SLS storage ring.

The CPMU for SLS is a U14 with 14mm period, a mininum gap of 3.8 mm. With 120 periods it has a total magnetic length of 1.6m. The interface is identical to the standardized in-vacuum undulator family at the SLS.

For the magnet material NMX S45SH from Hitachi is used. At room temperature it has a remanence of 1.33 T and a coercivity of 21 kOe. Operating the undulator at the optimum temperature of 135 K the romance increases to 1.5 T and, more important, the coercivity to 50 kOe. For comparison, the standard in-vacuum undulators at SLS have a remanence of only 1.08 T at 36 kOe which corresponds to about 40% lower field. The magnets are covered by a CoNi sheet with a thickness of 0.1 mm.

In the case of thick enough $(>0.1\mu m)$ inner non-magnetic metallic sheet, as it was shown in [4], the pole material electrical conductivity influence on the beam channel impedance is negligibly small, and the beam channel between metallic sheets may be considered as a flat vacuum chamber with thick enough metallic walls.

Using this model the longitudinal and transverse impedances, wake potentials, loss and kick factors of the CPMU have been calculated taking into account the frequency dependent conductivity of the wall material. An analysis has been performed versus material, temperature, gap variations and different SLS operation modes: nominal (bunch length 4mm) and 3rd harmonic cavity operation mode (bunch length 12 mm).

The calculations are made by exact formulae for round chamber [5] with diameter equal to the distance between the parallel planes. For the flat chamber the longitudinal characteristics impedance and loss factor are the same, while the transverse ones (vertical impedance, kick factor) should be multiplied by $\pi^2/8$ [6].

The frequency dependent (AC) conductivity σ_ω that describes the material electrical properties is expressed via the static (DC) conductivity σ_{st} as $\sigma_\omega = \sigma_{st}/(1-j\omega\tau)$, where ω is the frequency and τ is the Drude relaxation time [7] of the metal that depends on the temperature. Table 1 presents the Drude relaxation time for copper and aluminium for different temperatures.

Table 1. Drude relaxation time for the copper and aluminium under different temperatures.

	τ (10^{-14} sec)			
Metal/T(K)	77	130	273	373
Cu	21	12	2.7	1.9
Al	6.5	3.78	0.8	0.55

The relaxation time decreases with the temperature increase. The static conductivities for Cu and Al are $58.0\cdot10^6\ \Omega^{-1}m^{-1}$ and $36.6\cdot10^6\ \Omega^{-1}m^{-1}$ respectively.

LONGITUDINAL IMPEDANCE

The longitudinal impedances of CPMU for the cases of copper and aluminium sheets at temperatures of 77K and 130K are presented in Fig.1.

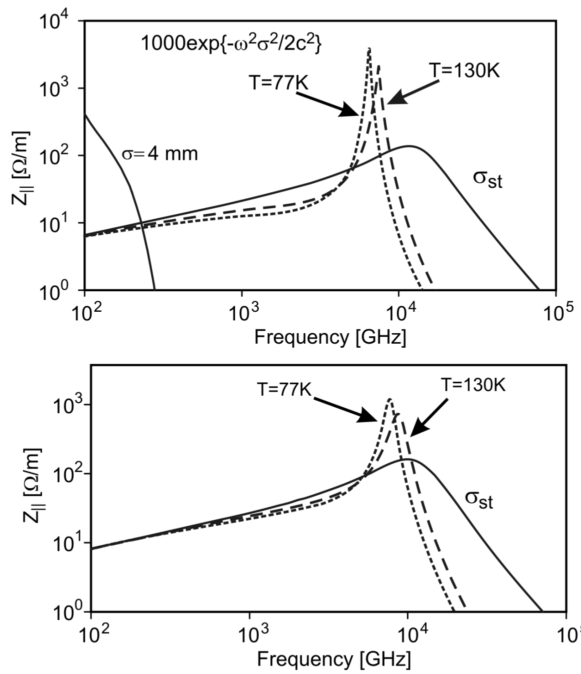

Figure 1: Real part of longitudinal impedance of Cu (top) and Al (bottom) sheets for DC and AC conductivities

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For comparison the spectrum of 4mm rms length SLS bunch and impedance for DC conductivity are shown. As is seen the AC impedance significantly differs from the DC one. AC impedance has the high maximum shifted to the low frequency part of the spectrum. The temperature effects are essential at high frequency part of the impedance. For both operation modes: included 3rd harmonic cavity (σ=12mm) and without it (σ=4mm) the bunch spectrum doesn't reach the high frequencies where the temperature effect of AC conductivity makes significant impact. As a result, the wake potentials and the loss factors actually coincide with the DC conductivity case for both operation modes (Fig.2).

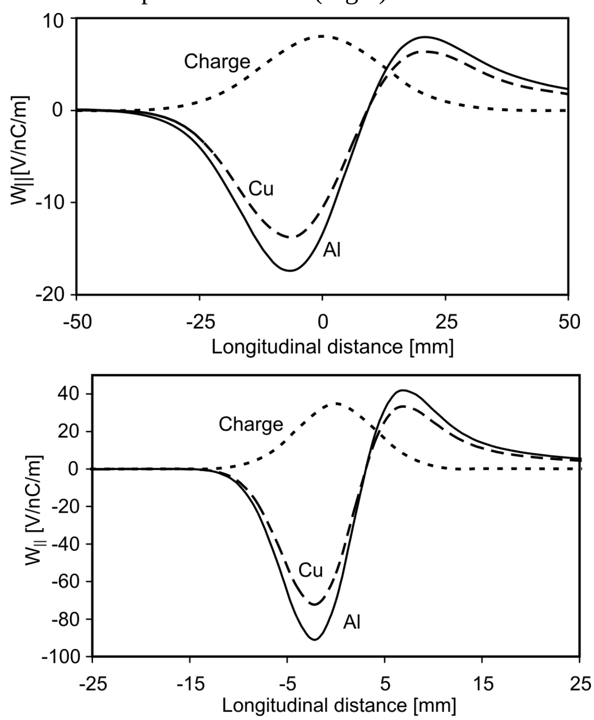

Figure 2: Longitudinal resistive wake potentials in CPMU for two operation modes: with (top) and without (bottom) 3rd harmonic cavity for the cases of Cu and Al covers. AC conductivity, T=130K.

In Table 2 the loss factors for Cu and Al vacuum chambers in case of AC and DC conductivities for two operation modes are presented. The differences for AC and DC conductivity cases do not exceed 0.25%.

Table 2: Loss Factor (V/nC/m)

	σ=12 mm		σ=4mm	
	AC	DC	AC	DC
Cu	6.396	6.389	33.3	33.2
Al	8.045	8.042	41.91	41.87

TRANSVERSE IMPEDANCE AND WAKE

At low frequencies the transverse impedance hasn't significant influence from the temperature and relaxation time: the curves for T=77K, T=130K and for the static conductivity coincide both for copper and for aluminium cover sheets (Fig.3). As it follows from the figure, the impedances have equal finite values at zero frequency. This value is equal to $Z_0/2\pi a^2$ (a is the tube radius and $Z_0 = 120\pi\Omega$ is the free space impedance) for the cases of DC and AC conductivities as well.

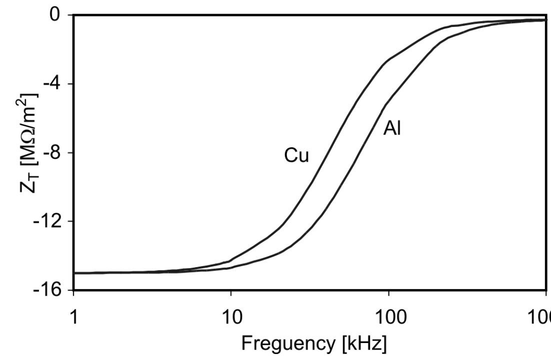

Figure 3: Imaginary part of transverse impedance for the copper and aluminium sheets. Low-frequency region.

The weak dependence on the relaxation time is observed in high frequency region of the transverse impedance (Fig.4). There is a splash of impedance distribution in the case of AC conductivity at frequency of about 10 THz in comparison with DC conductivity that can be essential for ultra short bunches.

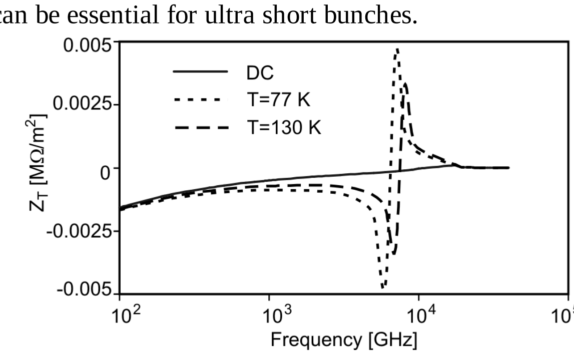

Figure 4: Imaginary part of transverse impedance for the copper sheet. High-frequency region.

For the SLS bunch in both operation modes the impact of the high frequency part of the impedance to transverse wake potential and the kick factor is negligibly small. The transverse wake potentials for SLS bunches are dominated by the low frequency part of the impedance and are presented in Fig.5. The AC and DC conductivity cases actually coincide (Figure 5).

In Table 3 the results of kick factor calculation for two operation modes and for two possibly used cover metals for AC (T=130K) and DC conductivities are given. As it is seen, no any significant influence of frequency dependence, i.e. low temperature negative effect to kick factor is observed.

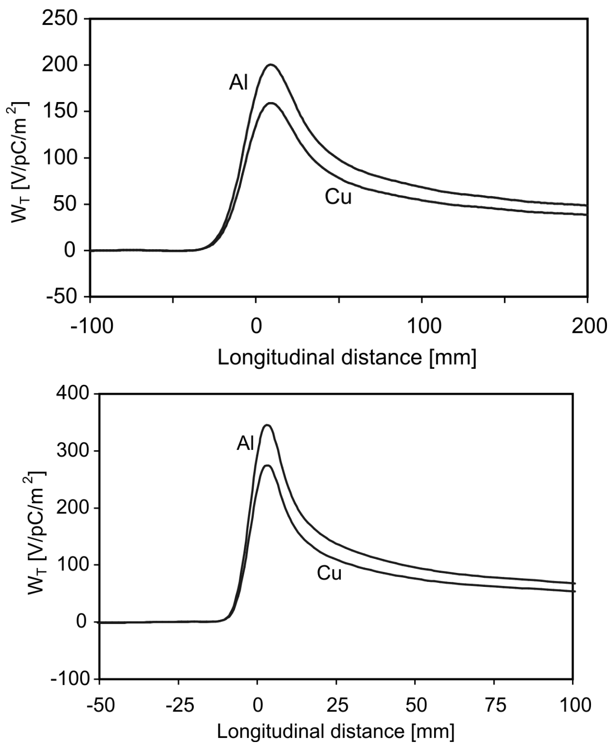

Figure 5: Transverse resistive wake potentials for two operation modes: with (top) and without (bottom) 3rd harmonic cavity for the cases of Cu and Al covers. AC conductivity, temperature T=130K.

Table 3: Kick Factor (V/pC/m^2)

	σ=12 mm		σ=4mm	
	AC	DC	AC	DC
Cu	113.6	113.5	197.0	196.7
Al	142.9	142.85	247.7	247.6

GAP VARIATIONS

The graphics of the loss and kick factors (Fig.6) for the various gap values are given for the cases of copper and aluminium cover sheets for the temperature T=130K for two operation modes (4 and 12mm). The gap variations are given from 1mm up to 6mm (nominal value 4mm).

As it is seen, the level of the loss factor significantly depends on the bunch length. The ratio of loss factors for 4mm bunch operation mode and 12mm one is equal to 5.2 both for copper and aluminium sheets, while the kick factor is less sensitive to the bunch length: corresponding ratio is equal to 1.7. The similar ratio between aluminium and copper sheets is ~1.26 both for loss and kick factors.

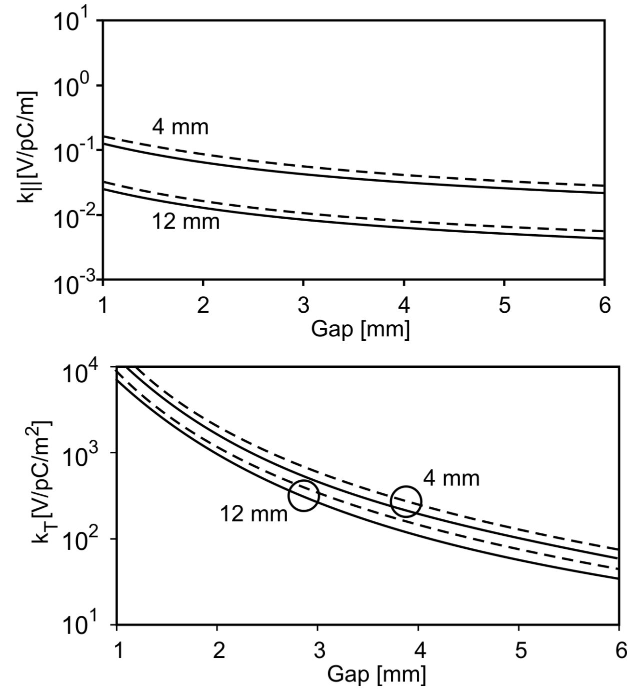

Figure 1: Loss (top) and kick (bottom) factors distribution versus gap value. Solid: copper; dashed: aluminium

As expected, for the SLS bunch lengths, the results are in good agreement with the long range approach [8] that predict the linear dependence of loss factor and cubic dependence of the kick factor on the undulator gap.

CONCLUSION

The resistive effects in cryogenic permanent magnet undulator, proposed for installation in SLS storage ring, are investigated. The impedances of the undulator beam channel are calculated for AC conductivity under the temperatures of 77K and 130K.

The loss and kick factors for the SLS bunch are calculated that result on negligibly small effect of frequency dependent conductivity at low temperature.

The work is performed within the framework of PSI-CANDLE collaboration.

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