LONGITUDINAL AND TRANSVERSE RESISTIVE WAKE FIELDS IN PSI-XFEL UNDULATOR

M. Ivanyan#, A. Grigoryan, V. Tsakanov, CANDLE, Yerevan, Armenia
M. Dehler, PSI, Villigen, Switzerland

Abstract

The resistive longitudinal and transverse wakefields, longitudinal loss and transverse kick factors excited by the electron bunch in undulator section of the PSI-XFEL are given. The ordinary and in vacuum undulators are considered. For in vacuum undulator the modified technique for impedance calculation is developed. Analysis of impedances and wakefields is performed.

INTRODUCTION

The PSI-XFEL is projected as the high brightness and low-emittance coherent X-Ray facility [1]. The undulators, included in XFEL are the important parts of the facility and are the sources of resistive wall wakefields due to smallness of the gap, high peak current and short bunch length. In PSI-XFEL project both ordinary and in vacuum undulators are supposed to be used.

The ordinary undulators vacuum chamber are expected to be made of aluminium or aluminium with internal NEG (Non-Evaporable Getter) cover. The magnet poles of in vacuum undulator are covered by two layers Ni-Cu foil inside. The cross-sections of both structures may be modelled by the rectangular geometry. The aspect ratio a/b of both structures is greater than 2 (a-horizontal, b-vertical half aperture) and the round chamber geometry with radius b can be used to evaluate the impedances [3]. The longitudinal impedance then coincides with the flat chamber impedance, while the vertical transverse impedance should be multiplied by the geometrical factor $\pi^2/8 \approx 1.23$ [3,4]. The horizontal transverse impedance vanishes.

The presented investigations include the calculations and analysis of the longitudinal and transverse impedances, wake potentials, loss and kick factors for both types of the undulators. The electromagnetic field transformation technique, developed in [2], is used for evaluation of the impedances and wake potentials of the multi-layer vacuum chamber with finite wall thickness.

ORDINARY UNDULATOR

The vacuum chamber of an ordinary undulator magnet for PSI-XFEL is supposed to be made of aluminium (Al) with the vertical aperture confined by the undulator gap of 6mm. We studied the longitudinal and transverse impedances, wake potentials, loss and kick factors of the Gaussian bunch in finite thickness aluminium vacuum chamber (conductivity $\sigma_{Al} = 36.6\Omega^{-1}m^{-1}$) without and with thin internal NEG cover (conductivity $\sigma_{NEG} = 0.31\Omega^{-1}m^{-1}$).

Longitudinal Impedances and Wakes

The simulations show that for the wall thickness above 1µm the aluminium chamber impedance is actually independent of the wall thickness and coincides with the case of infinite wall chamber. Figure 1 presents the real part of longitudinal impedance for the aluminium chamber with wall thickness of 1 mm and the aluminium chamber covered by 50 nm NEG. The external diameter is kept equal to undulator gap of 6mm. For comparison the impedance for 1mm thickness NEG tube is given.

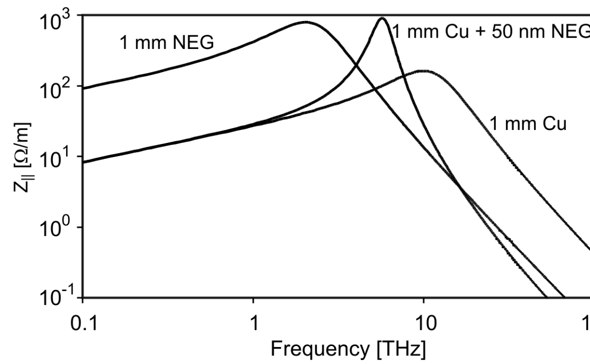

Figure 1: Real parts of longitudinal impedance for Al, NEG and Al+NEG vacuum chambers.

The corresponding longitudinal wake potentials for 16μm PSI-XFEL bunch length is presented in Figure 2.

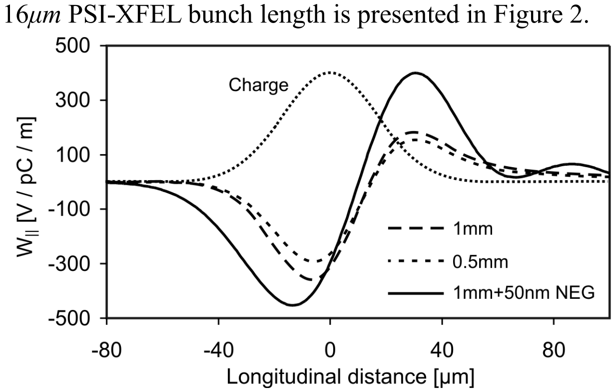

Figure 2: Longitudinal wake potentials of PSI-XFEL bunch for Al (thickness 0.5mm, 1mm) and Al+NEG undulator vacuum chamber.

The loss factor per unit length versus wall thickness for Al and Al+NEG undulator vacuum chamber are presented is Figure 3.

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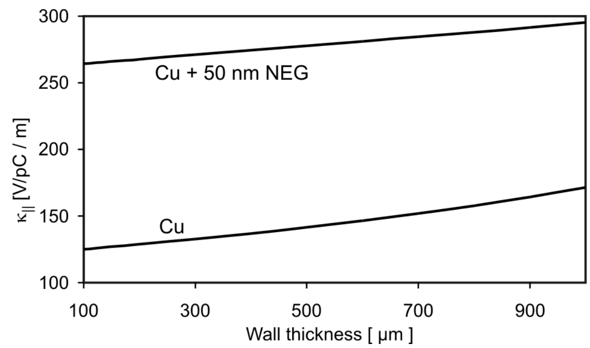

Figure 3: The loss factor versus wall thickness for Al and Al+NEG (NEG-50 nm) undulator vacuum chambers.

Transverse Impedances and Wakes

In the case of wall without any cover the bunch field differs from the point-like charge radiation field in the short-range region $s \le 2.5\sigma$ (Fig. 4), while in the cover presence the transverse wake potential in spite of significant growing gets special properties: both for the point-like charge and for short bunch the periodicity of the transverse wake potential behind the bunch may be observed (Fig. 5). The period length and modulation depth are conditioned by the cover thickness.

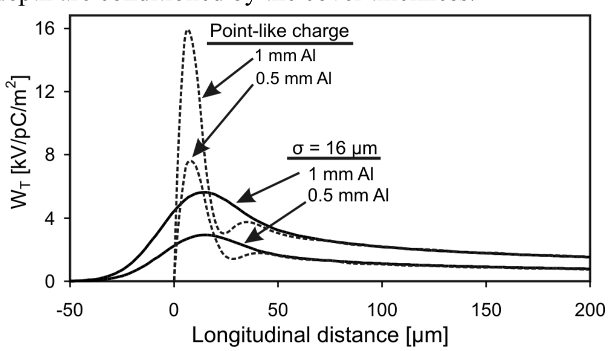

Figure 4: Transverse wake potentials in Al chamber for point-like (dotted) and PSI-XFEL bunch (solid).

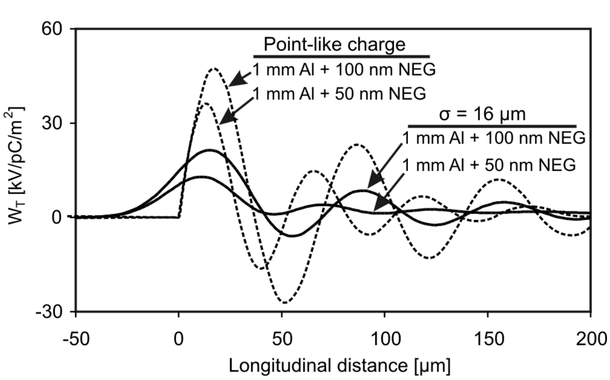

Figure 5: Transverse wake potentials in Al+NEG chamber for point-like (dotted) and PSI-XFEL bunch (solid).

Transverse loss factor κ_T (kick factor) per unit length and per unit offset is determined by the imaginary part of dipole transverse impedance $Z_T(\omega)$.

Figure 6 presents the dependence of PSI-XFEL bunch ($\sigma = 16\mu m$) kick factor in AL+NEG vacuum chambers on the NEG cover thickness. The Al layer thickness is 1 mm. Dashed lines show the kick factors for the Al and NEG vacuum chambers with infinite wall thickness.

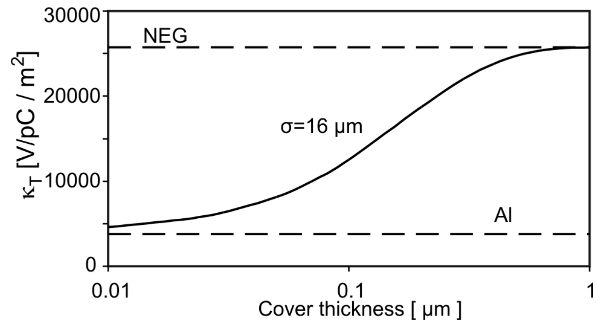

Figure 6: Kick factor versus NEG cover thickness.

As is seen the kick factor strongly depends on the NEG cover thickness. For the short bunch and comparatively thick internal NEG cover the kick factor is conditioned by the bunch interaction with the internal low conductivity NEG layer. Figure 7 presents the kick factor of the PSI-XFEL bunch in Al and Al+NEG undulator vacuum chamber. Thus, even minor thickness of the NEG cover ($50nm$) results in the kick factor increase by the factor of about 2 (Fig. 7). For the wall thickness presented in the Figure the kick factor is conditioned by the wall material and inner radius of the tube.

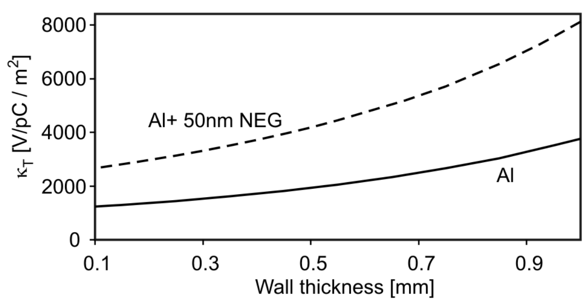

Figure 7: Kick factor versus wall thickness for Al (solid) and AL+NEG (NEG-50nm) (dashed) vacuum chambers.

Conclusion

The NEG cover presence due to bunch short size and smallness of the gap increase both the loss and kick factors more than twice for the thin enough (50 nm) cover sheet. On the other hand, reduction of the wall thickness from 1 mm to 0.5 mm leads to almost two times decrease of the loss and kick parameters without any distortion of impedance and wake curves.

IN VACUUM UNDULATOR

The magnet poles of the PSI-XFEL in vacuum undulator are covered by two layers Ni-Cu foil inside. The thickness of the closed to the poles nickel cover is equal to $50\mu m$ and the copper layer thickness is equal to $60\mu m$. Vertical and horizontal transverse sizes of the effective beam channel, formed by the covering sheets are equal to 16 and 4.2 mm respectively. The ratio of these sizes is larger than 2.5, and the channel may be considered as a flat vacuum chamber [3]. The copper cover layer is thick enough to neglect the nickel layer influence on the radiation characteristics of the bunch. Thus, the chamber may be considered as a flat chamber with infinite copper wall thickness.

The effect of the outer Ni layer is visible only for very thin inner copper layer as is seen in Fig. 8.

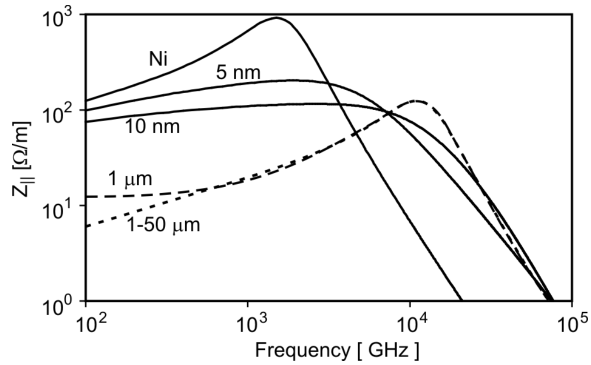

Figure 8: Longitudinal impedance for various thickness of copper layer; also shown is the nickel tube impedance.

Nickel is a ferromagnetic material. Its magnetic permeability is taken equal to $100\mu_0$ with μ_0 the magnetic permeability of vacuum. The reduction of copper layer thickness down to $0.1\mu m$ acts on the low frequencies distribution of impedance. Further reduction leads to the significant distortion of impedance curve. The impact of nickel layer to the longitudinal wake potential is visible only for very thin ($<0.1\mu m$) copper layer (Fig. 9).

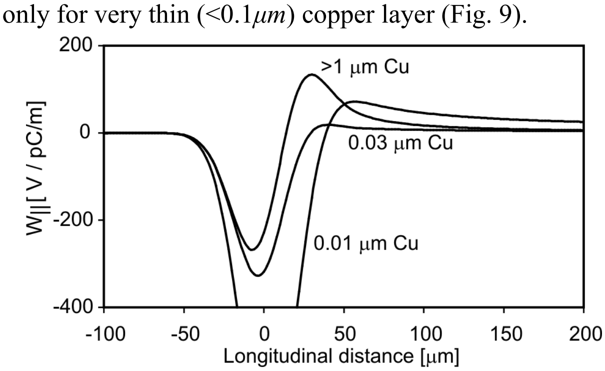

Figure 9: Resistive longitudinal wake potentials of in vacuum undulator for different thickness of copper layer.

The very low frequency part of transverse impedance strongly depends on the outer magnetic layer even at thick inner non-magnetic (Cu - $60\mu m$) layer (Fig. 10).

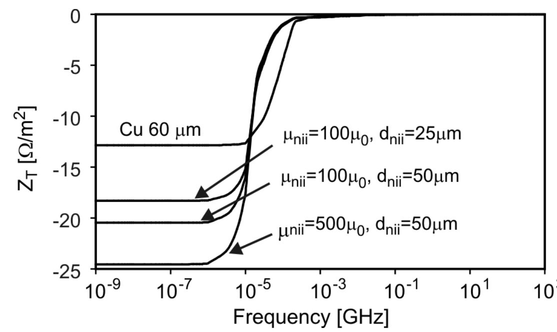

Figure 10: Imaginary part of transverse impedance of in vacuum undulator for different permeability of Ni. For comparison the case without outer layer is given.

However, due to shortness of the bunch the kick factor is conditioned by the high frequency part of the impedance and is equal to 2.6 kV/pC/m^2. The effect of the nickel layer to transverse wakefield is visible only for very thin copper layer (Fig. 11).

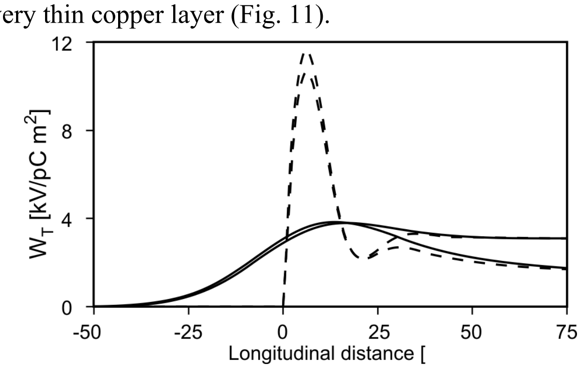

Figure 11: The point (dotted) and PSI-XFEL bunch (solid) transverse wake potentials of in vacuum undulator for thick and thin copper layers.

Conclusion

The properties of impedance and wakefield of in vacuum undulator of PSI-XFEL have been analysed. The dependence of transverse impedance on the magnetic properties of Ni layer material is studied. It is shown that the wake potentials are conditioned by the inner Cu layer.

SUMMARY

The analysis of the longitudinal and transverse impedances and wake potentials for PSI-XFEL ordinary and in vacuum undulators has been performed. The impact of the layers thickness is studied.

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

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