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IMPACT OF NEG COATING THICKNESS AND RESISTIVITY ON BEAM COUPLING IMPEDANCE

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Abstract

In diffraction-limited storage rings, non-evaporable getter (NEG) coatings are generally used to assure the ultrahigh vacuum, which, however, also increase the beam coupling impedance that can affect beam dynamics. Ignoring the influence of coating roughness, the impact of NEG coatings on the impedance mainly depends on the coating thickness and resistivity. In this paper, we investigate the impedance characteristics of a round CuCrZr vacuum chamber coated by NEG with different thickness and resistivity.

INTRODUCTION

For diffraction-limited storage rings (DLSRs) designed based on multi-bend achromat lattice, its vacuum chamber size is generally limited by the requirements for high gradient multipole magnets and high performance insertion devices. Small vacuum chamber is not conducive to maintaining the ultra-high vacuum environment for beam circulating in the ring. To assure the ultra-high vacuum, it is necessary to make a layer of NEG coating on the inner surface of vacuum chamber to improve the pumping speed [1]. However, NEG coating will increase significantly the resistive wall (RW) impedance especially in the high frequency region, resulting in a reduction in the threshold of single bunch instabilities, e.g., microwave instability and transverse mode coupling instability [2].

For vacuum chambers with NEG coating, the IW2D (ImpedanceWake2D) code is most widely used to calculate the RW impedance [3, 4]. For ease of impedance calculation in the windows operating system, we referred to the core source code of IW2D and wrote a Mathematica script to substitute for IW2D. After debugging, both results were basically consistent. Therefore, all impedance calculations in this paper were performed using this Mathematica script.

To calculate the RW impedance, in addition to the parameters of vacuum chamber, generally, two key parameters of NEG coating are required to set: thickness and resistivity. For DLSRs, the coating thickness is usually around 1 μm [1], and the coating resistivity, depending on the coating method, often varies in the range of 1.25×10^{-6}~7.1×10^{-5} Ω·m [5]. It naturally leads to the question: what is the best choice of the thickness and resistivity of NEG coating for mitigating its influence on the RW impedance ? To answer this question, it is better to sweep the two parameters and evaluate the impedance accordingly. Once obtained the impedance data, we can further calculate the longitudinal loss factor and transverse kick factor to preliminarily assess the impact of NEG coating.

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THEORY AND METHOD

Impedance Calculation

As mentioned earlier, we used a Mathematica script (equivalent to IW2D) for NEG coating parameter sweeping calculation. The resistivity and thickness of NEG coating are swept in the range of 1×10^{-7}~1×10^{-4} Ω·m and 0.1~ 2 μm, respectively. The round vacuum chamber is assumed to has a radius of 11 mm and material of CuCrZr with resistivity of $\rho = 2.18\times10^{-8}$ Ω·m.

Loss Factor and Kick Factor

For a Gaussian bunch, the loss factor and the kick factor are respectively given by :

$$K_{loss} = \frac{\omega_0}{2\pi}\sum_{p=-\infty}^{\infty}\mathrm{Re}[Z_{\parallel}(p\omega_0)]\exp[-(p\omega_0\sigma_t)^2], \quad (1)$$

and

$$K_{\perp} = -\frac{\omega_0}{2\pi}\sum_{p=-\infty}^{\infty}\mathrm{Im}[Z_{\perp}(p\omega_0)]\exp[-(p\omega_0\sigma_t)^2], \quad (2)$$

where σ_t is the rms bunch length, ω_0 is the revolution angular frequency, p is an integer, $\mathrm{Re}[Z_{\parallel}]$ is the real part of the longitudinal RW impedance and $\mathrm{Im}[Z_{\perp}]$ is the imaginary part of the transverse RW impedance.

IMPACT OF NEG COATING

Impact of NEG Coating Resistivity on Impedance

Figures 1 and 2 show the longitudinal and transverse RW impedances of per-unit-length vacuum chamber with a 1 μm NEG coating, respectively. It is obvious that the NEG coating mainly affects the impedance behaviour in the frequency region of higher than 10 GHz. It should be noted, in this frequency region, that the impedance behaves like a resonator, and the resonant peak of the real part gets higher and the corresponding bandwidth gets narrower with the increase of resistivity. For the cases of resistivity in 5×10^{-6}~1×10^{-4} Ω·m, the difference among them is small. It indicates that, with the resistivity in this range, the impact of NEG coating on the longitudinal and transverse impedance has a weak dependence on resistivity. For the case of resistivity in 1×10^{-7}~5×10^{-6} Ω·m, the imaginary part significantly decreases with a decrease in resistivity, while the real part exhibits complexity as shown in Figs. 1 and 2(top) where different curves cross each other in 10^{10}~10^{13} Hz.

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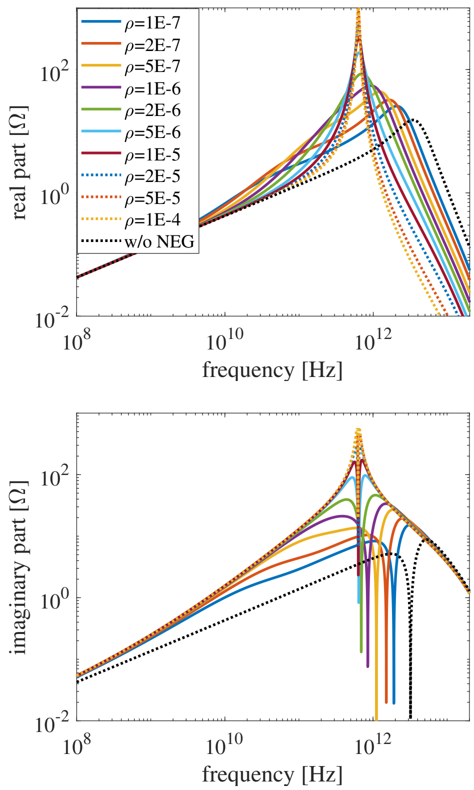

Figure 1: Longitudinal RW impedance of per-unit-length vacuum chamber with different NEG resistivities.

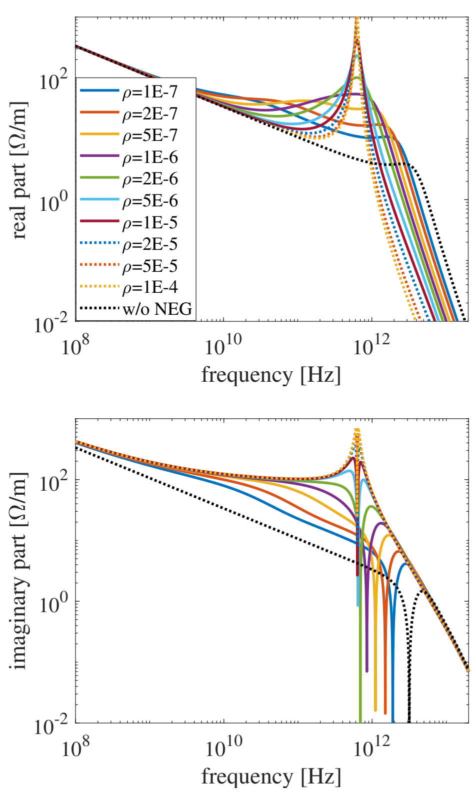

Figure 2: Transverse RW impedance of per-unit-length vacuum chamber with different NEG resistivities.

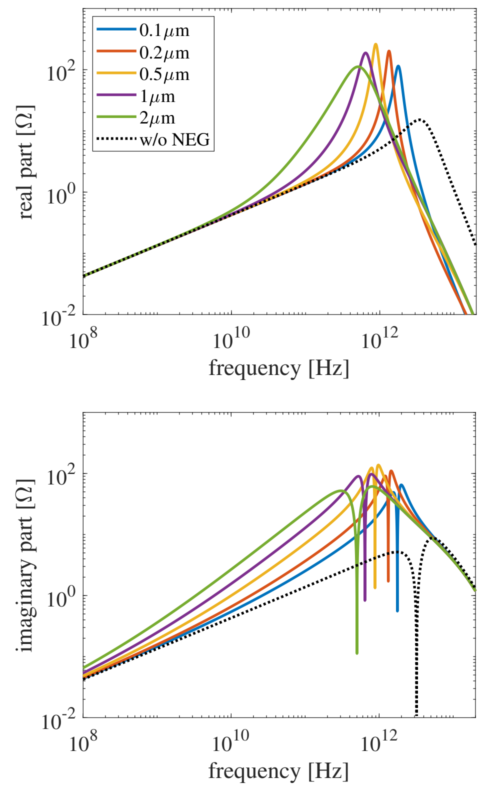

Figure 3: Longitudinal RW impedance of per-unit-length vacuum chamber with different NEG thickness.

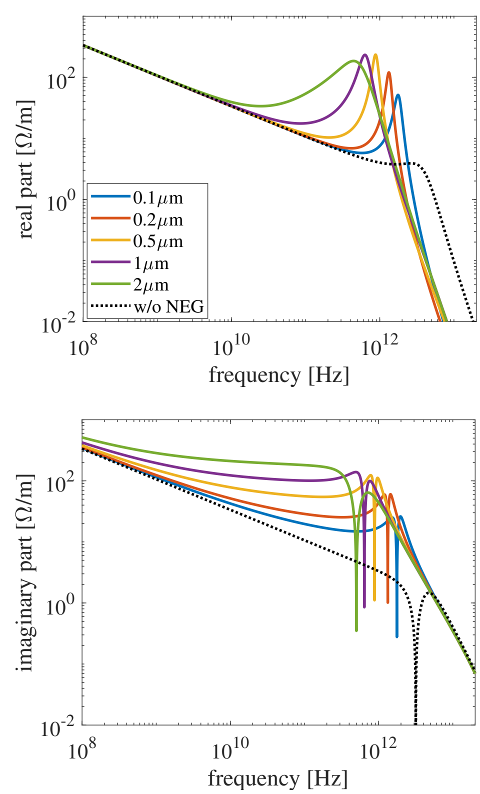

Figure 4: Transverse RW impedance of per-unit-length vacuum chamber with different NEG thickness.

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Impact of NEG Coating Thickness on Impedance

We choose the case of resistivity of 5×10^{-6} Ω·m to evaluate the impact of NEG coating thickness. As shown in Figs. 3 and 4, both longitudinal and transverse impedances behave like a resonator in the frequency range of 10^{10}~10^{13} Hz: the resonant peak gets lower as the thickness is raised from 0.5 to 2 µm or descended from 0.5 to 0.1 µm, and the resonant frequency gets smaller with increasing the thickness. It is found that the NEG coating thickness has a larger influence on the imaginary part than the real part, e.g. the observable discrepancy of the real part between the cases of '2 µm' and 'w/o NEG' starts from about 10^{10} Hz which is two orders of magnitude higher than that of the corresponding imaginary part. It is obvious that the imaginary part is increased significantly with the thickness.

Impact of NEG Coating on the Loss Factor and Kick Factor

The longitudinal loss factor and transverse kick factor of per-unit-length NEG coated vacuum chamber are shown in Figs. 5 and 6, respectively. As expressed in Eqs. (1) and (2), both factors are a function of the rms bunch length. The case of 2 mm rms bunch length is taken into account here.

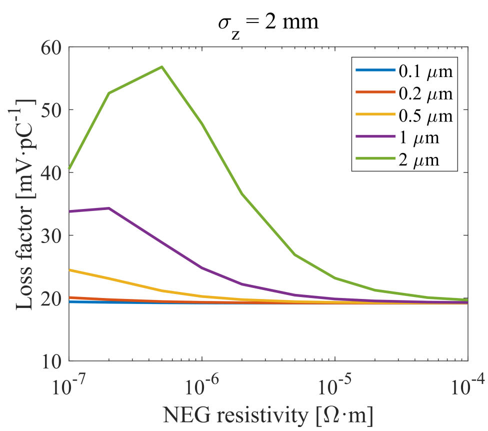

Figure 5: Loss factor for different resistivity and thickness of NEG coating.

We can see that both loss and kick factors can be reduced by reducing NEG coating thickness, and that the reduction level of loss factor increases with reducing the resistivity, while it is contrary for the kick factor. For the case of thickness in the range of 0.1~1 µm, the resistivity variation in the range of $5{\times}10^{-6}$~$1{\times}10^{-4}$ Ω·m has a slight effect on the loss factor and the kick factor. For the case of thickness in the range of 1~2 µm, the loss factor generally increases obviously and the kick factor decreases significantly with the decrease of resistivity in $1{\times}10^{-7}$~$1{\times}10^{-5}$ Ω·m.

As for the kick fator shown in Fig. 6, we can see that if the thickness is reduced from 1 to 0.5 µm in the resistivity range of $1{\times}10^{-6}$~$1{\times}10^{-4}$ Ω·m, the kick factor can be reduced by ~33%; if the thickness is further reduced to 0.2 µm, the kick factor can be reduced by ~54%. This reduction is significant. If the thickness is set to 1~2 µm, the kick factor

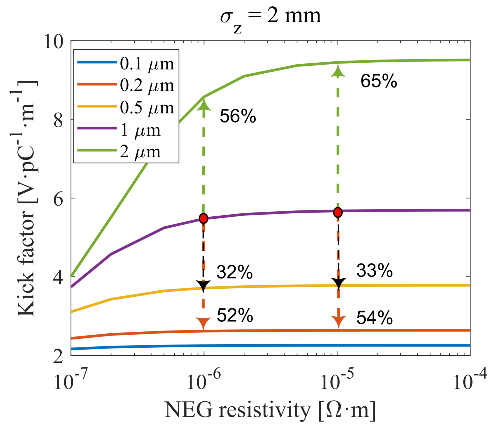

Figure 6: Kick factor for different resistivity and thickness of NEG coating.

can be reduced significantly by reducing the resistivity only less than $5{\times}10^{-7}$ Ω·m. If the thickness is set to 0.5 µm, or even to 0.1~0.2 µm, the kick factor is hardly reduced with the reduction of the resistivity.

CONCLUSION AND OUTLOOK

In this paper, the RW impedances of the round vacuum chamber with radius of 11 mm and material of CuCrZr were calculated using a Mathematica script, via sweeping the resistivity and thickness of NEG coating in the ranges of $1{\times}10^{-7}$~$1{\times}10^{-4}$ Ω·m and 0.1~2 µm, respectively. Resonance-like impedance with a high peak was observed for the longitudinal RW impedance in the case of resistivity in the range of $5{\times}10^{-6}$~$1{\times}10^{-4}$ Ω·m. Reducing the resistivity can decrease the kick factor, but it is likely to increase the loss factor. The impact of NEG coating had only been discussed with the impedance, loss factor and kick factor. In the future, the impact of NEG coating on the single bunch instability for a designed DLSR will be further studied through macro-particle tracking simulations.

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