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Resistive-wall impedance of an elliptical multilayer beam pipe and its induced incoherent tune shift

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Introduction: In order to investigate the influence of non-uniform thickness of the coating on the impedances, the analytical expressions of the resistive-wall impedances for the elliptical multilayer beam pipe, considering the confocal interfaces, are studied in the ultrarelaticistic limit. For a beam pipe with elliptical cross section, the quadrupolar impedances can be produced and incoherent tune shifts will be induced in the two transverse planes. The complex incoherent frequency shift due to the quadrupolar impedance is derived from beam oscillation equations, which shows that the direct current (DC) value of the quadrupolar impedance dominates the frequency shift and both the conductivity and the permeability of different layers with finite thickness should be considered.

1. Form Factor

Since in case of an ultrarelativistic beam, the form factors depend only on the geometry of the chamber, the form factors can be defined as the ratio of the impedances for an infinite thick elliptical chamber and that for an infinite thick circular chamber.

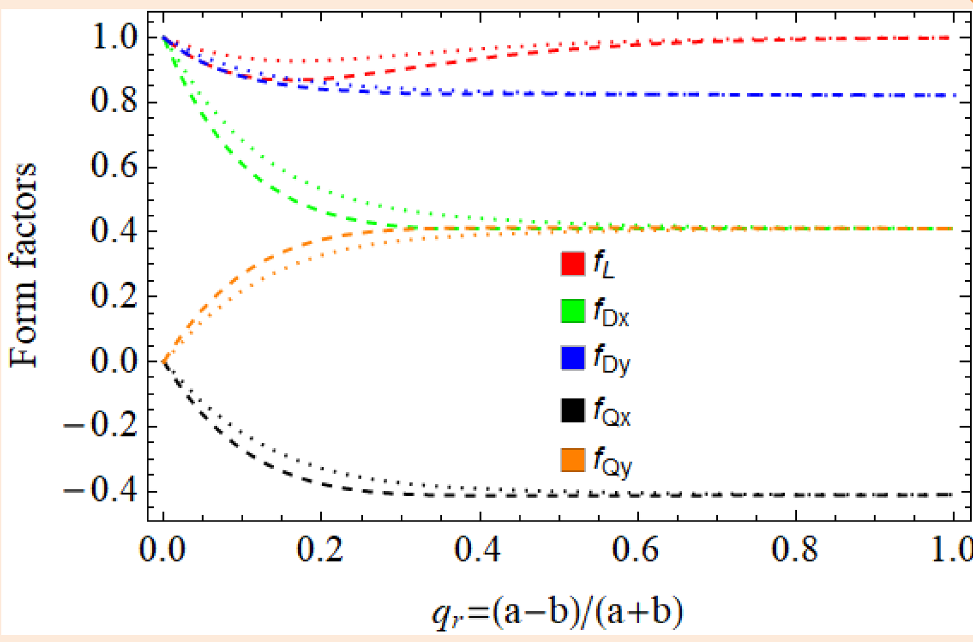

Fig.1. The form factors are calculated as a function of frequency in the range of $\frac{4}{\mu_0 \sigma F^2} \ll \omega \ll \chi^{\frac{1}{3}} c/b$, where $\chi = \frac{1}{\mu_0 \sigma b c}$, b is the pipe radius, σ is the conductivity of the metal conductor.

2. Resistive wall impedance with nonuniform NEG coating

Considering the confocal interfaces, two different impedance models are defined to investigate the influence of the nonuniform thickness of the NEG coating on the impedances. In addition, the impedances are also calculated with IW2D. In the calculation, the chamber size is 28×37.5mm, which is representative to the CEPC CDR. The beam pipe is made of copper with NEG coating on the inner surface.

Table 1. The thickness of NEG coating

	Horizontal thickness	Vertical Thickness
Model X	1 μm	1.34 μm
Model Y	0.75 μm	1 μm
IW2D	1 μm	1 μm

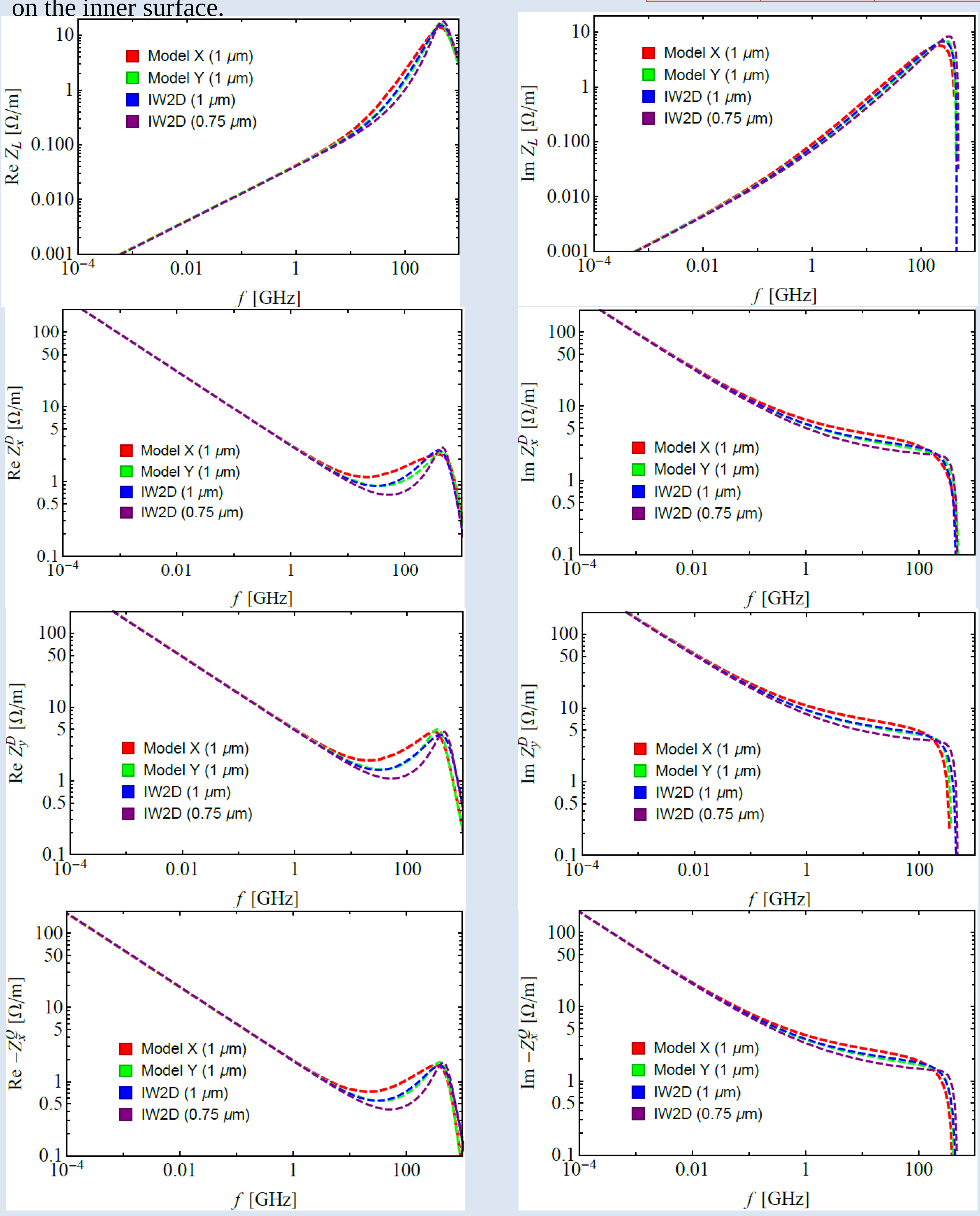

Fig.2. Impedances of NEG coating chamber

The results show that the impedances given by Model Y are consistent well with the product of the form factor and that given by IW2D with coating thickness of 1 μm. From the results we can conclude that the impedances are more sensitive to the vertical thickness of the NEG coating, other than the horizontal thickness.

3. Incoherent tune shift

For a beam pipe with an elliptical cross section, the quadrupolar impedance will be produced. During multibunch operation in a circular accelerator, the complex mode frequency shift is sensitive to the long range wake, which will be further enhanced by the quadrupolar component. In order to get more accurate estimation of the quadrupolar impedance and its induced tune shift, materials outside the beam pipe should be considered and impedance model for multilayer elliptical beam pipe is required. The incoherent tune shirt is expressed as

$$\frac{d\Delta\nu_\beta}{dI} = \frac{C}{8\pi^2\left(\frac{E}{e}\right)\nu_\beta}\sum_{p=-\infty}^{\infty} Im\, Z_\perp^Q\,(pM\omega_0),$$

where $\nu_\beta = \omega_\beta/\omega_0$, M is the bunch number, ω_0 is the angular revolution frequency.

The parameters of the beam pipe is representative to CEPC CDR. Two different models, named Model A and Model B, are considered in our studies. In model A, the material outside the chamber is defined as infinitely thick air. While in Model B, a layer of magnetic material with finite thickness, surrounded by infinitely thick air, is added.

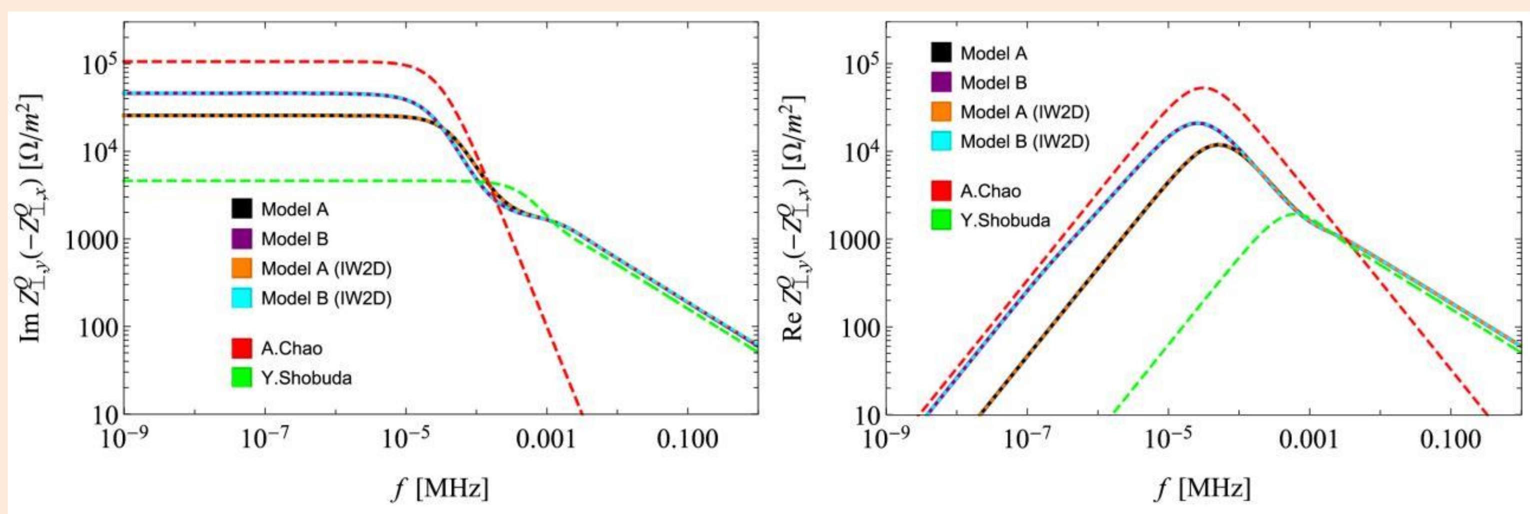

Fig.3. Imaginary (left) and real (right) parts of the quadrupolar impedances for different impedance models.

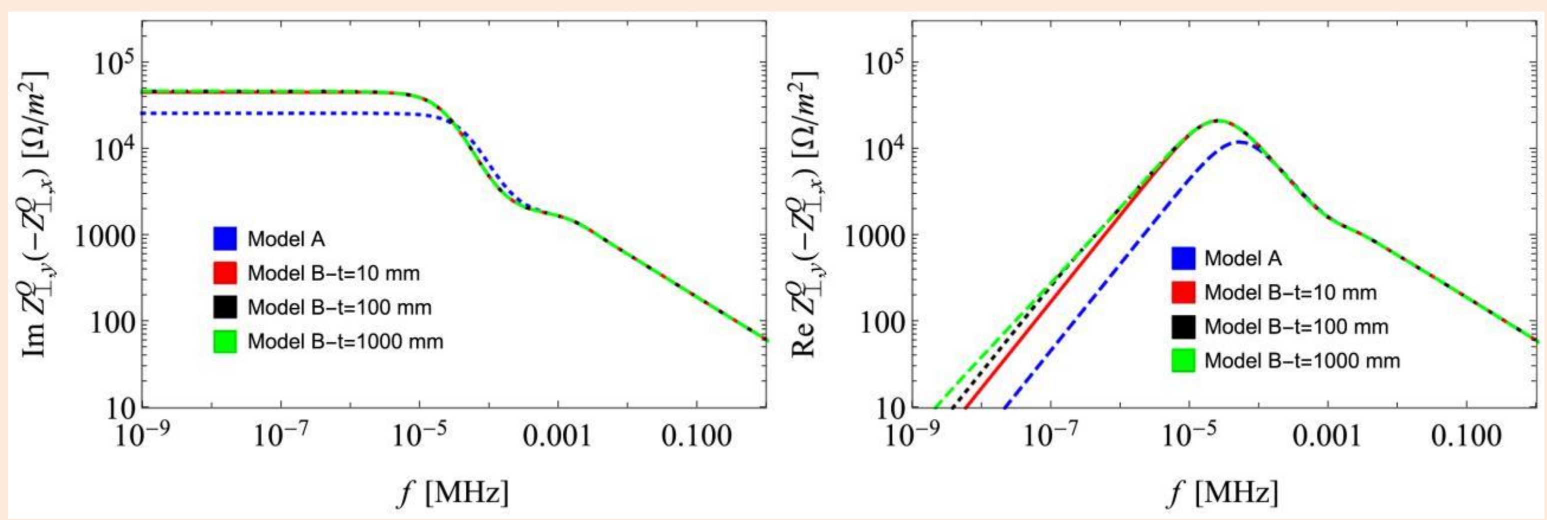

Fig. 4. Imaginary (left) and real (right) parts of the quadrupolar impedances for difference thickness of magnetic material.

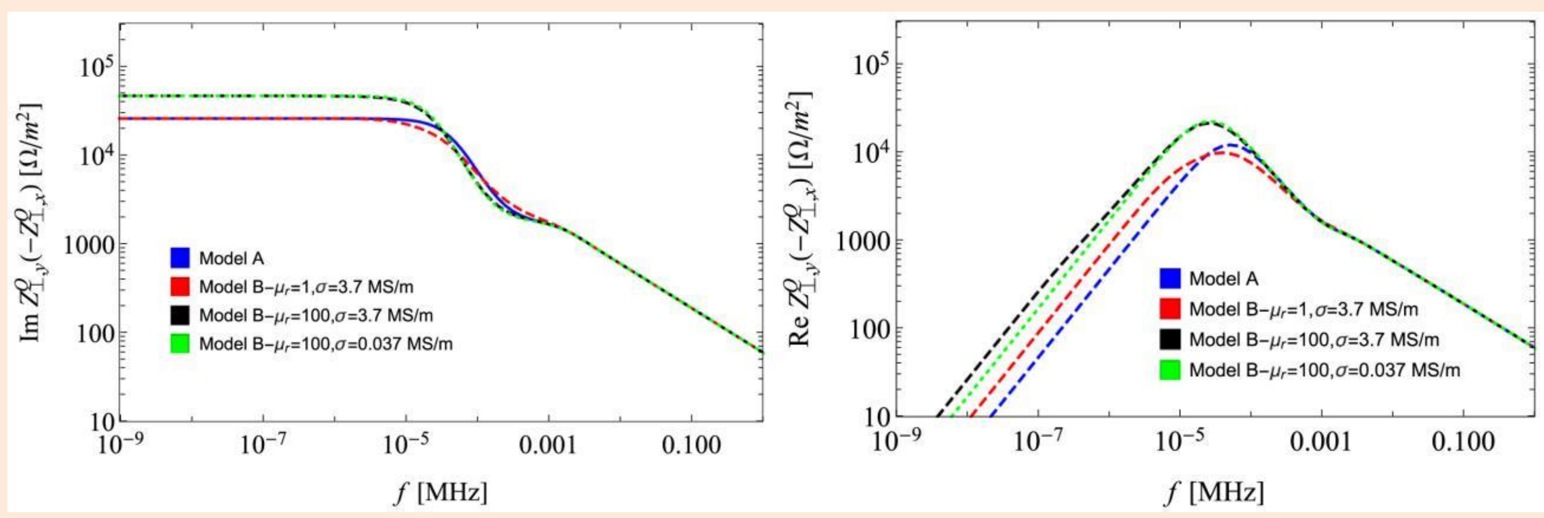

Fig. 5. Imaginary (left) and real (right) parts of the quadrupolar impedances for different conductivities and permeabilities of the magnets.

Table 2. Tune slopes of CEPC Z operation due to quadrupolar contribution for different impedance models.

Model	Tune slope(x/y) (A^{-1})	Form factor f_y^Q (-f_x^Q)
A. Chao	0.65/-0.64	0.41
Y. Shobuda	0.06/-0.06	0.28
Model A	0.16/-0.15	0.33
Model B	0.28/-0.28	0.33
Model A(20%)+Model B(80%)	0.26/-0.25	0.33

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