SHIELDING OF BEAM PIPE ON RAPIDLY VARYING MAGNETIC FIELD

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Abstract

In low emittance rings, beam is quite sensitive to orbit oscillations. Fast correctors will be used to correct the beam orbit. The fast varying magnetic field will generate eddy current on the beam pipe, which will in turn change the phase and the amplitude of the magnetic field. The shielding effect of the beam pipe on a fast varying magnetic field is simulated for different frequencies. The results are also benchmarked with the measurements in the lab.

INTRODUCTION

In the new generation of synchrotron radiation photon sources, smaller transverse beam emittance is proposed for high brightness. The user experiments normally require the reproduction and stabilization of a closed orbit within 1/10th of the electron beam size. Therefore, closed orbit stabilization against external vibrations is essential to ensure low emittance and high brightness. Fast orbit feedback systems are commonly used to suppress the orbit perturbations in the relevant frequency range up to kHz [1]. The AC component of the correction magnetic field can induce eddy current inside the vacuum chamber, and result in poor response of the high frequency corrections [2]. Therefore, the material of the beam pipe at the fast correctors should be carefully chosen, and the influence of the field reduction and delay should be considered when evaluating the performance of the feedback system.

In this paper, the amplitude degradation and the phase shift of rapid varying magnet field in the presence of vacuum chamber relative to the unperturbed field are studied. The dependences of the phase shift and amplitude attenuation on the correction frequency, as well as the geometry of the magnet and the vacuum chamber are discussed. The results are also benchmarked with the test measurement in the lab.

SIMULATION MODEL

The shielding of the beam pipe on rapid varying magnetic field is first studied by simulations with the code CST [3]. The schematic view of the simulation model is shown in Fig. 1. In the simulation, a transient magnetic field is generated by two parallel coils. A section of cylindrical beam pipe is located in the middle. To calculate the amplitude reduction and the phase shift, a current signal with sine wave of frequency f_0 is defined in the coil as excitation signal. The vertical magnetic fields inside and outside the beam pipe are recorded by a point field monitor. For a input signal with f_0=10 kHz and a stainless steel beam pipe with inner radius of 11 mm and thickness of 1 mm, the magnetic field inside the beam pipe is compared with the unperturbed field. The result is shown in Fig. 2. We can see that due to the eddy current effect, the strength of the magnetic field has been reduced by a factor of 0.8 and a phase shift of 2.7° exists between the two signals.

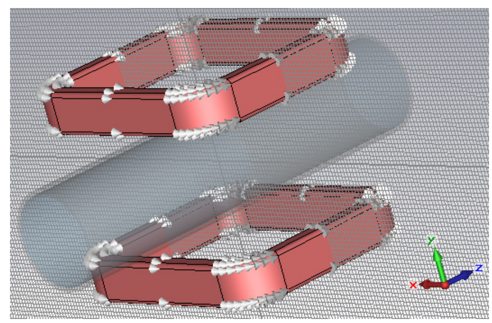

Figure 1: Simulation model.

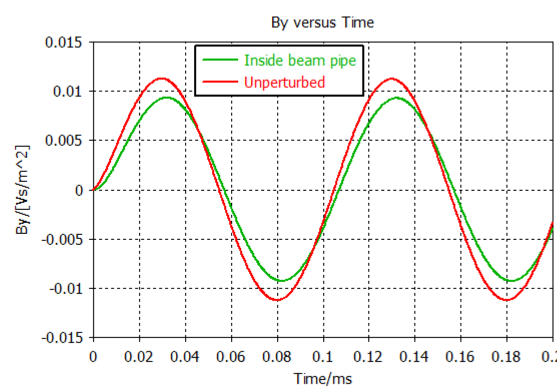

Figure 2: Magnetic field inside the beam pipe compared with the unperturbed signal.

SIMULATION RESULTS

With the simulation model described in the former section, the dependences of the phase shift and amplitude attenuation on frequency, as well as the geometry of the vacuum chamber and the magnet coil are discussed.

Phase Shift and Amplitude Attenuation vs. Frequency

The dependence of the phase shift and field attenuation on the frequency of the signal is summarized in Fig. 3. The other parameters are kept constant while doing the frequency scan. The frequency is varied from 100 Hz to 10 kHz. It shows that the phase delay increases almost linearly with the frequency of the signal, and the amplitude attenuation also increases with the frequency.

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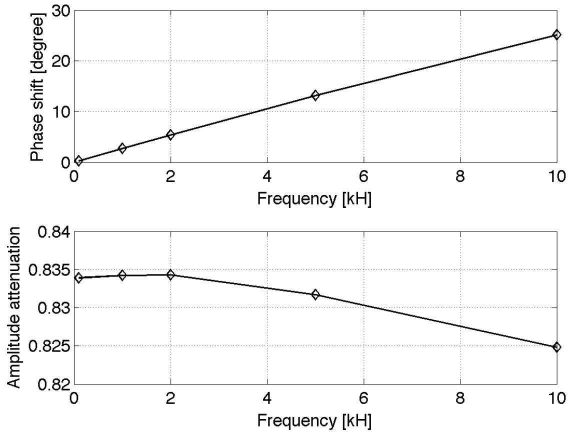

Figure 3: Dependence of phase shift (up plot) and amplitude attenuation (down plot) on frequency.

Phase Shift and Amplitude Attenuation vs. Beam Pipe Conductivity

The eddy current effect is quite sensitive to the conductivity of the beam pipe. The dependence of shielding effect on the conductivity of the beam pipe is shown in Fig. 4. It shows that the phase shift increases with the conductivity of the beam pipe. With the simulation model, the phase shift reaches 90° with conductivity of 1E7 S/m at frequency of 1 kHz. The amplitude attenuation is also quite sensitive to the conductivity. Therefore, high resistive material is preferred to reduce this effect.

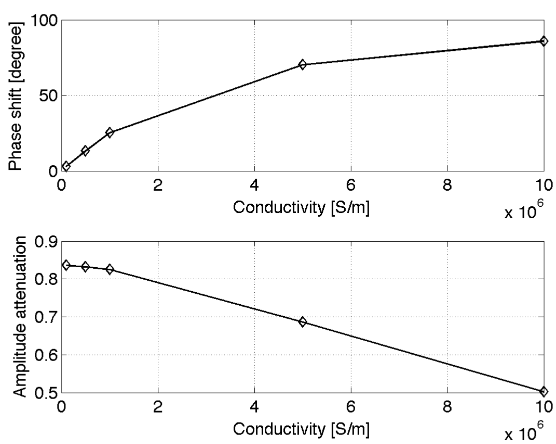

Figure 4: Dependence of phase shift (up plot) and amplitude attenuation (down plot) on the conductivity of the beam pipe.

Phase Shift and Amplitude Attenuation vs. Beam Pipe Thickness

The dependence of the phase shift and amplitude attenuation of the magnetic field on the thickness of the vacuum chamber is summarized in Fig. 5. The phase shift increases rapidly with the thickness of the beam pipe. The amplitude of the magnetic field decreases when increasing the thickness of the beam pipe.

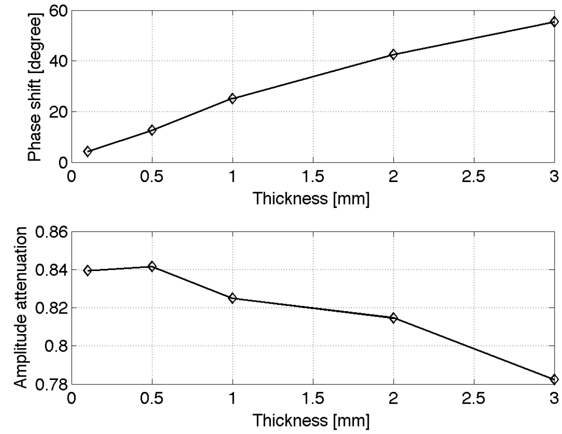

Figure 5: Dependence of phase shift (up plot) and amplitude attenuation (down plot) on the thickness of the beam pipe.

Phase Shift vs. Beam Pipe Aperture

The shielding of the beam pipe on the fast varying magnetic field is also dependent on the aperture of the beam pipe, as illustrated in Fig. 6. It shows that the phase shift increases with the beam pipe aperture, while the amplitude attenuation is not quite related to the aperture size. Anyway, smaller beam pipe aperture is still beneficial in decreasing the effect of shielding.

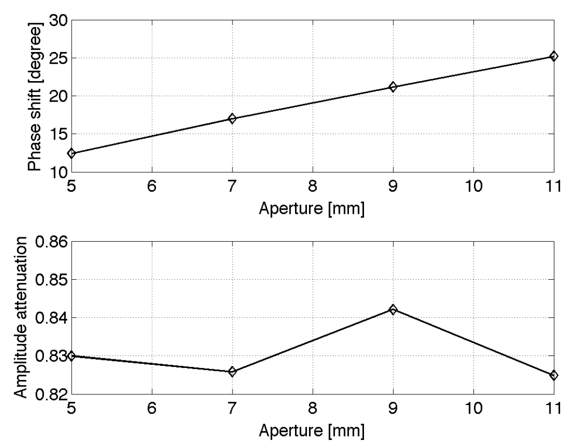

Figure 6: Dependence of phase shift (up plot) and amplitude attenuation (down plot) on the beam pipe aperture.

Phase Shift and Amplitude Attenuation vs. Dimensions of the Magnetic Coil

The dependence of the phase shift and amplitude attenuation on the dimensions of the magnetic coil is summarized in Fig. 7. The phase shift is less related to the transverse dimension and gap between the magnetic coils, but it increases with the length of the coil along the beam pipe axis. However, the amplitude attenuation increases rapidly when we reduce the transverse dimension or the length of the coil, and decreases when we reduce the height.

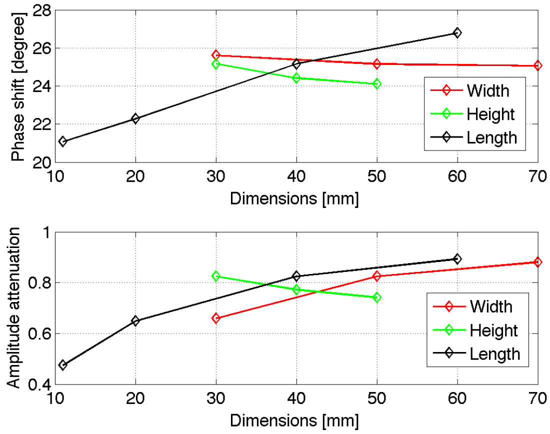

Figure 7: Dependence of phase shift (up plot) and amplitude attenuation (down plot) on the dimension of the coil.

CROSSCHECK WITH TEST MEASUREMENT IN THE LAB

In order to check the validity of the simulation model, a test measurement of the delay in the penetration of the time varying magnetic field due to the eddy current effect is performed with a section of stainless steel vacuum chamber. The source signal is provided by a waveform generator. The magnetic field is generated by a coil winded on a ferrite block. Sine waves of frequency from 50 Hz to 10 kHz are used. The unperturbed field and the field inside the vacuum chamber are measured simultaneously and displayed on an oscilloscope. The amplitude attenuation and the phase shift of the magnetic field inside the vacuum chamber are obtained by comparing with the unperturbed field.

The measurement results are summarized in Fig. 8 and Fig. 9. We can see that the phase shift increases with the frequency of the input signal. The amplitude attenuation of the magnetic field is small up to 2 kHz, and the amplitude reduces rapidly above 2 kHz. The skin depth at 2 kHz of the vacuum chamber is about 10 mm, which is ten times of the thickness of the vacuum chamber.

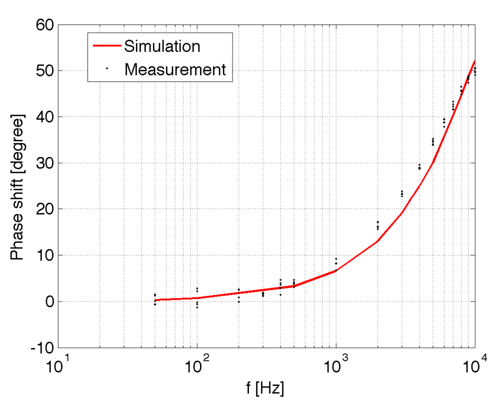

Figure 8: Phase shift versus frequency.

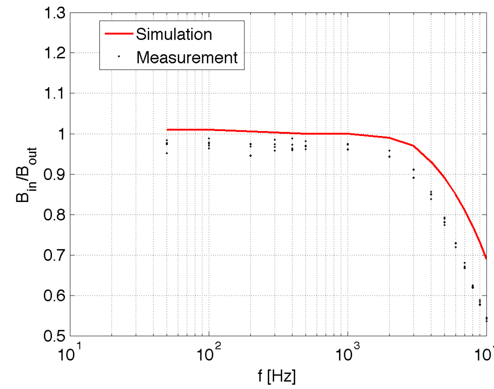

Figure 9: Amplitude attenuation versus frequency.

The measured results are compared with the simulations, which corresponds to the red curves in Fig. 8 and Fig. 9. We can see that considerably good consistent has been reached between simulation and measurement on the phase shift. While the amplitude attenuation is a little smaller in the simulation compare to the measurement. This is reasonable since the model has been simplified in the simulation somehow.

SUMMARY

The phase shift and amplitude attenuation of the fast varying magnetic field due to the eddy current effect of the vacuum chamber are studied. The dependences of the shielding on frequency, as well as the geometry of the vacuum chamber and the magnet coil are investigated by simulations. The reliability of the numerical simulation is benchmarked with measurements, and considerably good consistent has been reached.

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