IMPEDANCES CALCULATIONS OF BELLOWS IN HLS II STORAGE RING

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Abstract

The upgrade project of Hefei Light Source storage ring is under way. In this project, a new Bellows, in which shielding is provided by sprung fingers that can slide along the beam screen, is installed at the accelerator interaction area in order to reduce this impedance to an acceptable value. The contributions of Bellows to short range wake fields and broadband impedance were calculated numerically by Mafia code and the analytical method.

INTRODUCTION

The upgrade project of Hefei Light Source storage ring is carrying on, the designed perimeter is 66.13m .Bellows is an important part of storage ring, which is consisting of hundreds of devices. When the beam is passing through the bellows in the speed of light, On the one hand the induced current has the same value as the electron beam in the bellows, which produce higher thermal load, on the other hand the bellows is a kind of cavity structure, which is increasing the coupling impedance between the beam and the vacuum chamber, so we use the bellows with a RF-shield structure structure to replace the normal one. In this article we are using the procedures of Mafia to calculate the short-range wake fields and broadband impedance of the bellows, but we obtained the long-range wake fields and the impedance by the analytical method, which is using the E- module of the Mafia procedures to calculate shunt impedance, Q value and so on.

STRUCTURE OF THE BELLOWS

The bellows with RF-shield structure is constituted by several metal strips with small resistance .which is connected the corrugated structure of the bellows, So that the wall current can only flow in the shielding layer. Which is used to avoid a class-cavity structure to reduce the high-order modes excitation (Figure 1). Both ends of the bellows are CF100 flanges, and the inner tube cross-section is an octagon.

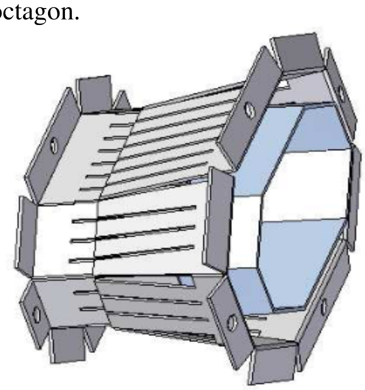


Figure 1: the model of the RF-shield structure structure.

WAKE FIELDS OF BELLOWS

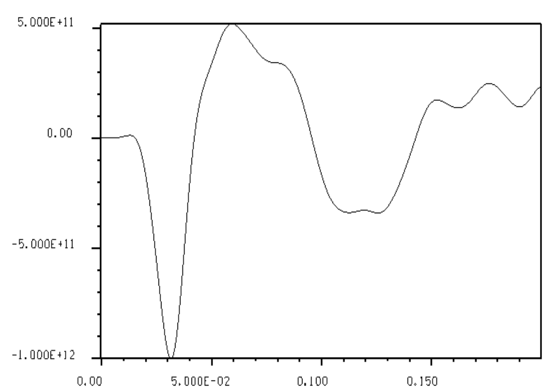
The short-range wake fields,which is generated by the interaction between the beam and bellows, will cause a single bunch instabilities[1]. Especially when the single bunch is operating with high current in Hefei storage ring, the short-range wake fields of the entire storage ring is very important, the longitudinal and transverse short-range wake fields of the bellows is shown in Figure 3 ,which is calculated by the T3- module of the Mafia procedures in the time domain[2]. We obtained the normalized impedance spectroscopy through the fast Fourier transform of the wake fields and bunch. Assume now that the charge q_1 is continuously distributed over the z-axis according to the time distribution function $I_{(\tau)}$ such that:

$$q_1 = \int_{-\infty}^{+\infty} I_{(t)} dt \qquad (1)$$

Applying the superposition principle, splitting the distributions into an infinite number of infinitesimal slice and adding their wake contribution. Then we obtain:

$$W_b(t) = \frac{1}{q_1} \int_{-\infty}^{\infty} w_z(t - t')I(t')dt' \qquad (2)$$

Where $w_z(\tau)$ is the wake function.



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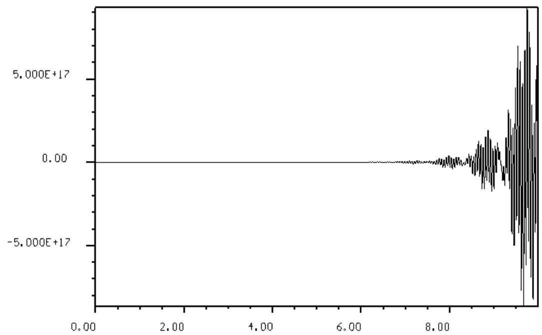
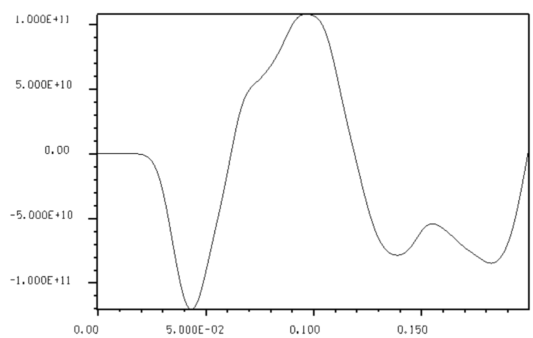


(b)

Figure 2: Longitudinal wake field [V/C] of Gaussian bunches in bellows versus distances form head of bunch [m].



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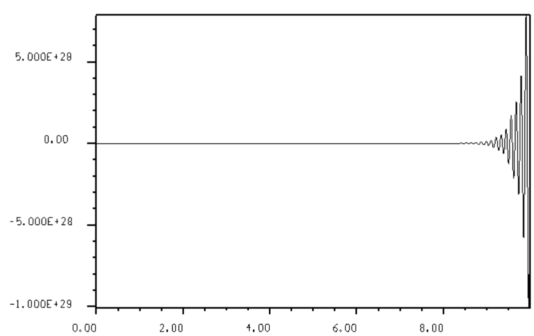

(b)

Figure 3: Transverse wake field [V/C] of Gaussian bunches in bellows versus distance s form head of bunch [m].

Figure 2 and 3 are the longitudinal and transverse wake potential of 5mm Gaussian bunches in bellows, Short-range wake fields plays an important effect on the single bunch instability, and the long-range wake field plays an important effect in the multi-bunch coupling instability .Form the result of calculation, we can find that the RF-shield structure structure of bellows has a strong inhibitory effect for the Continued turbulence of the long-range wake fields.

THE IMPEDANCE CALCULATION OF BELLOWS

The impedance spectrum of bellows consists of the narrow-band impedance and broadband impedance which are distinguished by their cut-off frequency. Narrow-band impedance is mainly caused by the long-range wake field of the bellows, and broadband impedance is a short wake field of the bellows, which can be efficiently calculated in the time domain. From fligure3 and figure 4, when the bunch is away from the bellows for a long distance, wake fields potential is divergence, so the long-range wakes fields simulated by mafia is inaccurate, so it is generally taken to resolve the long-range wake fields by the analytical method, then you need to use E module of mafia to calculate possible longitudinal mode, long-range wake field can be obtained from the following formula[3]:

$$G_{//}(\tau)=\sum_n \frac{\omega_n R_{sn}}{Q_n}\exp(-\frac{\omega_n \tau}{2Q_n})(\cos\omega_n^{'}\tau-\frac{1}{2Q_n^{'}}\sin\omega_n^{'}\tau) \quad (3)$$

$$\frac{dG_{\perp}^{'}(\tau)}{d\tau}=\sum_n \frac{\omega_r R_{\perp n}}{Q_n^{'}}\mathrm{Re}\{\omega_1\exp(j\omega_1\tau)\}=\omega_r\frac{R_s}{R_{\perp}}G_{//}(\tau)$$

Where ω_n is the resonant frequency, Q_n is the quality factor, $Q_r^{'}=\sqrt{Q_r^2-\frac{1}{4}}$, $\tau=s/c$, R_{sn} is the shunt impedance . In the frequency domain, we are using E module of MAFIA to obtain the eigenmode and the shunt impedance of the bellows (Table 1).

From the table 1, we can see that the higher-order modes of the bellows are relatively small, so that the high-frequency shielding structure has a significant role for reducing the high-order mode shunt impedance and suppress coupled bunch instability.

For a point charge, the beam impedance can be obtained by the Fourier transform of the wake function [3].

$$Z^{\delta}(\omega)=\int_{-\infty}^{+\infty} w_z(\tau)e^{-i\omega\tau}d\tau \quad (4)$$

Meanwhile the wake fields also can be obtained by impedance[4]:

$$W_z(\tau)=\frac{\int_{-\infty}^{+\infty} Z(\omega)I(\omega)e^{i\omega\tau}d\omega}{2\pi q_1} \quad (5)$$

Where $I(\omega)$ is the Fourier transform of the bunch current.

We know that, the shorter the bunch, the closer the resulting impedance spectroscopy to the theoretical value of the impedance[5]. But it is not proper to calculate the wake field and coupling impedance via the T3 module of Mafia with too short bunch, so in this article, we utilize 5mm bunch to calculate the impedance spectrum. before

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Table 1: The Eigenmode and the Shunt Impedance of The Bellows

Monopole	frequency（Hz）	Q	Rs	Rs/Q
1	4.915408E+08	0.284096240E+04	0.248048344E+06	87.3
2	5.626468E+08	0.244929321E+04	0.277149023E+04	1.13
3	6.479841E+08	0.211048096E+04	0.443156201E+04	2.10
4	1.037271E+09	0.250224585E+04	0.249216557E+00	9.96E-05
5	1.273711E+09	0.262759790E+04	0.380955666E+00	1.45e-04
6	1.347021E+09	0.176381799E+04	0.389852930E+04	2.21
7	1.599435E+09	0.200449390E+04	0.107983467E+05	5.38
8	1.787998E+09	0.278743066E+04	0.215873169E+04	0.774
9	1.962035E+09	0.335945850E+04	0.425166931E+03	0.127
10	2.026669E+09	0.478884668E+04	0.259848750E+05	5.42
11	2.042709E+09	0.516425537E+04	0.224949551E+05	4.36
12	2.118706E+09	0.424883252E+04	0.454301300E+03	0.167
13	2.157269E+09	0.371599561E+04	0.624817188E+04	1.68
14	2.219281E+09	0.515417871E+04	0.253289719E+05	4.91
15	2.302603E+09	0.464521680E+04	0.311447129E+05	6.70

that we must know the effective frequency range of the calculated impedance:

$$k \le k_{\max} = \frac{1}{2\sigma_z} \qquad (6)$$

In this article,

$$\sigma_z = 5mm\,, \omega = 2\pi \cdot c \cdot k\,, k \le k_{\max} = 100$$

we can see that the resonance impedance is obtained from the following formula:

$$Z_L(\omega) = \sum_n \frac{R_{sn}}{1 - iQ_n\left(\frac{\omega}{\omega_n} - \frac{\omega_n}{\omega}\right)} \qquad (7)$$

By using the T3 module of the procedures of Mafia, we can obtain the the normalized impedance spectroscopy via the fast Fourier transform of the bunch and wakefield.

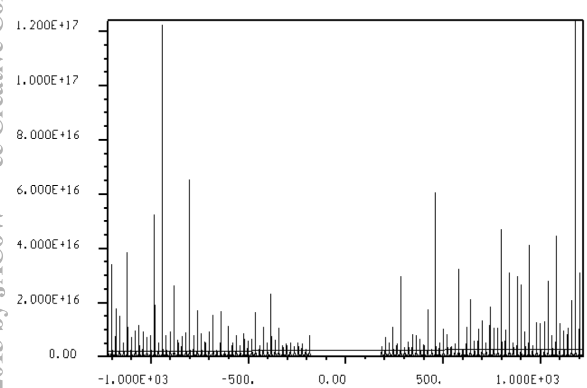

Figure 4: The longitudinal impedance spectrum of bellows versus wave number k.

CONCLUTION

As can be seen from the above calculations, the bellows with the high-frequency shielding structure inhibits the generation of high-order mode, and then reduce the effection of the wake fields on the beam. In the particle tracking process we use wake fields on the beam to study beam collective effect. For the storage ring, the bellows is just an impedance element, in the future, we will estimate all the impedance element impedance on the rin, such as the discontinuous gap between the blue of the vacuum chamber, RF cavity and so on. Then we will fit the wake function of the storage ring to analysis the beam instability, which was commissioned.

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