LOSS FACTOR AND IMPEDANCE OF IR BEAM DUCTS FOR SUPER-KEKB AND KEKB

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Abstract

As part of the design works of the interaction region (IR) of Super-KEKB (the upgrade of KEKB B-factory (KEKB)), the loss factor and impedance of beam ducts for the interaction point (IP ducts) were calculated by GdfiedL. The IP duct is round at IP and connected to beam ducts for electron and positron beams with a diameter of 20 mm via Y-shaped crotch ducts at both ends. The length of the straight section and the crotch section are about 200 mm. The beam crossing angle is 83 mrad. The loss factor of the IP duct was about 0.001 V/pC when the bunch length was 6 mm, which is much smaller than that of the IR ducts of KEKB. The longitudinal impedance showed that there was no mode trapped in the IP duct longitudinally. However, from the results of the calculations of the transverse impedance and eigenmode, it was found that many TE-like modes can be trapped at the crotch section if the beam is off-center of the beam duct vertically.

INTRODUCTION

KEKB is an electron-positron collider with asymmetric energies of 8 GeV and 3.5 GeV, respectively[1]. It has delivered a total integrated luminosity more than 1 ab^{-1} up to now and made a great contribution to confirm *CP* violation in the neutral *B* meson system. However, in order to pursue research on flavor physics, much more luminosity is required and the upgrade of KEKB, Super-KEKB, has been proposed[2]. The design luminosity of Super-KEKB is 8×10^{35} $cm^{-2}s^{-1}$, which is about 40 times larger than that of KEKB. The design works of IR of Super-KEKB is now in progress. The IR beam ducts have a complicated shape and the strong wake field can be generated at IR. It is, therefore, necessary to pay attention to two issues which are caused by the strong wake field. One is the heating program. The beam deposits its energy in the form of higher order modes (HOM). HOM propagates along the beam duct and heats up adjacent components. It is, therefore, necessary to know how much the power deposition is. The power deposition can be estimated from the loss factor. The second one is beam instability. If the beam is disturbed by HOM, the beam instability may occur and degrade the performance of the accelerator. So it is required to know the effect of HOM on the beam. It can be estimated from the impedance and the wake potential. At the design stage, therefore, the loss factor and impedance of the components must be checked. So far, several calculations of the loss factor and impedance of IR beam ducts of Super-KEKB and KEKB have been performed by GdfidL, which is a simulation code to compute electromagnetic fields in 3-D structures[3]. The results of calculations are provided in this report.

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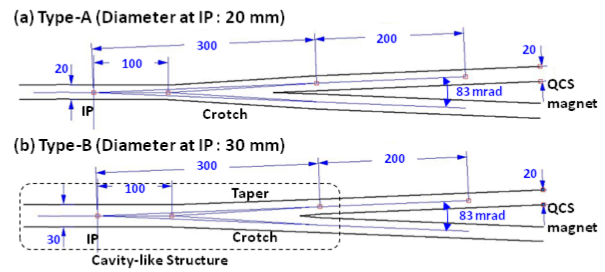

Figure 1: IP ducts for Super-KEKB

LOSS FACTOR

IP duct for Super-KEKB

At this time we have two candidates for the IP duct of Super-KEKB. Figure 1 shows drawings of the IP ducts. Both ducts are almost same in design except for the diameter at IP. It connected to beam ducts for electron and positron beams with a diameter of 20 mm via Y-shaped crotch ducts at both ends. The length of the straight section and the crotch section are about 200 mm. The beam crossing angle is 83 mrad.

Figure 1(a) shows Type-A IP duct with a diameter of 20 mm at IP. The diameter at IP is equal to that of the beam ducts at both ends. Because it doesn't form a cavity-like structure, HOM will be able to pass through the crotch ducts. Type-A IP duct, however, might be too weak to bear the weight of heavy masks which must be put at both side of it. To solve this problem, Type-B IP duct was designed. The diameter of IP is 30 mm and it will be able to bear the weight of the masks. In this case, however, HOM might be trapped in the IP duct because it forms a cavity-like structure.

The loss factor and longitudinal wake potential of both IP ducts were calculated by a time domain solver of GdfidL. Simulation models are shown in Fig. 2. The

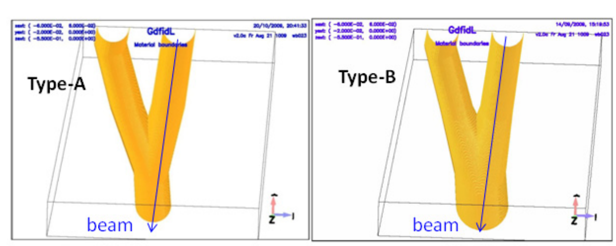

Figure 2: Simulation models of IP duct for Super-KEKB.

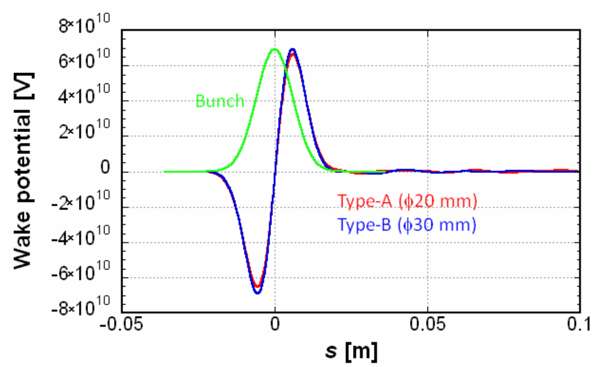

Figure 3: Longitudinal wake potentials of the IP ducts for Super-KEKB.

isotropic mesh size is 0.2 mm. A bunch was let through the IP duct, and the wake potential up to 5 m was calculated. The length and the charge of the bunch were 6 mm and 1 C, respectively. For the loss factor and longitudinal impedance calculation, the bunch was put on the center of the beam duct.

The longitudinal wake potentials are shown in Fig. 3 with the bunch. The height of peaks of the wake potential is almost same for both models. The loss factors obtained from those wake potentials and the power depositions corresponding to the design beam parameters (beam currents: 2.6 A × 3.6 A, bunch spacing: 4.7 ns) are listed at Table 1. The loss factor of Type-A is slightly larger than that of Type-B.

IR ducts for KEKB

For comparison, the loss factors and the power depositions of IR ducts of KEKB were also calculated. The beam ducts in IR were divided into following five parts for convenience of calculation.

- IP duct :
  IP duct is a straight duct (ϕ30 mm) with two tapers at both ends (left: ϕ52mm, right: ϕ55 mm). It has a SR mask with a height of 2.5 mm and a saw-teeth structure in the straight section. The length of the straight section, left-hand taper and right-hand taper are 580 mm, 200 mm and 250 mm, respectively.
- Y-shaped crotch ducts :
  The beam ducts for electron and positron are combined here to make a single duct. They are on both sides of the IP duct. The diameters are 72 mm (left) and 78 mm (right). The crossing angles of the crotch are 35 mrad (left) and 87 mrad (right). The lengths are 1120 mm (left) and 980 mm (right).
- Transition ducts from IP duct to Y-shaped crotch ducts:
  These ducts are transition parts between the IP duct and the Y-shaped crotch ducts. They have quite complicated shapes and the cross-sections are not circular in the middle of them. The lengths of them are 380 mm (left) and 410 mm (right).

Table 1 : Loss factor (σ_z = 6 mm) and power deposition at IR of Super-KEKB (2.6 A × 3.6 A, 4.7 ns spacing)and KEKB (1.1 A × 1.65 A, 6 ns spacing).

		Loss factor *k* [V/C]	**Power deposition *P* [W]**
Super-KEKB	IP duct (Type-A)	8.72×10^{8}	81
	IP duct (Type-B)	7.98×10^{8}	74
KEKB	IP duct	3.35×10^{10}	790
	Crotch (right)	8.35×10^{9}	201
	Transition (right)	2.70×10^{10}	637
	Crotch (left)	4.58×10^{9}	108
	Transition (left)	3.36×10^{10}	793
	Total (IR ducts)	10.72×10^{10}	2530

The loss factors for the bunch with a length of 6 mm are listed at Table 1. The total loss factor of the IR ducts of KEKB is 0.11 V/pC. The total power deposition of the beams of KEKB with typical beam currents (1.1 A × 1.65 A) and bunch spacing (6 ns) is 2.5 kW. The power deposition for the IP duct of Super-KEKB (0.07 kW) is much smaller than that of KEKB and both types of the IP duct seems to be acceptable. However, the models of the IP duct of Super-KEKB don't have some important components such as a SR mask, so re-evaluation of the loss factor and power deposition of the IP duct of Super-KEKB is indispensable in the detailed design process.

IMPEDANCE

Longitudinal Impedance of IP duct for Super-KEKB

The longitudinal impedances of the IP ducts of Super-KEKB are shown in Fig. 4. They were obtained from the longitudinal wake potentials up to 5 m. It was found that there is no noticeable peak in the longitudinal impedance of both Type-A and Type-B. This result means that there is no mode trapped in the IP duct longitudinally.

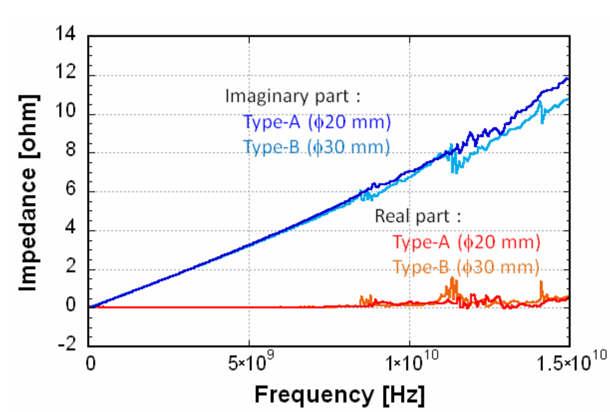

Figure 4: Longitudinal impedances of the IP ducts for Super-KEKB.

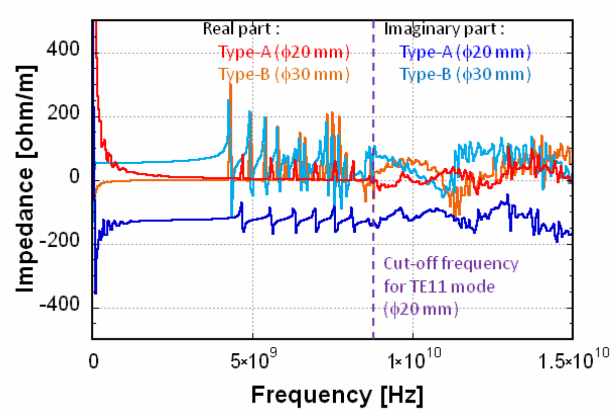

Figure 5: Vertical transverse impedances of the IP ducts for Super-KEKB.

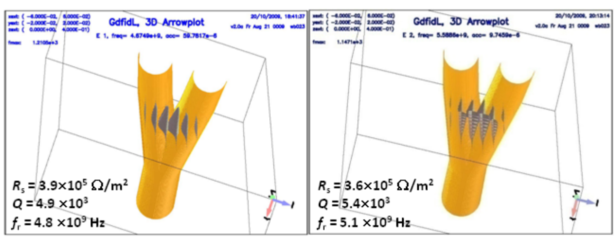

Figure 6: 3-D arrowplots of the electric field of typical eigenmodes in the IP duct of Super-KEKB (Type-A).

Transverse Impedance of IP duct for Super-KEKB

In order to obtain the transverse impedance, calculations with an off-center beam were also performed. The bunch was put off-center by 2 mm vertically or horizontally. The transverse wake potentials were calculated up to 5 m and the transverse impedances were obtained from them. When the bunch was displaced horizontally, there is no noticeable peak under the cut-off frequency for TE11 mode in circular duct with a diameter of 20 mm (8.79 GHz). On the other hand, it was found that there are many peaks when the bunch was displaced vertically as shown in Fig. 5. This means that the vertical deviation of beam from the center of the IP duct excites many modes which are trapped in the IP duct.

In order to identify each trapped mode, eigenmode calculations were performed by an eigenmode solver of GdfidL. The number of the calculated eigenmode is 15. As the result of the calculation, it was found that many modes are trapped at the crotch section. 3-D arrowplots of the electric field of typical eigenmodes are shown in Fig. 6. The direction of the electric field is perpendicular to the beam axis and these trapped modes are TE-like modes. The resonant frequencies of these TE-like modes agree with the center frequencies of peaks of the transverse impedance and it was confirmed that the sources of those peaks were the TE-like modes trapped at the crotch section. The shunt impedance, Q-value and resonant frequency of the eigenmode which corresponds to the peaks of the transverse impedance are listed at Table 2. The number of the trapped mode of Type-A is lower than that of Type-B, and the shunt impedance and Q-value of Type-A tend to be lower than those of Type-B. Type-A, therefore, seems to be more suitable for the IP duct of Super-KEKB. However, the effects of these modes on the beam have not been checked yet. The investigation on them will be done near future.

Table 2 : Shunt impedance R_s, Q-value Q and resonant frequency f_r of the eigenmodes which agree with the peaks of the transverse impedance.

Duct	Mode#	R_s [Ω/m^2]	Q	f_r [Hz]
Type-A	1	3.90×10^5	4.88×10^3	4.67×10^9
	2	3.67×10^5	5.43×10^3	5.59×10^9
	3	3.77×10^5	5.81×10^3	6.32×10^9
	4	4.01×10^5	6.11×10^3	6.97×10^9
	5	4.54×10^5	6.36×10^3	7.57×10^9
	6	3.98×10^5	6.54×10^3	8.13×10^9
	8	9.19×10^4	6.37×10^3	8.64×10^9
Type-B	2	1.44×10^6	5.37×10^3	4.31×10^9
	3	1.27×10^6	6.01×10^3	4.93×10^9
	4	1.24×10^6	6.41×10^3	5.40×10^9
	5	1.01×10^6	6.60×10^3	5.79×10^9
	6	3.92×10^5	6.36×10^3	6.00×10^9
	8	8.75×10^5	7.05×10^3	6.21×10^9
	11	1.08×10^6	7.55×10^3	6.48×10^9
	13	4.06×10^6	7.73×10^3	7.00×10^9
	14	1.11×10^8	8.11×10^3	7.04×10^9

SUMMARY

The loss factor and impedance of IP ducts for Super-KEKB were calculated by GdfidL. The loss factor is much smaller than that of IR ducts for KEKB. When the design beam currents are stored, the total power deposition at IP of Super-KEKB is about 70 W. There is no mode trapped in IP duct longitudinally. On the other hand, it was found that the vertical deviation of beam from the center of the duct excites many TE-like modes which are trapped at the crotch section. Investigation of the effect of these modes on the beams remains as the next step.

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