Design Study of Vacuum System for the KEK B-Factory

Yusuke Suetsugu and Ken-ichi Kanazawa

National Laboratory for High Energy Physics,
1-1 Oho, Tsukuba-shi, Ibaraki-ken, 305

Abstract

Design study on the vacuum system for the KEK B-Factory is in progress. High current and low emittance beams characterize the B-Factory rings. A study of reducing the effects of synchrotron radiation, that is, gas desorption, heating and radiation corrosion, is one of the most important subjects in the design. Efficient pumping schemes to evacuate beam ducts and structures of cooling channel to absorb heat effectively are investigated by model calculations. Radiation shield effects of candidate materials for beam ducts are also evaluated using a computer simulation code.

Introduction

The KEK B-Factory[1)] is an accelerator system dedicated to the studies of B-physics, that is, the measurement of the CP-violation parameters. The main accelerator is an energy asymmetric two-ring electron-positron collider, which consists of High Energy Ring (HER, for 8 GeV electrons) and Low Energy Ring (LER, for 3.5 GeV positrons). These two rings are planed to be installed in the present TRISTAN Main Ring tunnel. A design of vacuum system for these rings is progressing now.

Main parameters of these rings are summarized in Table 1. Conspicuous features of these rings are high current and low emittance beams for the purpose of achieving high luminosity. Intensity of synchrotron radiation (SR) emitted from beams become consequently high (see also Table 1). In designing the vacuum system for these rings, therefore, effects of SR as follows should be considered and treated carefully.

(1) gas desorption from duct surface
(2) local heating of beam duct
(3) radiation damage around beam duct

To cope with these effects, some calculations for a basic structure of beam ducts were performed. In this report, some results are described.

Pumping scheme

SR causes gas desorption from duct surface, whose amount much exceeds that of thermal desorption. It is important to design a pumping system to evacuate beam ducts efficiently as well as to pay attentions to surface treatment of beam ducts.

An aimed average pressure is about 1×10^{-7} Pa all over the ring. This pressure clears the conditions settled by beam lifetime, back ground noise for detectors and ion trapping (for HER). A required pumping speed is estimated as about 100 l/s/m when the gas desorption coefficient (η) reduces to 1×10^{-6} molecules/photon. Pumps adopted in the design are ion pumps (IP) and non evaporable getter (NEG) pumps. For higher pressure (>1×10^{-6} Pa), where gas load is high, only IP is used. NEG pumps are used in low pressure (<1×10^{-6} Pa) to compensate the decrease of pumping speed of IP.

Table 1. Main parameters of the KEK B-Factory
(Values in parentheses are those in 2×10^{33} cm^{-2}s^{-1})

	LER	HER	
Energy	3.5	8.0	GeV
Circumference	3018		m
Luminosity	$1\times10^{34}(2\times10^{33})$		cm^{-2}s^{-1}
Beam Current	2.6(0.52)	1.1(0.22)	A
Natural Bunch Length	0.5		cm
Emittance $\varepsilon_x/\varepsilon_y$	$1.9\times10^{-8}/1.9\times10^{-10}$		m
Bending Radius	15	91	m
Length of B magnet	0.4	2.56	m
# of B magnet / cell	2	2	
Cell length	19		m
# of cells	112		
SR at Normal bend -------			
Critical energy	6.35	12.49	keV
Total power	2.30	4.38	MW
Max power density	3.61	6.0	kW/m
Total photon number	7.35×10^{21}	7.11×10^{21}	phot./s
Average photon density	3.19×10^{18}	3.63×10^{18}	phot./s/m
SR at Wiggler ------------			
Bending radius	8.33	44.4	m
Total power	4.3	2.1	MW
Max power density	33	30	kW/m

An effective pumping scheme is to adopt a distributed pumping system. Distributed ion pump (DIP) is useful for HER where the length of a bending (B) magnet is long (2.56 m). For LER, however, the length of B magnet is short (0.4 m) and DIP cannot be used.

Two pumping schemes can be proposed for LER, that is, we call (1) a distributed type and (2) a lumped type (see Fig.1). In the distributed type, a beam channel has a side channel. Both channels are connected through slots. Pumping ports for IPs are attached to the side channel. Distributed NEG pumps are installed in the side channel. The lumped type, on the other hand, is to set pumping ports at the beam channel directly. In this case IP combined with NEG pump is attached to these ports.

Pressure distributions in model ducts were calculated using the Monte Carlo method. The size of model ducts and parameters used in the calculation are tabulated in

Table 2. Gas molecules were assumed to be desorbed from the center of one side with a constant rate (1×10^{-5} Pa•l/m/s). Ion pumps were set at 1 m from each ends. The conductance of slots between two channel is about 500 l/s/m.

In the high pressure region ($P>1\times10^{-6}$ Pa), an average pressure for the distributed and the lumped type were 2.9×10^{-7} Pa and 2.6×10^{-7} Pa, respectively. The calculated pressure distribution in the low pressure region ($P<1\times10^{-6}$ Pa) is shown in Fig.2. The average pressure of the distributed type reduce to 1.2×10^{-7} Pa. For the lumped type the average pressure in this pressure region is same as in the high pressure region. The distributed type gives lower pressure even if the total pumping speed is almost same for each types.

Further investigations, such as manufacturing process and impedance, should be made in selecting the most suitable pumping scheme. From the point of view of vacuum property, however, the distributed type is better.

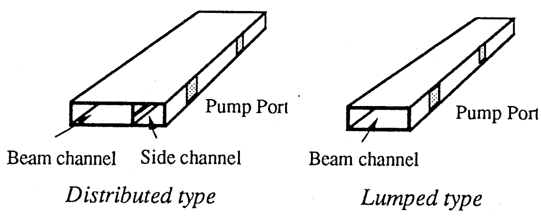

Fig.1 Two pumping schemes for LER

Table 2 Parameters used in the calculation.

	Distributed type		Lumped type	
Pressure region	High	Low	High	Low
Beam channel [mm]	50×100×6000			
Side channel [mm]	50×50×6000		none	
Slot between two channels [mm]	5×6000		none	
Total pumping speed [l/s]	800	820	800	800
IP [l/s]	400×2	200×2	400×2	200×2
NEG pump [l/s]		70×6m		200×2

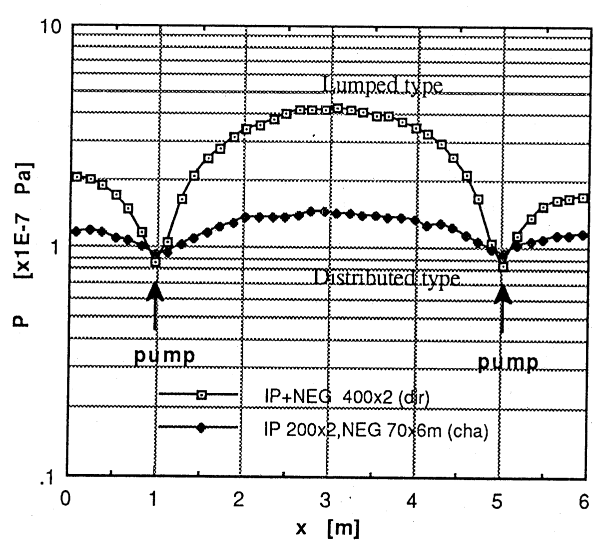

Fig.2 Pressure distribution for two pumping schemes at low pressure region.

Structure of cooling channel

SR power absorbed in a duct wall causes local heating. Wall temperature should be sufficiently lower than the softening temperature of materials so as to keep their mechanical strength. The local heating also causes a deformation of beam duct and non-uniform distribution of stress. Furthermore, the heat cycle is said to give rise to cracks on the wall surface.

The SR power on the duct amount to about 6 kW/m in normal bend sections and as much as to about 30 kW/m in wiggler sections as shown in Table 1. The cooling system of beam ducts should be considered carefully as well as selecting duct materials with good thermal conductivity. Here some model structures of cooling channel are considered for aluminum and copper, and the cooling effects are compared. The model structures are drawn schematically in Fig.3 .

A temperature distribution of in a duct wall was calculated using the two dimensional FEM. The program used is MSC/NASTRAN Sol.24 (linear analysis)[2]. The temperature of cooling water is set to be constant at 25°C. The flow speed and the heat transfer ratio are optimized for each model.

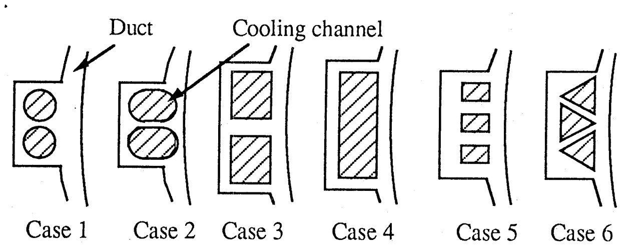

Fig.3 Models of cooling channel.

The maximum temperatures in the duct wall are summarized in Table 3. It is found that an aluminum duct can be used in normal bend sections but not in wiggler sections since the temperature at a power density of 30 kW/m exceeds about 200°C, where mechanical strength decreases (shown by underlines in the table). On the other hand, a copper duct may be used even in wiggler sections if the cooling system is designed cautiously.

Table 3 Calculated maximum temperatures.

Material	Power Density [kW/m]	Case 1 [°C]	Case 2 [°C]	Case 3 [°C]	Case 4 [°C]	Case 5 [°C]	Case 6 [°C]
Cu	30	172.9	154.8	161.4	-	146.0	134.1
	20	123.6	111.5	115.9	-	-	97.7
	7.68	62.9	58.2	59.9	-	-	-
	5.69	52.6	49.2	50.5	-	-	-
Al	30	<u>290.6</u>	<u>258.9</u>	<u>276.4</u>	<u>365.8</u>	<u>252.9</u>	<u>237.1</u>
	20	<u>202.1</u>	180.9	192.6	<u>252.2</u>	176.9	166.4
	7.68	93	84.9	89.4	112.2	83.3	79.3
	5.69	74.6	68.7	71.9	90	68.4	65.4

Among these six structures of cooling channel, the maximum temperature is low for Case 5, 6 and high for Case 4. It is found to be more efficient for heat transfer to take the wide heat transfer area by dividing a cooling channel into sub-channels than simply to make the cooling channel close to the heating point.

The manufacturing of complicated cross sections like case 5 or 6 can be made by an extrusion for aluminum, but not so easy for copper. Some structures such as fins inside cooling channels would improve the heat transfer property even in the case such as Case 1 or 2.

Radiation shield

Radiation damage to components around beam ducts, such as high-voltage feed-throughs, organic insulators and cooling water tubes, spoils the performance of accelerators. A cautious radiation shielding is important

The SR going through a beam duct was estimated using the computer program EGS4. Parameters used in the calculation are as follows.

	LER	HER	
Minimum photon energy	0.05	0.05	MeV
Maximum photon energy	0.3	0.6	MeV
Incident angle	1.5	2.0	deg.
Beam energy	3.5	8.0	GeV
Beam current	2.6	1.1	A
Operation time per a year	5000	5000	hours

The absorbing material is water. Curves of annual does on the outer surface of a duct versus duct thickness for HER are shown in Fig.4. Material of the duct is aluminum or copper. The tolerable dose is set about 3×10^9 rad/year relying upon CERN and SLAC[3]. As shown in this figure, the radiation power cannot be reduced to below the critical value by only aluminum. Lead shielding of about 1 mm is indispensable for aluminum beam ducts. If the duct material is copper with a thickness larger than 5 mm, however, lead shielding is unnecessary. Almost the same result was obtained for LER.

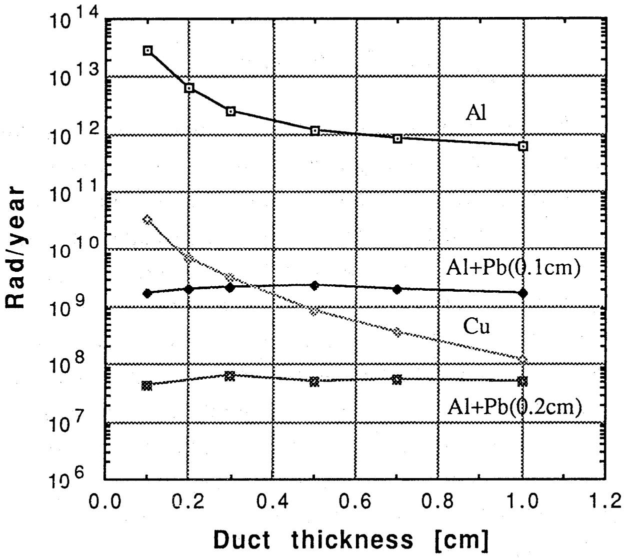

Fig.4 Annual dose calculated for HER.

Conclusions

Some calculated results to cope with the effects of intense SR were presented. The distributed-type pumping scheme with distributed NEG pumps is able to evacuate beam ducts efficiently. It was found that the cooling channel divided into sub-channels to take the wide heat-transfer area is more effective than a single channel. A lead shielding of about 1 mm is indispensable for aluminum beam ducts although copper beam ducts shield radiation sufficiently by themselves.

Acknowledgements

The authors would like to thank Dr.H.Hirayama for his development of the EGS4 code and Mr.M.Tsuchiya (IHI) for his thermal calculation of beam ducts.

References

1. "Accelerator Design of the KEK B-Factory", KEK Report 90-24.
2. This calculation was performed in cooperation with Ishikawajima-Harima Heavy Industries Co., Ltd..
3. "An Asymmetric B Factory based on PEP", LBL PUB-5303.