Present status of KEKB vacuum system

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Abstract

The commissioning of KEKB (KEK B-factory) started in December, 1998. The vacuum system is working almost satisfactorily although several vacuum troubles occurred around the collision point. The photon stimulated gas desorption coefficient of copper beam chamber is decreasing steadily and reached to about 1×10^{-5} molecules photon^{-1} just before the summer shutdown, where the integrated linear photon flux is close to 10^{24} photons m^{-1}. No excess heating was observed for bellows and gate valves up to the beam current more than 500 mA.

1. Introduction

The commissioning of the KEKB accelerator (KEK B-factory) started in December, 1998, after about five years' construction. The KEKB is an electron-positron collider with asymmetric energies to detect the CP violation in bottom quark decay [1]. The KEKB consists of two rings, that is HER (High Energy Ring) for 8.0 GeV electrons and LER (Low Energy Ring) for 3.5 GeV positrons. Main parameters of KEKB are listed in Table 1. The design beam currents are 1.1 A and 2.6 A for HER and LER, respectively. Withstanding high gas and heat load due to the intense synchrotron radiation, therefore, was the most important issue in designing the vacuum system. The commissioning progressed almost satisfactorily, and the physics experiment started from June. Just before the summer shutdown from August, the beam dose (integrated beam current) reached to 74 and 123 mA·Hours and corresponding photon dose (integrated linear photon flux) were 7.8×10^{23} and 6.2×10^{23} photons m^{-1} for HER and LER, respectively. The maximum stored beam currents were about 514 and 542 mA for HER and LER, respectively. The vacuum system is working almost smoothly although several troubles occurred near the collision point. The photon stimulated gas desorption (PSD) coefficient, η [molecules photon^{-1}], at arc section is decreasing steadily with beam dose. Here we overview the vacuum system of the KEKB at first and then report the present status of it.

2. Outline of vacuum system

Some features of KEKB vacuum system are also summarized in Table 1 [2]. Most of beam chambers including arc sections are made of OFC (Oxygen Free Copper, ASM10100) for its ability to withstand intense heat load and to shield the radiation from beam [3]. Other chambers at straight sections are made of stainless steel or aluminum. Most of copper-copper connection was welded using an electron beam. The inner surface of beam chamber was chemically polished, which is specially developed for KEKB [4].

The main pump is NEG (Non Evaporable Getter ST-707, SAES GETTERS CO. Ltd.) pump (200 l s^{-1} for a typical cartridge). Auxiliary pump is a 200 l s^{-1} sputter ion pump located at about every 10 m. The estimated average liner pumping speeds are 65 and 70 l s^{-1} m^{-1} for HER and LER, respectively, for CO just after activation. Goal pressure is in the range of 10^{-7} Pa during operation with a maximum current assuming the η of 1×10^{-6} molecules photon^{-1} [5]

A Helicoflex gasket (Le Carbone K.K.) that just fits each aperture of chamber is used for vacuum seal, which

Table 1 Main parameters of KEKB

	LER (Low Energy Ring)	HER (High Energy Ring)
Beam Energy [GeV]	3.5	8.0
Design Beam Current [mA]	2600	1100
Circumference [m]	3016	
Bunch Length [mm]	4	
Bending Radius [m]	16.31	104.46
Critical Energy of SR [keV]	5.84	10.9
Max. Liner Power Density of SR [kW m^{-1}]	14.8	5.8
Average Liner Photon Density [photons m^{-1}]	3.3×10^{18}	3.2×10^{18}
Chamber material (arc)	OFC (Oxygen Free Copper)	
Main pump	NEG Cartridge	NEG Cartridge + NEG Strip
Auxiliary pump	Sputter Ion Pump (200 l s^{-1})	
Average Linear Pumping speed [l s^{-1} m^{-1}]	70	65
Goal pressure with beam [Pa] ($\eta = 1\times10^{-6}$ molecules photon^{-1})	in the order of 10^{-7}	
Vacuum monitor	CCG (Cold Cathode Gauge)	

SR : Synchrotron Radiation, NEG : Non Evaporable Getter pump has also a role of RF contact between flanges. All bellows (about 2000 in total) have RF-shield structure inside [6]. CCGs (Cold Cathode Gauges, about 580 in total) monitor the total pressure of whole rings. RGAs (Residual Gas Analyzers, 24 in total) give the residual gas species during operation. The rough pumping system, composed of a turbo-molecular pump and a scroll pump, is completely oil free.

The construction of KEKB started in 1994. More than 2000 beam chambers and their attachments were installed in last two years. The installation finished at the end of November. The installation was proceeded under careful quality control [7]. The base pressure was in the range of 10^{-8} Pa just before the commissioning.

3. Status of vacuum system

3.1 Decrease of η

Figure 1 shows a typical variation of η at HER arc section (copper chamber) against the beam dose. Here the constant liner pumping speed of 30 l $s^{-1}m^{-1}$ is assumed for the estimation of η. In the beginning η was about 1×10^{-1} molecules photon^{-1} and relatively high compared to a copper chamber received a chemical polish. The η, however, is decreasing steadily with beam dose. Now the η reached below 1×10^{-5} molecules photon^{-1}. The η for LER gives the same tendency and reached near 1×10^{-5} molecules photon^{-1}. The decrease of η for HER and LER are almost same with respect to photon dose. The corresponding photon dose is indicated at upper axis of the figure. The decrease of η is in the range of expected one from our R&D [8]. For reference, the pressure rise $\Delta P/\Delta I$ [Pa mA^{-1}] is given at the right axis of the figure.

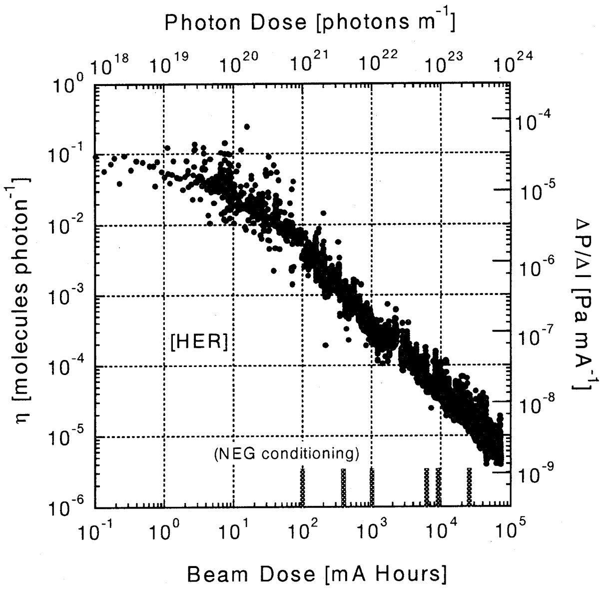

Fig.1 Variation of η (arc section) against beam dose

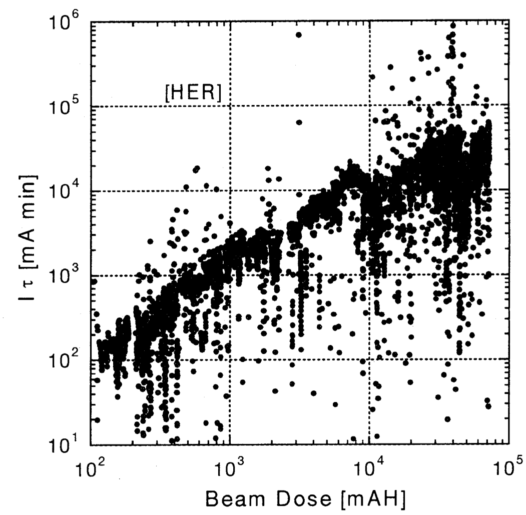

Fig.2 Variation of $I\tau$ against beam dose

The activation of NEG was carried out for 6 and 7 times for HER and LER, respectively. The bars in the lower abscissa of Fig.1 are the conditioning timings at HER. The timing of conditioning was determined by the absorbing gas load of 0.3 Torr l m^{-1} and the change of decrease rate of $\Delta P/\Delta I$. The number of conditioning is somewhat larger than expected one due to the high η at initial stage and the influence of a vacuum leak accident near the collision point. In the conditioning, the NEG is heated up to 130 °C in one hour and kept for 1 hour, and then heated again further to 250 °C in 1 hour and kept for another 1 hour. The ion pump evacuates the out gas from the NEG during the conditioning. The pressure should be kept less than 1×10^{-3} Pa during the conditioning to protect NEG.

3.2 Beam lifetime

As the η decreased, the beam lifetime increased. Figure 2 presents the variation of beam current I [mA] × lifetime τ [min] against the beam dose for HER. The increase is not so smooth as η since the lifetime depends on not only the vacuum pressure but also operation conditions and beam parameters. The lifetime until the beam dose of about 1×10^{4} mA·Hours, however, was almost determined by the average pressure. The dip at 1×10^{4} mA·min is caused by the vacuum leak accident near the collision point orbit. The dip at 4.5×10^{4} mA·min is due to the installation of the BELLE detector for physics experiment and following vacuum leak accident near the collision point.

Now $I\tau$ is about 4×10^{4} mA·min for HER. For the case of HER, the estimated $I\tau$ from the $\eta = 7\times10^{-6}$ molecules photon^{-1} at arc section is about 1.2×10^{5} mA·min assuming that the residual gas is CO and the lifetime is determined by the bremsstrahlung. Actually CO accounts for more than 50 % of the residual gases during operation. Observed $I\tau$ is about one third of the expected value. The following reasons will explain the difference: (1) Small aperture at movable mask inserted to decrease the background to physics detector. (2) Higher pressure at some sections with small physical apertures, such as collision points and injection points, compared to arc sections. (3) Beam parameters such as a tune, orbit are not optimized. The similar discussions can be applicable for LER. The $I\tau$ is about 3×10^4 mA·min for LER now. In LER the blow up of beam size are also observed for high current and the pressure shows non-linear dependence against the beam current in some cases.

3.4 Temperatures of components

We are monitoring temperatures for more than 2000 points for bellows, gate valves, cooling waters and some special chambers, such as those of collision points and injection points. No excess heating was observed for the bellows and gate valves up to now. Some points at interaction region indicate high temperature at large beam current. We are going to improve the cooling efficiency during the shut down time.

3.5 Other Pressure Issues

(a) Effect of photoelectron

At every CCG of LER that is located at a pumping port close to the downstream side of a bending magnet, a false indication of pressure due to photoelectrons was observed. The output current was proportional to the beam current and observed even without a permanent magnet of CCG. By attaching a small dipole magnet at the neck of the gauge port, these electrons were steered and the output current of CCG became normal. The detailed mechanism how photoelectrons enter into a CCG is studied at present. A simple simulation shows that the photoelectrons generated inside the beam chamber can not enter directly into the anode of CCG. There may be some other processes involved here.

(b) Pressure burst

At some straight section in LER where linear pumping speed is smaller than other section, a pressure burst phenomenon was observed. Typical pressure behavior against beam current is shown in Fig. 3 (gauge #1 and #3). The critical beam current, where the burst occurred, increased as beam dose. The most promising explanation of this phenomenon is an ion induced pressure instability [9]. The increase of critical current can be understood by the decrease of ion-induced gas desorption from a chamber surface. Further investigation is planned about this phenomenon.

4. Summary

The commissioning of KEKB that started in December 1998 was carried out almost satisfactorily although some vacuum troubles occurred around collision point. The η is decreasing smoothly from the beginning. The η at arc section reached near the 1×10^{-5} molecules photon^{-1} for both rings now. The temperature of vacuum components such as bellows and gate valves shows no excess heating up to now. Vacuum sealing by Helicoflex gasket is stable. Some interesting pressure behaviors were observed in LER and are to be investigated further. The next operation will start from October this year with higher beam currents. The more careful attention should be necessary for the temperature of various vacuum components.

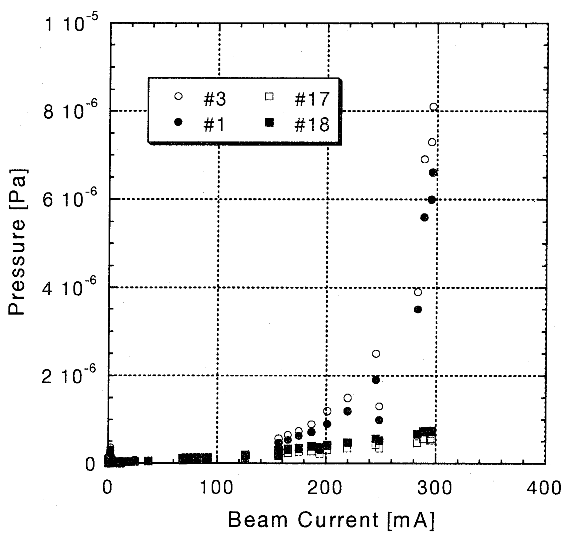

Fig.3 Example of pressure burst observe in LER, where gauge #1 and #3 are in a straight section, and #17 and #18 are in an arc section

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