DESIGN OF THE CPMU VACUUM SYSTEM AT THE HEPS*

L. Zhang†, H.H. Lu, S.C.Sun, Institute of High Energy Physics, Chinese Academies of Sciences, Beijing, China

Abstract

The High Energy Photon Source (HEPS) is a 3rd generation synchrotron radiation light source. Its beam energy is 6 GeV and its emittance is less than 60 pm·rad, which can provide high brilliance hard X-rays to several tens of experimental stations. The Cryogenic Permanent Magnet Undulator (CPMU) is one of the key components to achieve the high brilliance. And its vacuum system is necessary to provide an ultra-high vacuum environment for CPMU operation. To design the CPMU vacuum system, we do experiments to test the outgassing rate, estimate the total gas load, calculate the effective pumping speed, design the baking program and select all pumps and other vacuum devices. This paper presents the design specifications and the assemblage status of the CPMU vacuum system.

INTRODUCTION

The length of the CPMU magnetic structure is 2 meters and the period length is 13.5mm [1]. The magnet blocks are made of PrFeB material which has many superiorities at low temperatures [2]. The CPMU will work at the liquid nitrogen temperature (80K) because of the higher remanence field and coercivity. The undulator adopts the in-vacuum program which can reduce the working gap and enhance the magnetic field. The parameters and specifications of the CPMU at 80K are listed in Table 1.

Table 1: Parameters of CPMU 13.5

Period length	13.5 mm
Period number	140
Working temperature	<85K
Vacuum degree (no beam)	5×10^{-10} Torr
Vacuum degree (with beam)	2.5×10^{-9} Torr
Working gap	5-9mm
K value	1.26@Gap=5mm
Peak field	1T@Gap=5mm
RMS of Phase errors	<3°
1^{st} field integral	<100Gscm

When the beam passes through the gap of CPMU, the high-speed particles will interact with the residual gas in chamber and cause the reduction of beam lifetime and beam instability [3]. So it's significant to design a rational vacuum system for CPMU that can provide an ultra-high vacuum environment.

Vacuum system plays an important role in CPMU prototype. It not only provides an ultra-high vacuum environment for the beam, but also can be a cryomodule insulation for the cooling system.

In this paper, there are 3 aspects of the design process that are highlighted: 1) Calculate the total gas load of the system; 2) Calculate effective pumping speed and select suitable vacuum pumps; 3) Baking.

CALCULATE THE TOTAL GAS LOAD

To design the system, firstly the total gas load of CPMU should be estimated. It mainly contains outgassing of each material in the chamber, gas load caused by beam and the leak of the chamber (can be ignored).

Outgassing of each Material

After the magnetic design and mechanical design [4], the structure of CPMU is nearly definite. So the materials and surface areas of all parts that in vacuum chamber are clear. The materials of all parts are listed in Table 2.

Table 2: Materials of all parts in Vacuum Chamber

Parts	Material	Area(cm^2)
Chamber	Stainless steel	43600
Bellow	Stainless steel	25700
Fasteners	Stainless steel	15700
Girder	Aluminum alloy	29000
M3 Holder	Aluminum alloy	45700
Magnet	PrFeB coated with TiN	12500
Poles	Iron coated with TiN	6800
Conductive Foil	OFHC	3600

Most materials of the parts in vacuum are common and the outgassing rate can be known from the vacuum manual. Only the data of TiN is unknown, so the outgassing rate test is necessary for a more accurate calculation.

The samples of outgassing rate test are coated PrFeB magnets (no magnetism). The surface area of each sample is about 22 cm^2, so the area of all the 80 samples is about 1760 cm^2. The photo of the samples is shown in Figure 1:

Figure 1: The sample and the support with 80 samples.

* Work supported by Project of High Energy Photon Source Test Facility
† email address: zhanglei87@ihep.ac.cn

The outgassing rate is measured by orifice throughput method and the schematic diagram of the test equipment is shown in Figure 2.

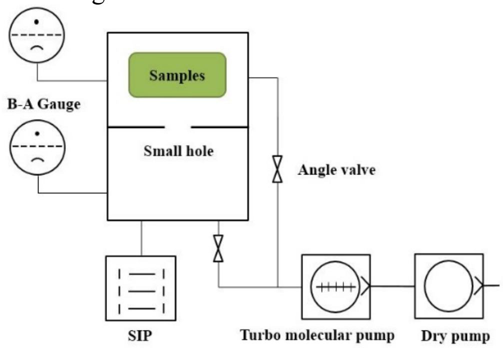

Figure 2: Schematic diagram of the test equipment.

The outgassing rate test should be done twice: one is for measuring the gas load of support with 80 samples, and the other is only for the support. Then the outgassing rate of the samples can be calculated and the data is shown in Figure 3.

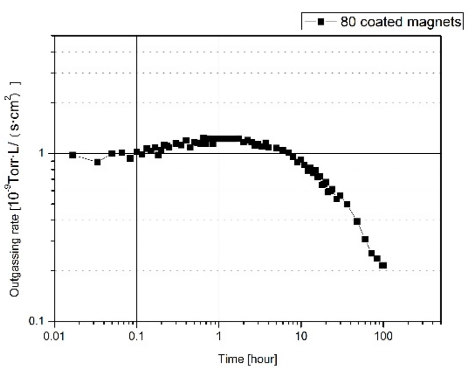

Figure 3: The outgassing rate of the samples.

According to the Eq.1, the gas load of the all materials in vacuum chamber can be calculated. And the result is 1.08×10^{-5} Torr·L/s.

$$Q_S = \sum(q_i \times A_i) \quad \text{(Torr·L/s)} \qquad (1)$$

q_i is the outgassing rate[Torr·L/(s·cm^2)]of one material and A_i is the surface area(cm^2).

Gas Load Caused by Beam

The gas load caused by the beam in the CPMU mainly includes the heat effluent of the material (can be ignored) and the photondesorption gas load caused by the synchrotron radiation.

In order to estimate the photondesorption gas load, an approximate formula Eq.2 is used [5]:

$$Q_{gas} = 24.2EI\eta \quad \text{(Torr·L/s)} \qquad (2)$$

E is beam energy (GeV); I is Beam intensity (A); η is photondesorption coefficient (molecules/photon), and the general value is $\eta=2\times10^{-6}$.

The linear gas load Q_L is:

$$Q_L = \frac{Q_{gas}}{2\pi\rho} \quad \text{(Torr·L/(s·m))} \qquad (3)$$

ρ is bend radius (m).

The photondesorption gas load can be calculated according to the Eq.4 and the result is $Q_{beam}=8.68\times10^{-7}$ Torr·L/s.

$$Q_{beam} = Q_L \times L \quad \text{(Torr·L/s)} \qquad (4)$$

L is the length (m) of CPMU.

Total gas load

The total gas load without beam is $Q_S=1.08\times10^{-5}$ Torr·L/s.

The total gas load when the beam passes through CPMU is $Q_D = Q_S + Q_{beam} = 1.17\times10^{-5}$ Torr·L/s.

CALCULATE EFFECTIVE PUMPING SPEED AND SELECT SUITABLE PUMPS

Calculate Effective Pumping Speed

There are two cases when calculating the effective pumping speed: static state and dynamic state. Both of the two speeds should be calculated, and the larger one is the actually effective pumping speed we need.

We can calculate pumping speed using Eq.5

$$S_E = \frac{Q}{p} \quad \text{(Torr·L/s)} \qquad (5)$$

S_E is effective pumping speed, Q is gas load (L/s) and p is pressure (Torr).

By calculation, the total effective pumping speed should be larger than 2160 L/s in order to satisfy the requirement both in static and dynamic conditions. The minimum effective pumping speed is $S_E=3240$ L/s with some safety margin.

Select Suitable Pumps

Based on the analysis above, a series of vacuum pumps are selected and shown in Table 3, and a schematic diagram of the vacuum system is sketched in Figure 4.

Table 3: List of Vacuum Pumps

Pumps	Speed (L/s)	Amount
Sputter ion pump	400	4
NEG pump	400	4
Titanium sublimation pump	800	2
Turbo molecular pump	250	1
Dry Pump	7	1

ISBN 978-3-95450-182-3

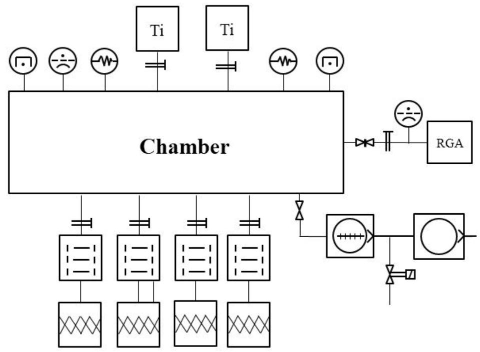

Figure 4: The schematic diagram of the vacuum system.

The manufacturing of CPMU prototype is ongoing. And the main parts in vacuum such as chamber, in-vacuum girders, magnets, poles, M3 units and bellows have been manufactured and are being cleaned. The vacuum devices such as pumps, gauges and valves are also ready, shown in Fig. 5.

Figure 5: The vacuum chamber and some vacuum devices.

BAKING

After manufacturing, the vacuum chamber should be cleaned carefully. Then the pumps and other vacuum devices should be installed on the chamber. In order to achieve ultra-high vacuum environment, CPMU vacuum chamber which mainly includes the magnet arrays must be baked. Baking can speed up the process of outgassing, so the gas molecules absorbed and adsorbed by materials in the chamber can be released and discharged more quickly [6]. The chamber can be baked with heating tape wrapped around, the baking temperature will be controlled at about 200 degrees centigrade. The material of magnet is PrFeB, so the baking temperature of the magnet should be below 60 degrees centigrade to avoid the demagnetization risk. To bake the magnet arrays safely, the hot nitrogen gas through the liquid nitrogen pipe will be adopted. The whole process of baking will last 3 days.

SUMMARY

A CPMU prototype is under construction. The main parts in vacuum such as chamber, in-vacuum girders, magnets, poles, M3 units and bellows have been manufactured and are being cleaned. The vacuum devices such as pumps, gauges and valves are also ready. Next step, vacuum system will be assembled and the ultimate vacuum degree will be measured.

ACKNOWLEDGEMENT

Thanks He P, Song H, Deng BL, Guo DZ and Zhang XZ for great helpful discussion and support to the work.

REFERENCES

[1] H. H. Lu et al., “Development of a PrFeB cryogenic permanent magnet undulator (cpmu) prototype at IHEP”, presente at IPAC’17, Copenhagen, Denmark, May 2017, this conference.

[2] J. Chavanne , G. Le Bec, and C. Penel, “Cryogenic Permanent Magnet Undulators, Synchrotron Radiation Synchrotron Radiation News”, 24: 3, pp.10- 13, 2011.

[3] F. Broggi, A.R.Rossi, A. Bacci, “Effects of the residual gas scattering in Plasma Accelerrtion Experiments and LINACs”, in *Proc. PAC’09*, 2009.

[4] S. C. Sun et al., “Mechanical design of a cryogenic permanent magnet undulator at IHEP”, presented at IPAC’17, Copenhagen, Denmark, May 2017, this conference.

[5] PEP-II Team. “An asymmetric B factory (based on PEP) conceptual design report”, Menlo Park: SLAC, 1993: 305-358.

[6] J. C. Huang et al., “Performance of a NSRRC In-Vacuum Undulator”, *IEEE Transactions on applied superconductivity*, Vol. 24, No. 3, June 2014.