

THE PRESENT STATUS OF VACUUM SYSTEM OF XFEL IN SPRING-8

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Abstract

The assembly and installation of the vacuum system of SACLA, XFEL in SPring-8 was done. The average pressure with beam achieved without bake out was 9.3×10^{-8} Pa. The flanges of C-band and S-band developed for XFEL hardly cause leak even when the damage on the seal edge was found. Magnetic shielding for components was also carried out.

INTRODUCTION

The vacuum system of XFEL in SPring-8 consists of the accelerator section of about 415 m and the undulator section of about 230 m. In total 433 sputter-ion pumps (SIPs), 122 NEG, 402 cold cathode gauges (CCGs), 20 Bayard-Alpert gauges, and 61 gate valves have been mounted in this vacuum system. The target pressure of less than 10^{-6} Pa with beam was determined to protect the accelerator from discharge and to prolong the lifetime of NEG of undulators. The vacuum assembly, installation and adjustment have been done from August 2009 to February 2011. The flange developed for XFEL hardly causes leak. The total assembly time was significantly reduced because the complex works of leakage search and reconstruction rarely need. The unbaked vacuum system also contributes quick start-up. The average pressures with beam in September 2011 were 8.9×10^{-8} Pa at the accelerator section and 1.2×10^{-7} Pa at the undulator section excluding the beam dump.

VACUUM SYSTEM WITHOUT BAKING

This vacuum system doesn't require bake-out because the target pressure is not low like storage rings. This resulted in the reduction in cost and man-hours of the vacuum start-up. Thanks to the unbaked vacuum system, we were free from the thermal expansion problems. The simple designs of the vacuum chambers, the support mechanisms, and the total system with reduced bellows were realized. However, for SIPs, in preparation for the case of their regenerative bakeout, the hanging-type support structure that does not give the thermal expansion force to the vacuum duct was designed. Because in this support structure the SIP is connected directly to the pumping chamber, number of bellows for position adjustment reduced significantly.

DESIGN OF VACUUM CHAMBERS

Most of the vacuum chambers are made from SUS316L except the copper accelerator tubes. Electrochemical polishing was applied for surface treatment. These chambers were unbaked, so the test of residual gas

analysis was adopted to confirm the result of cleaning. At least one chamber of every different shape was required this test. The basic designs of the cross-section shape of the chambers in the bunch compressor stage were rectangular with a combination of plates to reduce cost. The thickness of the plate in the narrow gap of the bending magnet is a 1.5 mm. The position of the welding line was designed to be away from the magnet center, because the heat during welding may increase the permeability that affect the magnetic field. The laser welding that generates less heat and less deformations, was adopted for some thin plates welding. Some chambers of large cross-section were designed to have internal reinforcement rib.

ASSEMBLY AND INSTALLATION

The assembly of the accelerator should be made in the clean environment to avoid contamination of hydrocarbon particles that generates outgas causing discharge. The required environment was determined as ISO Class 8 from the past vacuum assembly experience in SPring-8. However, the cleanness of the accelerator tunnel was not good when the building had just completed. The common clean booth consisting of four walls and a ceiling cannot be used, because the flange of the accelerator is distributed spatially complicated and some are very close to the wall. For this reason, the accelerator tunnel was separated by big partitions made of plastic sheets and the air in the assembly area was cleaned with HEPA filters. The particle number was monitored constantly during assembling. The assembling was stopped if the environment deteriorates [1]. The most important thing for ultra-high-vacuum assembly is the avoidance of hydrocarbon contamination. The MoS₂ paste is commonly used for the lubrication of the bolts in flange. Though, there is a fear of spreading hydrocarbon of the lubricant to the interior of vacuum chamber when the inexperienced

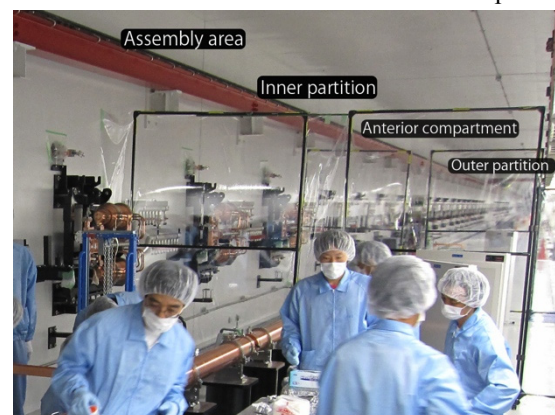


Figure 1: Separation of the assembly area by partitions.

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workers of the vacuum assembly use these bolts. Especially it is very difficult to keep high reliability of the cleanness required for the ultra-high-vacuum when so many workers assemble so many flanges. We adopted the DLC (Diamond Like Carbon) coating for lubrication of the bolt [1,2,3]. These bolts were used for the ADESY flange and the hybrid flange, the former is for the waveguide and accelerator tube, and the latter is put on the beam line. The mass spectrum of the SUS bolt with and without the DLC coating are shown in Fig.2. The mass spectrum of the DLC coated bolt shows little difference from the cleaned bolts. This means that the influence to the vacuum is little, even if the wear particles of DLC contaminate the vacuum chamber.

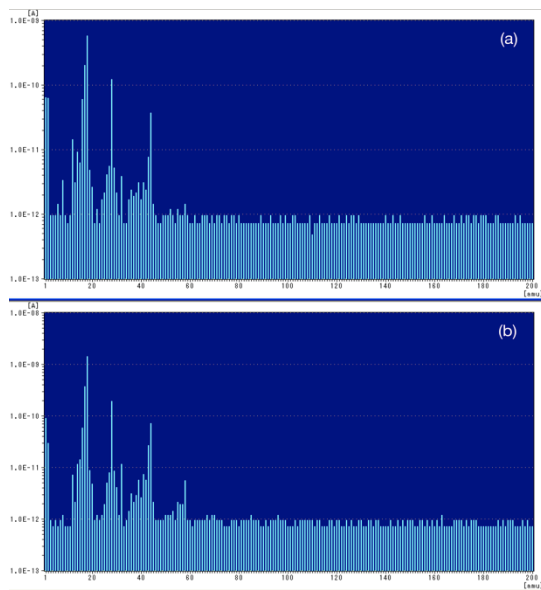


Figure 2: Mass spectrum of the SUS bolt. (a) SUS bolt with DLC coating; (b) SUS bolt after chemical cleaned.

ADESY FLANGE SYSTEM

ADESY flange that provides both RF and vacuum seal was developed for the waveguide and accelerator tube. The seal edge is pressed into the copper gasket deeply. The large deformation causes the plastic flow of the copper that results in filling the gap of the edge and making vacuum seal. For this seal mechanism, shallow scratches on the surface of the gasket do not affect the vacuum seal. For example, there is no detectable leak even when using the gasket that was machined a V-shaped groove of a 160 micro m depth from the air side to the vacuum side [2,3]. The ADESY system is a combination of the flange, pin, gasket, and the high strength bolts with DLC coating. This system demonstrates high performance when the bolts are gradually tightened under torque control until the flange gap becomes zero. More than 1200 pairs of the ADESY flange in C-band, and 68 pairs in S-band, were fastened without leak [1]. The leak detection sensitivity is 1.0×10^{-11} Pa · m³/sec. This high reliability contributes largely to

realize quick assembly of the vacuum system. During the assembly, damage of the seal edge was observed in one of the waveguide of C-band, though it was able to assemble successfully without any leak [4]. In the case of the very large flange (142.8×225.3 mm²) for L-band, leak was detected in the two of the 20 pairs. The cause is under investigation.

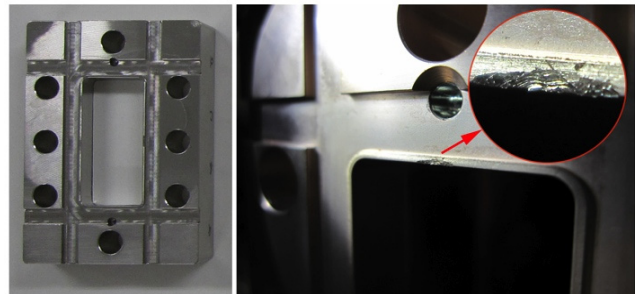


Figure 3: ADESY flange for C-band (left); Damage of the seal edge of the waveguide flange (right).

MAGNETIC SHIELDING

The vacuum devices like the CCG and the SIP that contain strong magnet, generate magnetic field around them. Some components containing the iron parts may increase the field at the unexpected locations. One reason is the iron attracts the environmental magnetic field, and another reason is the iron generates the field when it happened to be magnetized during machining or welding. Those fields have a possibility to distort the beam trajectory. Therefore the magnetic shielding is required especially for the field sensitive part.

Magnetic Shielding for CCG

CCG is adopted as the vacuum interlock sensor because of the fast response time of ~50 msec. CCG has permanent magnets. The magnetic field in the CCG gives bending force to the electrons emitted from the cathode. The electrons travel helically in the field. These long paths increase the probability of the colliding and ionization of the residual gas molecules. The pressure is derived from the ion current. For this reason, if the magnetic shielding is fabricated without any considerations, the distribution and intensity of the field in the CCG changes, and the paths of the electron become different. That is, the measured pressure becomes different from the real one. For example, the changes of the output voltages that represent the measured pressure of the CCG, and the diameter of the magnetic shielding cage are shown at the left in Fig.4. The deviation of the output increases when the iron approaches the CCG. Based on these data, the magnetic shielding tube was made of the degaussed carbon steel tubes of a $\phi 139.8 \times 4.5$ mm. The leakage field can be reduced to the geomagnetism level, when the CCG in the magnetic shielding tube is put apart at least more than 200 mm from the beam center, as is shown at the right in Fig.4.

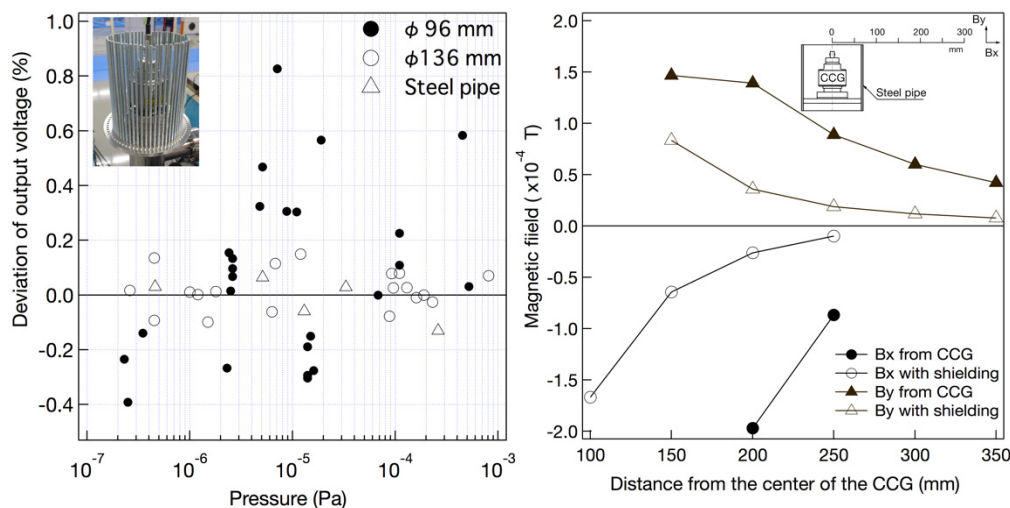


Figure4: The deviation of output voltage of CCG depending on the diameter of shielding cage consisting of the long iron bolts of M4 size (left); Shielding effect depending on the distance from the CCG (right).

Magnetic Shielding for the Entrance of the Insertion Devices

It is necessary to steer the electron beam orbit that passes through in-vacuum undulators on a straight line in high accuracy to obtain sufficient laser amplification. This can be achieved by a beam-based alignment. In this method, two BPMs are installed at interval of about 8 m at the entrance area of undulators to determine the reference orbit. It is necessary to suppress a geomagnetic field of 0.4G to about 1/100 so that the electron beam goes straight. The increase of the magnetic field was measured at the locations of the support because the iron parts of the support attracted the environmental magnetic field. To decrease this field, the iron material was changed to SUS316L, and the SIP and the CCG were put near the floor apart from the beam orbit. In addition, by wrapping the vacuum pipe in the 6 layers thick of the magnetic shielding sheet (Hitachi Metals Finemet), the field in the pipe was effectively suppressed to about 1/100 [5].

Magnetic Shielding for the Injector Section

At the low-energy injector section, an environmental magnetic field significantly affects quality of an electron beam. For this reason, the reinforcing steels in the floor concrete were degaussed. However, after installation of the components, increase of the field near the locations of the SIPs and the CCGs was measured. By installing the magnetic shielding to these components, the environmental magnetic field became uniform. Magnetic field at the beam axis could be almost zero by adjusting the long-coil that was prepared to cancel out the geomagnetic field [6].

SUMMARY

This paper reports the vacuum system, assembly and installation of the SACLA, XFEL in SPring-8. The

average pressure of this unbaked vacuum system achieved 9.3×10^{-8} Pa with beam. The use of the solid lubricated bolts and the clean environment that made by separating the tunnel contributed to this good pressure. Though the damage of the seal edge was found in the ADESY- flange for C-band, this flange was fastened without any leak. Several magnetic shielding are also reported.

REFERENCES

- [1] Teruaki Hasegawa, et al., "Assembly of vacuum components for the XFEL accelerator", The 7th Annual Meeting of Particle Accelerator Society of Japan, Himeji, Japan, August 2010, WEPS121, p.705 (2010).
- [2] Teruhiko Bizen, "Development of vacuum components for XFEL/SPring-8", EPAC08, Genoa, Italy, June 2008, THPP137, p.3682 (2008); <http://www.JACoW.org>.
- [3] Teruhiko Bizen, "Development of vacuum components for the project of X-ray free electron laser (XFEL/SPring-8)", J. Vac. Soc. Jpn. Vol.52, No. 5 (2009).
- [4] Takahiro Inagaki, Private communications.
- [5] Hideki Aoyagi, et al., "Geomagnetic shield for entrance area of undulators at SACLA", The 8th Annual Meeting of Particle Accelerator Society of Japan, Tukuba, Japan, August 2011.
- [6] Taichi Hasegawa, et al., "Uniformizing an environmental magnetic field of the injector section at SACLA", The 8th Annual Meeting of Particle Accelerator Society of Japan, Tukuba, Japan, August 2011.