VACUUM SYSTEMS RENEWAL FOR THE PF-AR UPGRADE

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Abstract

The Photon Factory Advanced Ring (PF-AR) at the High Energy Accelerator Research Organization (KEK) was upgraded to improve performance [1]. Vacuum systems were almost thoroughly redesigned and renewed to realize longer beam lifetime, higher stored current, and more reliable operation. Replacement of vacuum components was carried out in 2001. And the commissioning started in January 2002. After one-year operation, the beam lifetime grew 7 times longer than that of the former PF-AR.

INTRODUCTION

Originally constructed in 1984 as an 8GeV electron-positron booster injector for the TRISTAN main ring, the PF-AR became a 6.5GeV dedicated light source after the TRISTAN experiments ended in 1995. The PF-AR vacuum systems, however, were not satisfactory for a synchrotron light source, and therefore limited the beam lifetime to several hours and also the peak operating current to 40mA. In addition, frequent maintenance of pumps and cables were being required because of their breakdowns caused mainly by radiation.

In the PF-AR upgrading project, the vacuum systems were designed to meet the following requirements:

- Sufficiently low vacuum pressure (<5×10^{-7}Pa) to realize the beam lifetime of more than 10 hours with a 6.5GeV-100mA single-bunch beam stored
- Thermal tolerance for a 6.5GeV-100mA beam load
- Adaptation for new devices, such as beam position monitors, steering magnets, insertion devices, and SR (Synchrotron Radiation) beam lines
- Unification of vacuum control system into the EPICS [2]

Table 1: Ring and Vacuum Systems Parameters

[ ] : objective

Beam Particle	Electron	Duct Material	OFHC Cu
Beam Energy	5.0-6.5 GeV	Flange Seal	Racetrack-shaped Al Helicoflex
Injection Energy	2.5-3.0 GeV		
Beam Current	55[100] mA Single Bunch	Vacuum Pumps	TSP × 185
			DIP × 56
Beam Lifetime	50[60] Amin		SIP × 33
Horizontal Emittance	260[160] nmrad		TMP × 9
		Total Effective Pumping Speed	60000 l/s (for N_2)
Circumference	377.3 m		
Magnetic Radius	23.7 m	VacuumGauges	CCG × 80
Bending Magnets	56	Gate Valves	18
Critical Energy	26 keV	Bellows	150
Radiated Power	666 kW @6.5GeV100mA	Thermometers	RTD × 190
		Vacuum Control System	EPICS-based I/F: CAMAC+PLC
Average Pressure	1E-5[5E-6] Pa/A		

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These requirements involved drastic replacement of almost thorough vacuum components, for instance, beam ducts, vacuum pumps, vacuum gauges, thermometers, cooling water system, compressed air system, and their control system.

VACUUM PUMPS

The beam lifetime of the PF-AR is determined by ring average pressure because the main process of beam loss is bremsstrahlung. As the result of calculations of pressure distributions in arc sections, 168 TSPs (Titanium Sublimation Pumps; 300 l/s each) and 56 DIPs (Distributed Ion Pumps; 200 l/s each) were adopted as main pumps. And also 17 TSPs and 33 SIPs (Spatter Ion Pumps; 100-400 l/s each) were adopted in straight sections. Then the available pumping speed in the whole ring was estimated at 60000 l/s, and current-normalized pressure would be 5×10^{-6}Pa/A (CO equiv.) when the PSD (Photon-Stimulated Desorption) coefficient (η) reached 1×10^{-5} molecules/photon. In this case, the product of the beam current and the lifetime ($I\tau$) was expected to reach 60Amin (=100mA×10h).

Nine rough pump systems are placed along the ring, but during the accelerator operation they are separated from ring vacuum by valves.

BEAM DUCTS

From the viewpoint of thermal tolerance and radiation shield capability, OFHC copper was adopted as the material of main beam ducts. Thickness of the beam ducts is basically 6mm, which has almost the same shield capability as former 4mm thick Aluminum alloy ducts and 1mm thick lead sheets. The beam ducts are equipped with SR absorbers and cooling water channels to absorb the SR power load (4.5kW/m@6.5GeV-100mA in the bending region). Stainless steel bellows and flanges have less thermal conductivities, and are protected by the absorbers. Aluminum-oxide dispersion strengthened copper is also used for the photon absorbers at heavy load positions. Typical configuration of the beam ducts in the arc sections is shown in Figure 1. Each arc section consists of a series of these ducts.

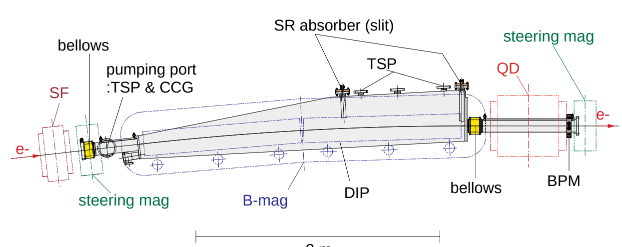

Figure 1: Typical Configuration of Beam Ducts

Outgassing process by thermal baking (150ºC, 48hours) was performed on the beam ducts prior to the installation for the purpose of the reduction of an initial gas load and the verification of their vacuum properties.

Special implements were necessary to install the beam ducts into the bending magnets because they had to be inserted from outside of the existing bending magnets under spatial restrictions.

VACUUM GAUGES

About 80 CCGs (Cold Cathode Gauges) are used for the ring vacuum monitoring. Thermal cathode ionization gauges, the most suitable gauges for the pressure measurements in the upgraded vacuum systems, were not employed because of the possible radiation damage to their controllers and the restriction of the budget. On the other hand employing CCGs alleviates these difficulties, but ordinary CCGs have instabilities in the measurements of ultra high vacuum. Then we tested the magnetically improved CCGs that hold the Penning discharge even in the 10^{-8}Pa range, and acquired calibration data with a pre-calibrated B-A gauge (Figure 2a). Fabricating CCG controllers using the calibration data enabled the reliable measurements in the 10^{-8}Pa range (Figure 2b).

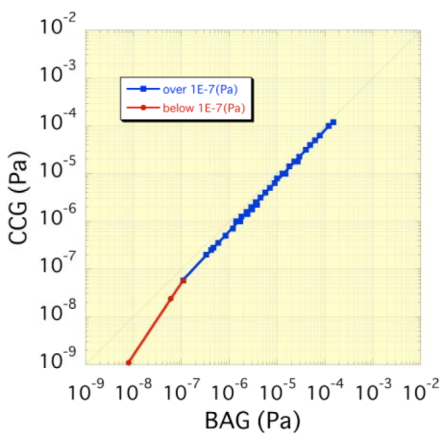

Figure 2a: CCG Calibration with Prototype Controller

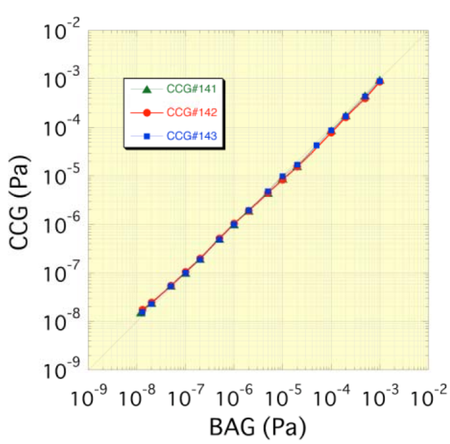

Figure 2b: CCG Calibration with Final Version Controller

VACUUM CONTROL SYSTEM

Vacuum control system was unified to the EPICS, which had already been adopted as the KEKB and the injector linac control system and was newly adopted as the PF-AR control system [3]. In the new vacuum control system, all of the vacuum devices except for the rough pumps can be controlled and monitored remotely on X terminals (Figure 3 as an example). Network connected CAMAC and PLC are used as the interfaces between the controllers of vacuum devices and the EPICS (Figure 4). PLC is also used for the vacuum interlock system.

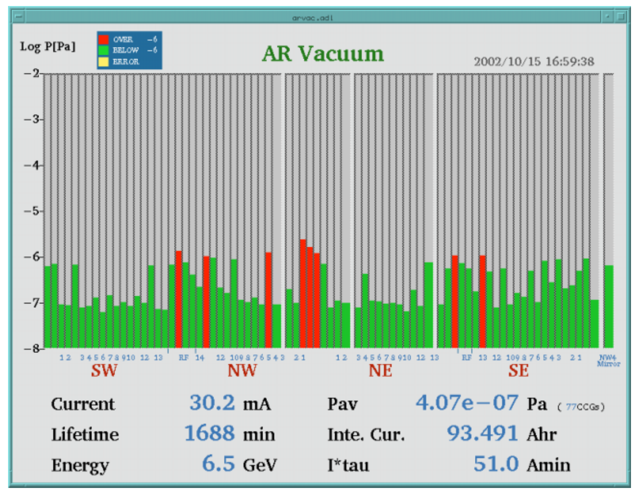

Figure 3: Ring Pressure Monitor Panel

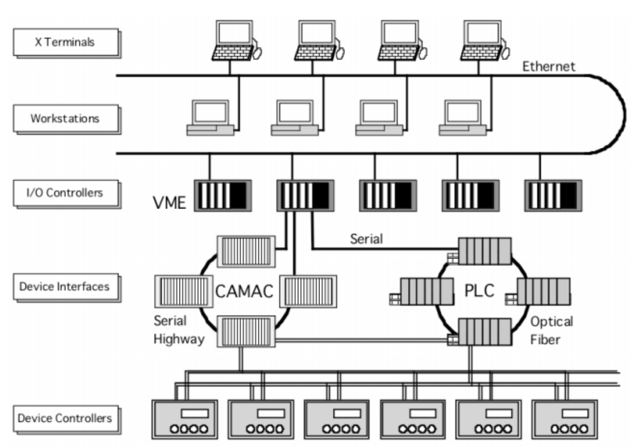

Figure 4: Diagram of Vacuum Control System

COMMISSIONING AND OPERATION

The commissioning of the upgraded PF-AR started in January 2002. Figure 5 shows the growth of the beam lifetime and the decrement of the ring average pressure. The beam lifetime as $I\tau$ has grown up to 50Amin, which is 7 times longer than that of the former PF-AR. Injection energy was raised from 2.5GeV to 3.0GeV in September 2002.

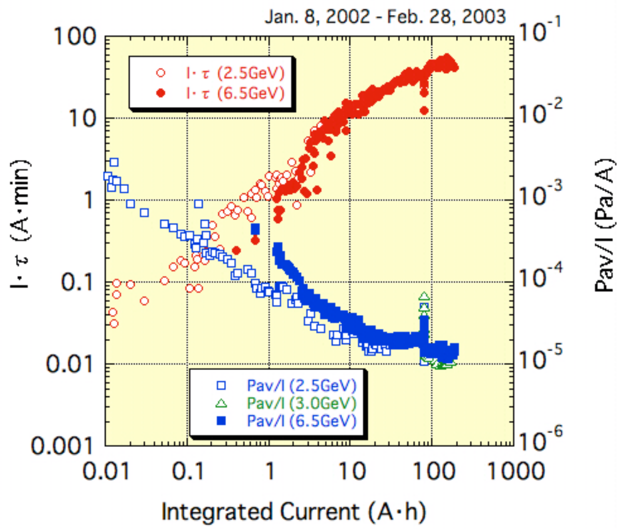

Figure 5:Progress of Ducts Self Cleaning and Growth of Beam Lifetime

Peak operating current has increased gradually, and currently reached 55mA. Operators inject the beam three times a day on schedule if neither a serious lifetime drop nor a sudden beam dump happens. Although the frequency of sudden lifetime drops is decreasing, this is one of the unsolved problems in the PF-AR operation.

While the growth of the beam lifetime seems ceasing, even longer lifetime is expected if lower pressure will be achieved. Because Figure 6, the relationship between the ring average pressure and the beam lifetime, indicates that the beam lifetime is currently being limited by the beam-gas scatterings (inversely proportional region), not by the Touschek effects (flat region).

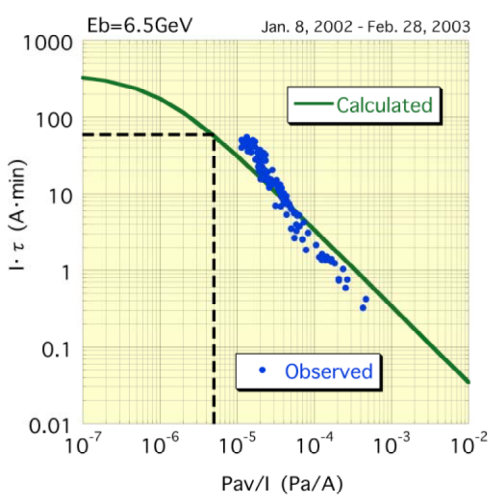

Figure 6: Relationship between Pressure and Lifetime

Figure 7a and 7b show the progress of the vacuum ducts self cleaning in the arc sections and the straight sections respectively. It is obvious that the pressures in the straight sections are dominant for the ring average pressure and seem still decreasing slowly. Reinforcement of the pumping ability in the straight sections would be effective to lower the ring average pressure.

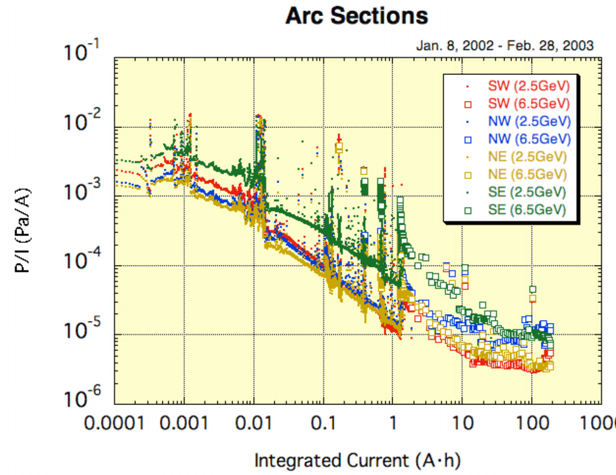

Figure 7a:Progress of Ducts Cleaning in Arc Sections.

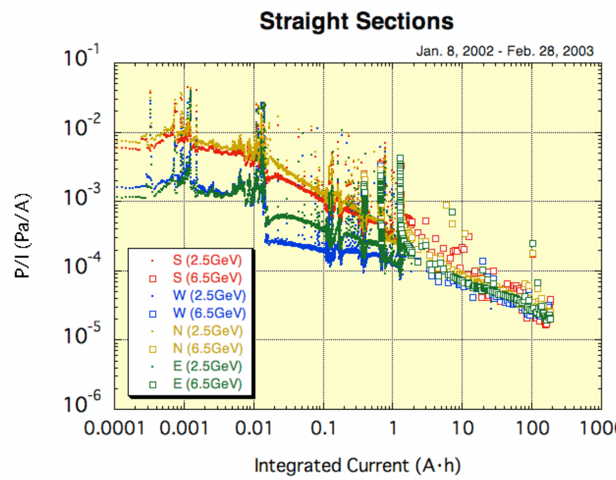

Figure 7b:Progress of Ducts Cleaning in Straight Sections

SUMMARY

The PF-AR vacuum systems had been upgraded and the commissioning and the operation started successfully. After one-year operation, the beam lifetime grew 7 times longer than that of the former PR-AR. Although the peak operating current is limited to 55mA, the required performances in vacuum systems have almost been achieved.

REFERENCES

[1] T. Miyajima, *et al.*, “Present Status of Photon Factory Advanced Ring”, these proceedings.

[2] http://lansce.lanl.gov/lansce8/epics/epics.htm.

[3] T. Obina, *et al.*, “Improvement of Photon Factory Advanced Ring Control System”, these proceedings.