# OPERATION OF THE TRISTAN VACUUM SYSTEM, INJECTION LINE AND ACCUMULATION RING

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## ABSTRACT

The operation of the TRISTAN vacuum system is described. Thermal gas desorption rate of the aluminum chambers was $10^{-9}$-$10^{-10}$ Pa.l/s.cm$^2$ as expected from the bench test. Pressure rise due to synchrotron radiation was 7 x $10^{-5}$ Pa/mA at 0.7 mA.hours and 3.2 x $10^{-8}$ Pa/mA at 4.7 A.hours. Beam energy dependence of the pressure rise was linear. No thermal problem due to synchrotron radiation was observed. The corrosion due to high energy radiation with the aid of humidity was found in the aluminum windows for X and gamma rays. Heating due to wall current discontinuity was occurred in a current transformer, ceramic chambers, and normal viton seal type gate valves.

## INTRODUCTION

The construction of the TRISTAN vacuum system (injection line and accumulation ring) which is the first all-aluminum alloy ultra high vacuum system was completed. The first beam was injected in October 1983. Beam was stored at 2.55 GeV in November and was accelerated to 5.2 GeV in December. In February 1984, the operation of the internal targets was started. In June beam was accelerated to 6.5 GeV with the parallel operation of the normal and the superconducting cavities. The obtained maximum beam intensity was 65 mA for single bunch and 90 mA for multi-bunches. Successful operation shows no substantial problem of the all-aluminum alloy vacuum system and gives us much valuable information.

## INJECTION LINE

Injection line is a transport line between the 2.5 GeV linac of the photon factory(PF) and the accumulation ring (AR). The line consists of the specially extruded aluminum alloy vacuum chambers[1]. The line is 350 m long and has two branches for $e^+$ and $e^-$ (Fig.1). It is divided into 12 sections by the gate valves[2]. Each section was evacuated by a turbomolecular pump (TMP, 50 l/s), and a rotary pump (RP). At a pressure of $10^{-4}$ Pa, a 50 l/s non-evaporable getter (NEG) was activated where the pump is operated at room temperature mode. Then operation of a 30 l/s sputter ion pump (SIP) was started. A power supply for the SIP is a DC-DC converter type[3].

All the chambers including the SIP were virgin where a helium leak check was applied. At the initial operation of the SIP, the SIP were baked. During the operation of the SIP no abnormal discharge was observed. Pressure of the injection line after 50 hour operation was on the order of $10^{-6}$ Pa which is 2 orders better than the required pressure ($10^{-4}$ Pa). Therefore we measured the pressure distribution of the line reducing the numbers of the SIP from 10 to 4 as shown in Fig.1. The pressure at one month after was the same with that of 4 days after and still less than the required pressure. It must be mentioned however that if the pressure is higher than $10^{-4}$ Pa load of the SIP could abruptly increase. Gas desorption rate at $10^{-6}$ Pa is on the order of $10^{-9}$ Pa.l/s.cm$^2$ which corresponds to the value[4] without baking. A baking (100°C, 5 hours) was applied to one of the sections of the line. During the baking no thermal problem was observed. After the baking the pressure was improved less than one order, but influenced gradually by adsorption from other sections.

The results obtained in the operation of the injection line were applied to the design of the transport line (300 m) from the AR to the main ring (MR), that is, (1) no heater for baking, (2) only 3 pumping stations for the line at stationary operation.

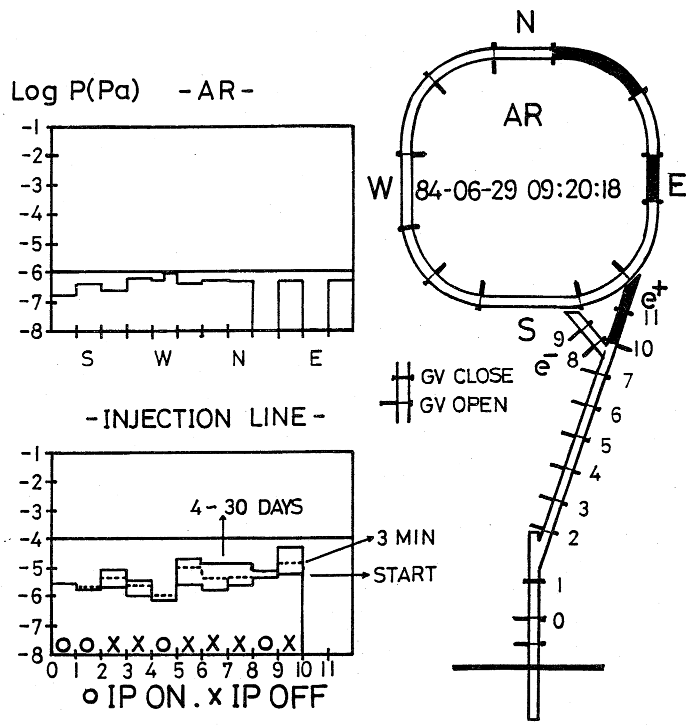


Fig.1 Layout of the TRISTAN vacuum system and pressure distribution.

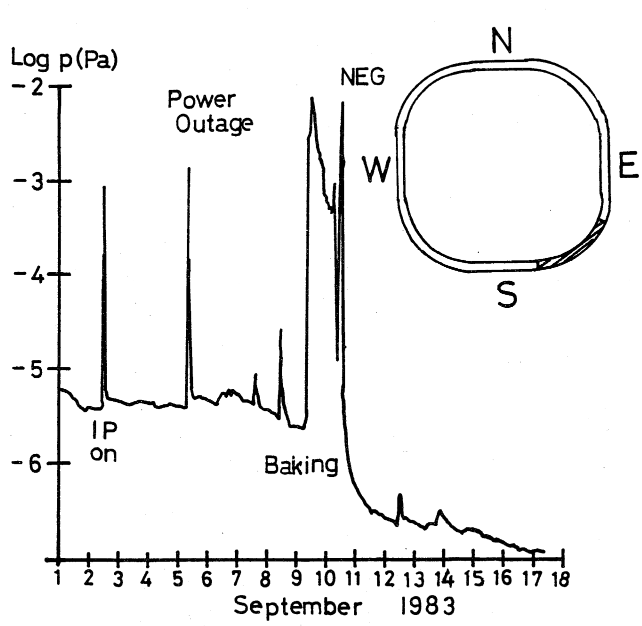


Fig.2 Initial pumping curve of a section in the AR.

ACCUMULATION RING

The AR which has a circumference of 377 m is divided into 12 sections by the gate valves[2]. Roughing pumps are 12 50 l/s TMP. Main pumps are 56 distributed ion pumps (DIP, 250 l/s) in bending magnet chambers (B-chambers). Sub-pumps are 70 SIP (30 l/s) and 70 NEG (50 l/s). 3 RF cavities are set in one of the 4 straight sections.An RF cavity has a roughing pump (250 l/s, TMP) and a main pump (2 x 500 l/s, SIP). Pressure of 8 sections in the arcs reached to $10^{-6}$ Pa after 1 week evacuation using only sub-pumps. $10^{-8}$ Pa was obtained in some of the sections using main pumps without any baking and discharge cleaning. Thermal desorption rate was on the order of $10^{-10}$ Pa.l/s.cm$^2$ at the pressure without baking[4].

A baking was applied 2 times to the section (S1) which includes 5 sets of a quadrupole and a bending magnets. The pressure change related to the first baking is shown in Fig.2. Within 3 hours after the baking, the NEG were activated and operation of the SIP was started without trouble.

DIP was tested for 2 hours where the pressure was on the order of $10^{-6}$ Pa. During the test, magnetic field was 3.6 K Gauss and the chamber was evacuated by roughing pumps. The peak pressure was on the order of $10^{-2}$ Pa. The test showed that the dark current was on the order of μA with no magnetic field and high voltage applied. Therefore the pressure of each section was measured using cold cathode gauges[3].

Dynamic gas desorption

The required pressure without beam is satisfied. However the required pressure with beam ($10^{-7}$ Pa) is not satisfied because of the pressure rise due to synchrotron light, that is, photo-induced gas desorption (dynamic gas desorption). Fig.3 shows the pressure rise as a function of beam current time integral, where the data are based on the pressure of 8 sections in the arcs. At the end of July 1984, it was estimated that about $10^4$ mA.hours were necessary to get the required pressure. It may take about 1 year to get the target. Therefore it is interesting to know if the pressure rise could be reduced by applying pretreatment on chambers. Electron bombardment[5] and RF discharge[6] have been tested on chambers of the MR.

The straight line in Fig.3 shows the result of PETRA, where the chambers were prebaked at 150°C and precleaned by Ar discharge. Beam energy at PETRA can be varied from 5 to 19 GeV. Critical energy ($\varepsilon_c$) of the synchrotron light is 1.44 KeV at 5 GeV. For the AR, $\varepsilon_c$ is 1.59 KeV at 2.55 GeV. Taking account of a frequent operation at the lowest energy, difference in factor 5 between the data could be from the pretreatments. The slope of the line is -0.63 for PETRA, -0.74 at less than $10^3$ mA hours and -1.5 at $10^3$ mA.hours or more for AR. The slope of -1.0 before Ar discharge cleaning and from -1.25 to -0.7 after the cleaning were obtained at photon factory[7], where a baking was applied. No explanation is obtained for the scattered data of the slope. The change of the slope at $10^3$ mA.hours can not be explained quantitatively though difference in operation energy and beam intensity are suggested. Deterioration about one order at 2200 mA. hours shows the influence of an exposure (11 sections) in an atmosphere for maintenance. Exposures of 1 section are 2660, 3240, and 3390 mA.hours. The deterioration of the latter 2 cases is small compared with that of the first case (2660 mA.hours). This may due to the short exposure less than 30 min. The data after 2200 mA.hours were rearranged by resetting current time integral. The obtained slope is -0.69 which is close to the value of less than $10^3$ mA.hours. Energy dependence of the pressure rise is shown in Fig.4. Linear dependence on beam energy are obtained. Therefore we may expect a little influence of the pressure rise during high energy operation.

Raw data of gas species with beam at 1.7 mA.hours are 38 ($H_2$), 12 (CO), 6 ($CO_2$), and 1.5 ($H_2O$). The ratio is constant at a pressure range between $1.3 \times 10^{-4}$ and $6.5 \times 10^{-6}$ Pa. The data without beam are 0.8 ($H_2$), 0.2 ($H_2O$), 0.17 (CO), and less than 0.01($CO_2$) at 1.7 mA.hours. At 18 mA.hours, the data with beam are 70 ($H_2$), 23 (CO), 10 ($CO_2$), and 4 ($H_2O$). No significant change in the ratio was shown at the two different current time integral. These data were obtained in the baked section. Beam life time at 20 mA.hours was $10^3$ sec at $2 \times 10^{-6}$ Pa and $2 \times 10^2$ sec at $1.3 \times 10^{-5}$ Pa for the beam intensity of on the order of mA. The result was compared with the theoretical values. The comparison showed that the number of an equivalent charge was between 14 and 16. The life time at 4.7 A.hours was 75 min at 5 mA and $2 \times 10^{-7}$ Pa. It can be approximately said that the life time of the AR increases with a square root of current time integral.

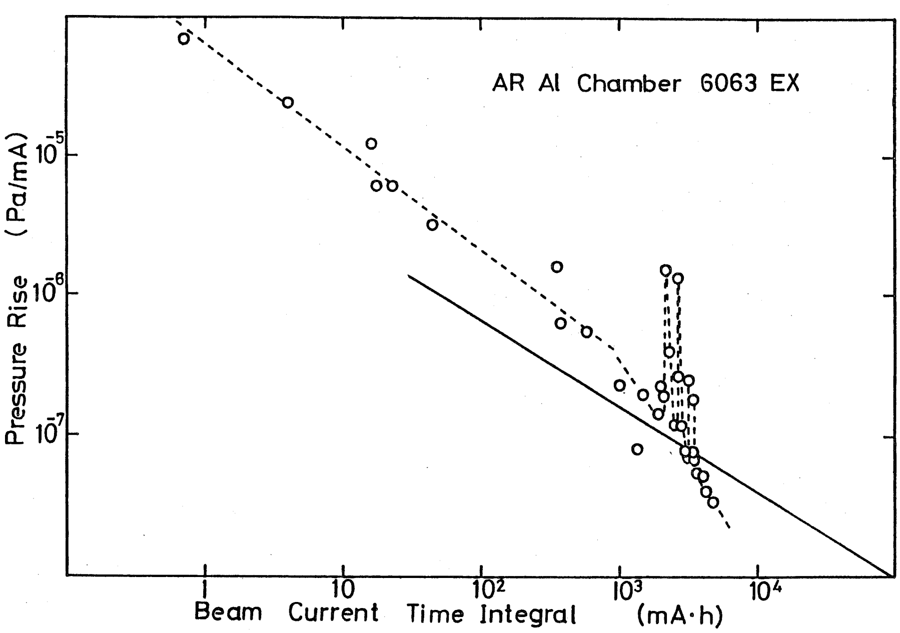


Fig. 3 Pressure rise of the AR as a function of a beam current time integral.

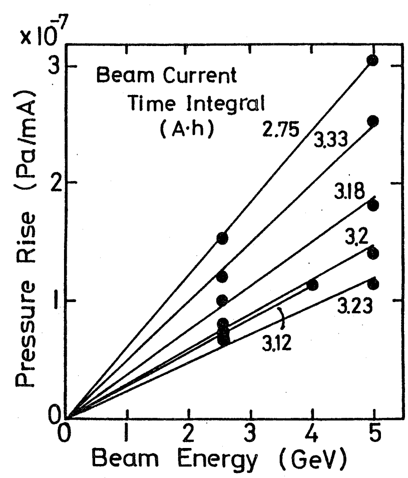


Fig. 4 Energy dependence of the pressure rise.

Table 1

Peak heights of the gas species from the nomal gate valve

| beam intensity (mA) | peak heights (arb. unit) $H_2$ | $H_2O$ | CO | $O_2$ | $CO_2$ |
|---|---|---|---|---|---|
| 0 | 4.5 | 16 | 3.5 | 0.5 | 0.5 |
| 10 | 95 | 170 | 110 | 5 | 35 |
| 15 | 100 | 320 | 110 | 10 | 35 |

## Wall current

In electron storage rings, electron beam excites wall current inside the beam chambers. Therefore we paid attention for the continuous current flow. The gate valves used in the AR satisfy the continuous current flow for both cases, open and close. They are so called dual flat mirror surface seals with differential pumping type gate valves[2]. No influence of the wall current was observed on these gate valves.

We were obliged to use the normal viton seal type gate valves to isolate the superconducting cavity in the AR. The valve has discontinuous structure for the current flow. Therefore beam intensity was less than 8 mA when the cavity was set in the AR. Peak heights of the residual gases from the gate valve during the operation are shown in Table 1. The dual flat mirror surface seals gate valves can be applied to the superconducting cavity for the next operation.

A pressure was deteriorated to $10^{-2}$ Pa because a current transformer (CT) to monitor beam intensity was heated at more than 20 mA of single bunch. The pressure deterioration at 30 mA started after about 30 min of the current build up. This was also a problem of wall current. The CT is a kind of a coaxial cavity and has a gap about 5 mm to cut wall current. In addition, permalloy and glass wool were included in the cavity. There was no problem after the CT was eliminated.

Ceramic chambers for kicker magnets also showed the heating problem. The chamber is a rectangular cylinder having a race-track type hole. Inside surface of the hole, Ti-Mo coating was applied to maintain the continuous current flow. The coating is 2 μm so that the magnetic field can be inside the hole. Temperature was, for example, 77°C at the both edges and 54°C at the center of the chamber for single bunch and 1 hour operation of 40 mA. The heating was due to a discontinuity of metal coating between the coated Ti-Mo film and the metallized bellows at the both edges. It was repaired by an improved evaporating source of Ti-Mo.

## Corrosion, humidity, and cooling system

Molybdenum internal targets have been used to produce gamma ray. 240 W synchrotron light is radiated on a target at 6.5 GeV and 20 mA. An independent coolant was used for the target cooling system. After 1 month operation, deposition of Cu and precipitation of aluminum hydroxide were observed on the surface of an aluminum cooling pipe. It was estimated that Cu came from a copper heat exchanger in the coolant. Therefore the target cooling systems are now connected to the AR cooling system.

An extraction window (80 μm, Al) is at the down stream of the target. After 48 hour operation of the internal target mode (5 GeV, 6 mA), aluminum hydroxide was observed on the outer surface of the window. This can be made by the high energy light with the aid of humidity and $N_2$ gas. Therefore the window was changed to a Be-plate (0.3 mm) and the plate was covered with an Al foil (80 μm). Helium gas was introduced into the space between the Be-plate and the Al-foil. A similar fact was also found in a X ray window.

An influence of humidity was observed with the high voltage connectors for SIP and DIP. It was estimated that humidity accelerated abnormal discharge at the connectors and that an insulator was carbonized and metal was oxidized by the discharge. This trouble can be overcome by reducing the humidity in the AR tunnel.

Maximum power of synchrotron radiation at B-chamber is 940 W/m at 6.5 GeV and 20 mA ($e^-$)[8]. Each bellows at both sides of a B-chamber receives power about 100 W. To protect bellows (0.3 mm), a 5 mm Al cylinder (absorber) was welded inside chambers so as to make a shadow on bellows. Since critical energy of the radiation at 6.5 GeV is 28 KeV, penetration depth is 2.8 mm and 83 % of the radiation (80 W) can be absorbed at the cylinder. The role of the absorber has been already confirmed by a radiation test using high energy electron beam of equivalent power and penetration depth[9]. In fact, no thermal trouble was observed in the bellows.

Power due to synchrotron radiation is 0.27 MW at 6.5 GeV and 20 mA ($e^+$, $e^-$). 0.88 tons/min of cooling water is necessary if 10°C temperature rise were admitted. A cooling set consists of 2 bending and 2 quadrupole magnets. Therefore there are 34 sets in the AR. Cooling pipes (inner diameter, 8 mm) are isolated from other metal using polyethylene tape to prevent galvanic corrosion. Total amount of the cooling water is now 0.3 tons/min at the flowing rate of 8 l/min. Temperature of the water was sometimes set below dew point. Therefore the dew was observed on the aluminum alloy chambers. Humidity control is necessary more strictly.

## CONCLUSIONS.

The all-aluminum alloy ultra high vacuum system (the injection line and the accumulation ring) has been operated without any substantial trouble. High reliability and performance of the aluminum vacuum system were proved. Much valuable information was given to improve the operation of the AR and has been applied to the design of the MR.

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