OPERATIONAL CHARACTERISTICS OF THE 30 GeV ELECTRON-POSITRON COLLIDER, TRISTAN

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1. Introduction

The first truly all aluminum vacuum system[1] for a large scale electron-positron colliding beam ring, TRISTAN was completed[2]. The first beam was stored in TRISTAN main ring (MR) on October 22, 1986, and a high energy electron-positron colliding experiment started in November 1986. At 25 GeV, maximum beam currents of 2 mA × 2 mA for each of two bunches were obtained. Successful operation showed no substantial problem with this first all-aluminum alloy, ultra-high vacuum system. Maximum luminosity is 10^{30} $cm^{2}sec^{-1}$ for 2 mA × 2 mA, 25 GeV beams. The MR has four colliding experimental areas: Fuji-VENUS, Tsukuba-TOPAZ, Oho-AMY, and Nikko-SHIP. The VENUS, AMY and SHIP detectors were rolled-in already. This paper will describe the first truly all-aluminum ultrahigh vacuum system and two months operational experience.

2. Vacuum System

Vacuum chambers and equipment

The MR, which has a circumference of about 3000 m, is divided by 50 gate valves. Roughing pumps for arc sections are 96 turbomolecular pumps TMP (50 ℓ/s). The main pumps are 264 distributed sputter ion pumps DIP in bending magnet chambers (6 m). The DIPs are made of aluminum with Aℓ-Ti-Zr cathodes and can be operated at magnetic fields between 0.8-5 kG. The sub-pumps are 448 sputter ion pumps SIP (15 ℓ/s) and 444 non-evaporable getter NEG (50 ℓ/s). The SIPs are made of aluminum alloy with Ti cathodes.

32 RF cavities were installed in four long straight sections. RF cavities are not made of aluminum alloy but of mild steel electroplated with about 0.1 mm thick copper. The roughing pumps are 32 turbomolecular pumps TMP with magnetic bearings (200 ℓ/s) for each RF cavity. The main pumps are four SIP (250 ℓ/s) for each RF cavity.

The aluminum alloy (6063-T6-EX) vacuum beam chambers are assembled in the bending and quadrupole magnets. The racetrack shape aluminum alloy bellows are inserted between the bending and quadrupole magnet chambers. The bending and quadrupole magnet chambers and bellows have just the same racetrack shape to obtain impedance matching and to facilitate automatic welding. For the RF sections and the colliding experimental regions, aluminum alloy (6063-T6-EX) circular pipes are used. Five sets of modular type non-evaporable getters are housed in the sides of the insertion quadrupole magnet chambers.

30 gate valves with racetrack apertures[3] for arc sections and 20 gate valves with circular apertures for straight sections are installed along the ring. A ceramic chamber with racetrack aperture is used for the injection kicker and beam intensity monitor. The gate valves and the ceramic chambers were welded to the vacuum chambers directly without flanges. 16 DC separators[4] are installed at both sides of the four collision points. There are two types of separators long and short separators. Maximum operating voltage without beam is ± 90 kV.

A pair of fixed masks made of lead are installed in the long straight sections. Movable masks made of lead are installed in between the long and short separators. All vacuum chambers are shielded with 10 mm of lead against hard X-rays.

Control

The vacuum system is controlled by computer (HIDC-80E) and a CAMAC system. SIP control is simplified by restrecting the operating pressure range of the SIP. The operating pressure range of these SIP and DIP is between 10^{-4} Pa and 10^{-8} Pa. The discharge current near 10^{-4} Pa is of the order of 1 mA. We therefore use 5.5 kV, 5 mA and 5.5 kV, 20 mA DC-DC converter-type high voltage power supplies. 96 MIC gauges[5] and 12 new type mass filters[6] were installed along the ring. The mass filter is made of aluminum alloy and a newly developed technique for transmitting the RF power is used. A newly-developed ion source is used, with a closed hemispherical mesh anode. This mass filter has a high sensitivity, 400 mA/Pa at 2 mA emmission current, without requiring a secondary electron multiplier. 238 inverted magnetron type cold cathode gauges, 66 Pirani gauges, and 238 Convectron gauges were used for pressure measurements.

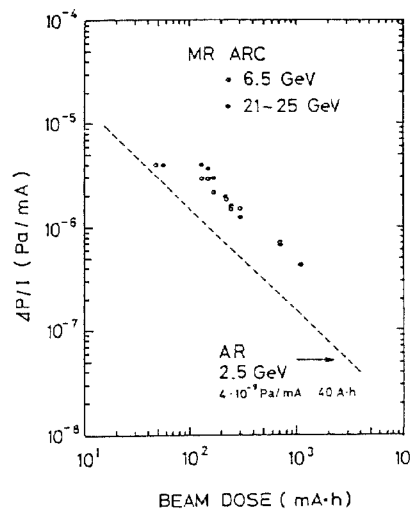

Fig. 1 Pressure rise due to beam vs. time integrated beam current.

Assembly

After the installation of the vacuum system, it was He leak tested and the vacuum chambers were aligned relative to the magnets and attached to them. A calibration was made for all of the fixed frames between the beam position monitors and the quadrupole magnets. The entire vacuum system with computer control was completed in September 1986.

3. Initial Operation

Each section individually isolated by its gate valves was first evacuated by a roughing pump. At a pressure of 10^{-4} Pa, 15 ℓ/s SIPs were started. Before installation, these SIP had not been subjected to any starting procedure and were truly as manufactured. During the operation of SIP (15 ℓ/s), no abnormal discharge was observed. NEG pumps of cartridge, modular or linear types, operated in the room temperature mode, were activation. Cooling was not required for NEG pump activation. The pressure of the arc sections along the ring was reduced to the order of 10^{-6} Pa. A baking test was done on only one section which included eight sets of bending and quadrupole magnets. The pressure

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change associated with the first baking was as predicted and no thermal or mechanical problems occured. The pressure in RF cavities reached the order of 10^{-7} Pa after evacuation of about 100 hours with baking and the RF high power conditioning. All DIPs which were started at a pressure of less than 10^{-4} Pa. During the starting procedure pressure increases upto the order of 10^{-3} Pa were observed. After operating the DIP continuously for about 1000 hours, the system was pumped down to the order of 10^{-7} Pa without any baking and or discharge cleaning.

4. Beam Operation

Base pressure and pressure rise

The first beam test was started on October 15. The first electron beam was stored at 6.5 GeV of injection energy on October 22. Following this, the electron beam was accelerated to 25 GeV and then the positron beam was accelerated to 25 GeV. The first electron-positron collisions were detected on November 19. During the following two months operation some vacuum problems have occured. Vacuum system performance in

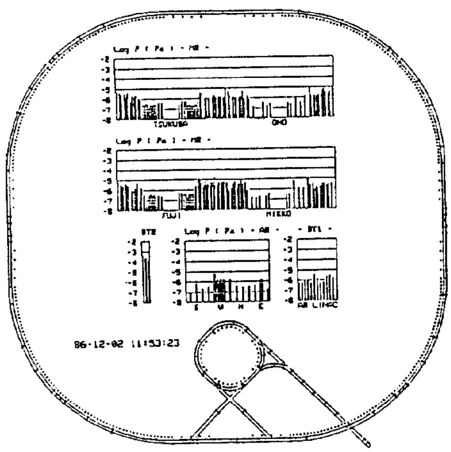

Fig. 2 Computer graphic display of pressure distribution along the ring and beam transport, gate valve status, and cooling water status.

the first stage of beam operation was as follows: average base pressure without beam was of the order of 10^{-6} Pa, average pressure with beam was 10^{-5} Pa, for 25 GeV, 2 mA × 2 mA beams.

The two months operational experience of the MR has shown that beam life times upto 1.5 hours can be achieved without any baking or discharge cleaning. In the two months operation, the average pressure increase in the ring with beam reached a value of about 10^{-7} Pa/mA for time integrated beam current of about 1000 mAh. In Fig. 1 the solid line describes this behavior as a function of the time integrated beam current.

The required pressure of 10^{-4} Pa without beam was not achieved. Also the required pressure of 10^{-7} Pa with beam was not achieved because of the pressure rise due to synchrotron radiation; photoinduced gas desorption and inefficiency of DIP as main pump.

The pressure distribution along the ring is shown in Fig. 2 using computer graphic display. We can see the pressure distribution for the beam transport line from linac to accumulation ring (AR), AR, the beam transport line from AR to MR, and MR, gate valve status, and cooling water status. Figure 3 shows beam energy, beam current, average pressure, and beam life time.

Wall current

In electron storage rings, the electron beam excites high frequency wall currents inside the beam chamber. Therefore we took care to ensure a continuous current flow by using the gate valves to provid a continuous conducting path. The vacuum chambers with racetrack apertures in the arc section and the circular apertures in straight section were connected using tapered pipe to obtain smooth wall current flow. Also connections of small and large size circular aperture pipes were made using tapered pipes.

To make good impedance matching for the racetrack shape bellows, an RF finger was inserted inside the bellows. The RF finger was made of Be-Cu alloy. To hold the RF contact between the RF finger and the aluminum bellows, the contact force of all fingers were measured. After two months operation, we have observed no problems with the RF fingers. For circular type bellows the RF shield was not inserted. The ceramic chambers for the kicker magnet and current transformers were racetrack inner shape just the same as the beam chamber. The ceramic chamber was bonded to an aluminum bellows which could then be welded to the aluminum chamber. A Ti-Mo film was coated on the inner surface to provide a continuous conducting path. The thickness of the film was about 2 µm so that the magnetic field of the fast kicker magnet could penetrate in the beam region. No heating of these ceramic chambers was observed.

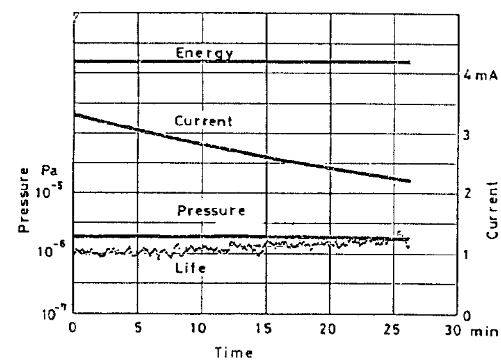

Fig. 3 Computer graphic of beam energy, beam current, average pressure and beam life time vs. time.

5. Problems and Improvements

The DIPs at the AR exhibited good pumping performance. which composes the pressure with the DIPs on and off. They also functioned reliably. The cathode material of these DIPs was Ti which has efficient pumping characteristics[7]. However the DIPs with Aℓ-Ti-Zr cathodes do not exhibit such efficient pumpng characteristics as shown in Fig. 4. Especially, during the initial stage of DIP operation the pumping action was very weak and outgassing from Aℓ-Ti-Zr DIP was observed. The main outgassing was hydrogen due to on hydrooxide film on the Aℓ-Ti-Zr alloy. This hydrooxide film absorbed much water. The hydrooxide film was grown during holding process in two years. The data predicts such hydrooxide film growth in high humidity condition.

All cathode material is in the process of being changed from Aℓ-Ti-Zr alloy to Ti. The first change was done for seven sets of DIP (6 m long) on December 1986. After the change of cathode material, the pumping characteristics were improved to the extent that they were nearly the same as DIP of the AR as shown in Fig. 5. Effective pumping speed in $10^{-4} \sim 10^{-6}$ Pa range was about 100 ℓ/s.m on the test bench. After changing the DIP cathode material from Aℓ-Ti-Zr to Ti, the pressure with the beam will reduce five times from the data (Fig. 6) of changed DIP in December 1986. In the next operation, the photodesorption rate will reduce about two times. Then the operating pressure will be reduced by about one order of magnitude and the life time will be expected about 10 hours.

The DC separators can be operated at the specified high voltage and have no problem without beam. However, the long type DC separator has two sets of parallel electrodes and a problem with unwanted discharge due to the beam occured at the connecting part of these two sets of electrode. The RF high voltage was induced between the gap of two sets of parallel electrodes by the beam. Therefore, a short bar and related electrodes were eliminated to suppress the unwanted discharge due to beam. The short type DC separator has two sets of parallel electrodes. The problem was unwanted discharge between the gap of two sets of electrodes. Therefore, the two sets of electrodes have been replaced by a one piece electrode, and additional short plates are installed in the connecting parts of the electrodes to suppress unwanted discharge due to the beam. The pressure rise due to the beam was observed. With the DC separator off, the pressure rises linearly with the beam current for good performance DC separator, however the pressure rise is proportional to the square of the beam current for not good performance DC separator. Outgassing from the DC separators was dependent on unwanted discharge inside the separators. Degraded vacuum in the colliding regions was caused by this pressure rise of DC separators.

Operation during 1986 FY was finished on February 20, 1986. The next beam operation will start May 10, 1987. During the machine shut down, two improvements have been made. First, the cathode material has been changed from Aℓ-Ti-Zr to Ti for all DIP electrodes. Second, the electrode structure of DC separator has been changed.

6. Conclusion

The all-aluminum TRISTAN vacuum system has been operated for two months. The first 25 GeV electron-positron colliding experiment was done successfully. But the vacuum system has problems resulting from DIP cathode material and unwanted discharge of DC separators due to the beam. Eight RF cavities have been installed concurrently with improvements of cathode material of DIP and correction of unwanted discharge of DC separators. The all-aluminum vacuum system satisfies conditions such as: high performance, impedance matching, simplicity, low wasted space between magnets, small size and low cost. The next machine operation will start on May 10, 1987 for electron-positron colliding experiments with higher energy, high luminosity and long life time.

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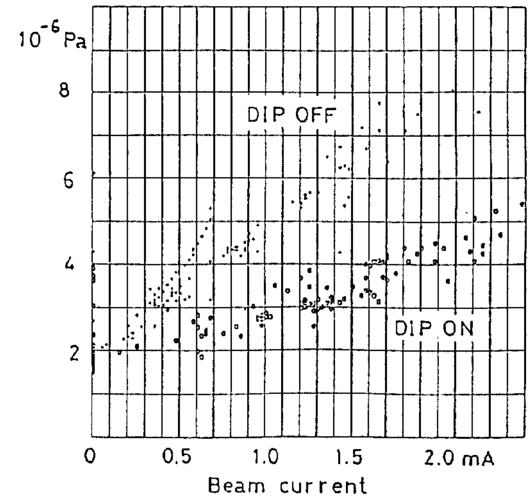

Fig. 4 Pressure change vs. beam current for DIP on or off in Aℓ-Ti-Zr cathode.

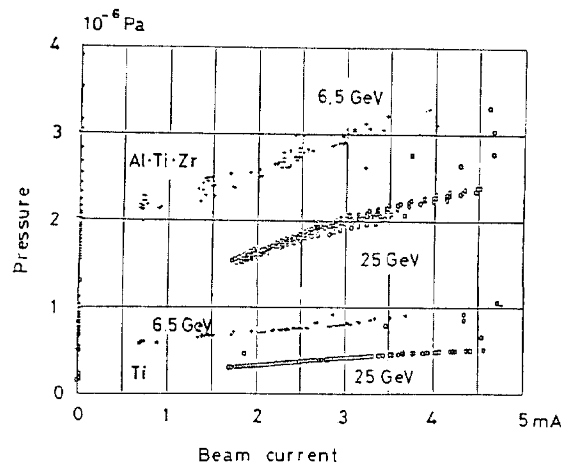

Fig. 5 Pressure change vs. beam current in Ti cathode and Aℓ-Ti-Zr cathode.

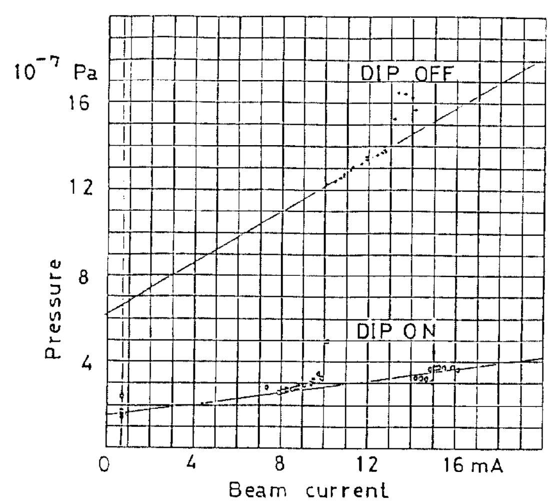

Fig. 6 Pressure change vs. beam current for DIP on or off in Ti cathode of accumulation ring.