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SOME TROUBLES IN OPERATION OF TRISTAN VACUUM SYSTEM

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ABSTRACT

During the four year operation of all-aluminum vacuum system of TRISTAN, many troubles confronted us. However inefficient pumping characteristics of aluminum cathode DIPs are resolved by changing the cathode from aluminum alloy to titanium. Mechanism of abnormal discharge of DC separators has been made clear. Reparing was already applied on the separators and a slight indication of improvement was obtained. Although gate valves based on a new concept showed troubles due to fatique failure together with structural defect, life characteristics are advancing by one or two orders compared with the one of the first stage. Sealing problems related flanges are basically the one of quality control and of welding. As for the high voltage connectors for IPs and DIPs, optimum design is necessary together with quality control. Failure of bellows of the beam stoppers needs well defined design. The leak of the internal target was due to the deffect of cooling structure. All these problems help the aluminum vacuum system to become a complete one.

INTRODUCTION

The construction of the first all-aluminum alloy vacuum system TRISTAN, accumulation ring (TAR) and electron and positron colliding ring (TMR) were completed in 1983 and 1986, respectively. By the four year operation of TAR and TMR, the aluminum alloy vacuum system shows no substantial problems as an ultra high vacuum system and its effectiveness compared with the traditional vacuum systems. The aluminum alloy vacuum system has now established the confirmed status for not only the vacuum system in accelerators but also in semiconductor industry. In addition, several aluminum alloy vacuum system has shown the ultimate pressure of 10^{-13} to 10^{-12} Torr[1, 2, 3] . However the aluminum alloy vacuum system has now been developed into a mature technology, many points to be improved are contained. The fact does not deny the effectiveness of the system as an ultrahigh vacuum system. On the contrary, the aluminum alloy vacuum system looks now much more promissng by developing soft wares and systems, and applying new materials. In this paper the troubles in the past four years are described together with the improvemet.

TROUBLES

Distributed ion pumps (DIP)

The reasons why aluminum alloy cathode distributed ion pumps (Al-DIP) were accepted for TMR are; (1) an initial pumping curve for an Al-DIP showed no significant difference compared with that of a titanium cathode distributed ion pump (Ti-DIP), (2) Though pumping speed of Al-DIP was 1/2 to 1/3 of that of Ti-DIP, construction and assemble were already started. However, preliminary operation of Al-DIPs in autumn 1987 showed less pumping speed than expected values. Another bench test of Al-DIP also showed less pumping speed together with high outgassing of hydrogen. The reason[4] of Al-DIP deterioration is estimated as, (1) the surface of Al cathode is covered with hydroxide, (2) the oxide contains much water, (3) the water is decomposed by high voltage application, (4) much hydrogen produced by the decomposition is overload for Al-cathode, (5) this tendency is accelerated in TMR by small rough pumping capacity compared with that of the bench test. An aditional bench test of Ti-DIP and test operation of eight Ti-DIPs in TMR showed better pumping characteristics. Therefore all of Al-DIPs were exchanged to Ti-DIPs.

This Al-DIP deterioration teaches us that aluminum surface is very sensitive, especially to the moisture, therefore, aluminum components must be transported or stored within sealed envelope together with desiccant, and that much more test before baking should be done.

DC Separators

For the DC Separators in TMR[5] , high voltage test without beam showed several hour keeping time without discharge in spite of the incomplete applied voltage less than ± 90 kV. However, during TMR operation at the beam current more than 2 mA, the large discharge occured in four separators at the applied voltage about ±40 kV. From the discharge characteristics it can be estimated that connecting short circuit parts of the electrodes discharged or overheated by wall current or rf field excited by bunched beam, and that the discharge grew to the large break down between two electrodes. The reason why the connecting parts are used is that the electrodes are divided into two pieces to absorb thermal expansion, and that the electrodes are electrically short-circuited using a spring which is covered by an anti-corona cover. The estimation was confirmed by the traces of discharge inside the anti-corona cover. Based on the facts, following improvements were made during the long shut down on March and April, 1987: (1)for L-type separators[5] , the spring has been eliminated and the two pieces of electrodes were connected outside the chamber using cable. For S-type separators[5], since the connecting part was also a supporting part of the electrodes, the electrodes were changed to a single piece electrode. (2) The electrodes and the central conductor of a high voltage feedthrough was connected by a copper ribbon (15-40 mm wide and 0.1 mm thick) where the central conductor was still movable to the electrode. (3) The anti-corona covers were set not to touch the electrode with a gap of 6 mm. (4) In order to avoid the discharge of feedthroughs in atmosphere, large corona rings of 300 mm in diamater were set on the feedthrough outside the chamber.

In spite of these improvement, in the next operation. the large discharge occured again at mainly two separators at the voltage of 40 kV when the beam current was over 2 mA. However, the discharge mode was different from in the last operation, that is, almost all discharges occured between the electrode and the chamber rather than between two electrodes. The micro-discharge current leading to the large discharge grew abruptly at some beam currents. This fact, suggests that the discharge still occured between the small gap by rf fields excited by bunched beam. It was considered that discharge occured between the central conductor and an electrode, or between an anti-corona cover and an electrode. The gap between the anti-corona cover and an electrode which was widened in last improvement might be still small. Or, it could be said that a bag shaped anti-corona cover had a structural defect against rf fields.

Then, during a short shut down, central conductor and electrode were all connected tightly by stainless steel blocks and a gap between central conductor and electrode was made wide to 5 mm for one separator in question. The anti-corona covers were removed entirely. Though the gap between two electrodes became 70 mm, it had no effect on beam orbit. As a result, no large discharge was observed in this separator even the beam current was over 8 mA. The micro-discharge current was less than 10 μA. So all of rest fifteen DC separators were decided to be repaired as same way during the long shut down in August and September, 1987. Results will be checked in the next operation.

Ceramic chambers

Ceramic chambers are important components to control beams by applying magnetic field with relatively high frequency. Ceramic chambers satisfy the continuity of wall current by applying Ti-Mo coating(2 μ m) on the inside surface of the chambers. One more important thing in TRISTAN is that the ceramic chamber can be connected to aluminum chambers. This was realized using aluminum bellows and aluminum brazing[6].

The discontinuities between the Ti-Mo coating and the aluminum bellows at the ends of the ceramic chambers caused heating (40～77℃, 2. 5 GeV, single bunch, 40 mA, 1 hour operation). The measurement of d. c. resistance does not detect the discontinuity. The heating brought about pressure deterioration first, but later the deterioration decreased.

Ceramic chambers without film coating were welded in TAR. From the chamber rf field excited by bunched beam was radiated to open air. The field damaged TV cameras and made the rf control system abnormal during operation. The best method to check if the film is or not in the ring is to measure electric capacitance, although the best way is seeing before welding.

There were twenty-one ceramic chambers in TAR. ten chambers were closely located to bending magnets. Therefore the ceramics were protected from heating using light absorbers (5 mm in thickness and height) made of aluminum[7] and by making the outside wall of ceramics 5 mm outside compred with that of the beam chamber. In spite of these, one end of several ceramics in several cm long was not be masked by the absorbers. In addition beam energy increase from 6.5 to 7.4 GeV at this time made the absorbers insufficient for masking (attenuation length is 2.3 mm for 6.5 GeV and 7 mm for 7.4 GeV). As a result severe heat cycles and heat distortion during beam storage were applied on the ceramics. The maximum temperature difference between aluminum chambers and ceramics was about 100℃. The three ceramic chamber showed sealing failure due to crack of the ceramics. For the ten chambers, Al-Cu claded absorbers (Al is 4 mm and Cu is 6 mm thick) were welded to the original aluminum absorbers. Attenuation length of Cu at 7.5 GeV is 0.2 mm. To make masking complete for several ceramic chambers, beam chambers were pressed so as to make relative height of absorbers higher. To reduce the temperature difference, heat pipes are attached to some of the ceramic chambers.

Gate valves

The gate valves in TRISTAN are based on new sealing concept, super-mirror-like flat-face seals with differential pumping[8]. Since the surface sealing is obtained by diaphragm (0.1 mm thick aluminum, A1050-H18) pressed against the isolating plate with mirror surface using compressed air, the diaphragm is the dominant factor of life of the valves.

In TAR, troubles of gate valves are mainly related to diaphragm and occured five times. As the valves are welded to the beam chamber, urgent repair was obtained by stopping air supply and evacuating inside the diaphragm. At first it was estimated that the abnormal contact of the isolating plate caused the trouble because of small gap between the plate and the diaphragm. Therefore the structure of the valves for TMR was changed to be no evacuating type by setting twenty springs inside the diaphragm. This structure needs larger air pressure for sealing. One trouble of race track type gate valves for TMR was due to fatique failure at the boundary between thin (0.2 mm) and thick (1 mm) part of diaphragm. It was estimated that the reason of the failure was higher air pressure. Required cycles were 100, however recheck of three gate valves showed 31, 42, and 52 cycles. By eliminating the sixteen springs and setting the pressure low (1 kg/cm^2), 255 and 350 cycles were obtained. The all gate valves were improved by eliminating the springs. This change needs evacuation inside the diaphragm for movement of an isolating plate.

Welding part was completely broken by stress concentration between shafts for an isolating plate and for an air cylinder. Because of this, a gate valve (ICF-203 Type) was kept close in spite of air cylinder being in open state. The stress was applied because the isolating plate and the air cylinder had no margin space to move. The welding part were changed so as to remove stress concentration for the same type valves.

Five troubles occured, one for ICF-152 type and four for race track type gate valves. From the outside, the gate valves were observed as if they were open. To suppress exposure of beam chamber to atmosphere as little as possible, all the valves were checked by taking X-ray photographs. Isolating plates have tap and one end of the shaft is screwed. This part was released by some oscillation, probably of a turbomolecular pump and a rotary pump for differential pumping. This was accelerated by keeping the isolating plate free (without pressing the diaphragm) for several weeks. The parts were tightened again and complete improvement will be applied soon.

Abnormal discharge of cold cathode gauge (CCG)

CCG have several advantages[9] for high and ultrahigh vacuum measurements. However the gauges operated for long time in high pressure showed abnormal discharges and can't be used in ultrahigh vacuum. This was often observed for CCG in rf cavity system. The bench test[9] using a rotary pump evacuation showed that for both CCG with aluminum or stainless steel cathode abnormal discharge started after several hour operation and detrimental failure after 200 hour operation at the pressure of 10^{-1} Pa. It was considered that adsorbed carbon on cathode changed secondary electron emission coefficient at ion or electron bombardment and caused the discharge. Therefore for CCG in TMR high voltage is off when gauge current is over a threshold. Cathode material is stainless steel for rf cavity measurement and aluminum for others.

Flanges, connectors, and non evaporable getters

ICF-152 type chambers for rf cavity roughing system consist of a cylinder 300 mm long where two ICF-152W, two ICF-070LAW, and two ICF-070W flanges are welded. The problem is a lack of hardness at the edge of 070 flanges. For twenty-three chambers hardness of the flanges at the between of holes for bolts was measured. Many of them showed the values less than the required values. The reasons for this problem are welding method, the shape of welding part, and flanges themselves. More than thirty 070 type leak valves showed also the lack of hardness. The last two examples point out the problem in quality control of flanges.

Most of damages like scratches on flanges are made during work for maintenance. The most impressive one was the flange for an rf quadrupole magnet chamber while an rf cavity was removed from the beam line. As the repair of this chamber takes much time, a spair chamber has been kept for an accident.

ICF-152 L type valves have some structural defect in supporting a Helicoflex gasket. The gasket is attached to the top of movable bellows in the valve and is used to seal at the fixed mirror surface. The gasket was released and showed sealing failure. We have more than ten examples including the ones used in bench test. ICF-114L type valves in TAR showed low leakage when they were close. This was resolved by selecting optimum tightening torque.

The connectors for DIPs in TMR, both SHV and BNC types, were not fitted with the connectors from coaxial cable. The outer diameter was a little bit larger than required size. The outer surface was polished using rotary bars. The larger size was passed by quality check at the factory because old fitting connectors were used.

Similar troubles were found two for IP connectors and nine for NEG connectors. Deformation of the connectors was found three and were reformed. We had two examples of vacuum leak from the crack of ceramics of the connectors. In general high voltage connectors are sensitive to moisture and dust which excite abnormal discharge at the connectors and give failure in insulation. Deteriorated connectors show carbonated surfaces which were observed more than ten connectors for DIP in TMR and nine for DIPs and IPs in TAR. Some of the cable connectors can not be removed by burning due to abnormal discharge. Most of these are SHV connectors. Since MHV connectors have better high voltage characteristics, all SHV connectors were changed to MHV connectors during work for DIPs. In addition, to protect the connectors from moisture, the 70% of connectors were covered by desiccant using polyethelene cylinders. Internal short of electrodes of IPs and DIPs was also observed. Most of the short was due to probably overheating of springs to connect the electrodes and connectors. Overheated springs were annealed and lost their elasticity. As a result the spring expanded and touched another electrodes or chamber wall. The reason of the heating was not clear yet, but for DIPs in TMR, some abnormal discharge was observed around the spring. The discharge was suppressed by quarts tubes surrounding the spring.

Ten linear type non-evaporable-getter pumps are used in straight sections for TAR. They were short-circuited during activation because of the expansion of linear getters by heating. By extremely slow increase of activation current, the linear getters were not short-circuited and functioned well.

Bellows

A beam stopper had the first failure of vacuum sealing at the stainless bellows which was operated about 1600 cycles. The stopper consistsof a linear motion driving mechanism. The bellows at the compressed state received big stress. A crack was observed at the neighborhood of welding line and is a typical fatique failure. Therefore the bellows was repaired so as to have longer length by 11 mm and to have more number of convolutions by five. The improved bellows has life twice of the old one. One year later the second failure was occured for the old type beam stopper.

A bellows coupling is a KF 25 Type pipe with a bellows about 10 cm long. The bellows is not so flexible but has enough expanding or contracting length to adjust about 10 to 20 mm. The pipe is used to connect a rotary pump and a turbo molecular pump. At the rough pumping system for the DC separators a crack at the KF flange and at the bottom of the convolution occured. Since several examples of crack at the bottom of the convolution occured, it was estimated the bellows can be used less than a few cycles. The bellows coupling is generally used a high pressure range, stainless steel bellows can be used for the same purpose.

The internal target was used to produce γ-rays for calibration of lead glass counters. The target is made of molybdenum cylinder, 7 mm in diameter and 218 mm in length. The target head is formed as 3 mm thick and 6 mm high. The cylinder including the head is insert into the beam chamber about 35 mm from the side surface of the chamber. Of the 218 mm length, 13 mm is a solid cylinder and remaind is pipe to be cooled by water. The water is supplied by coaxial pipe and the top of the pipe reached to the place only 28 mm from the solid. The structure of the cooling pipe has a possibility to produce bubbles which interrupt cooling by water. Crack or a pin hole was made just at the boundary from solid molybdenum to molybdenum pipe. This fact supports the possibility of the cooling failure.

The power input to the cylinder 35 mm long is estimated and can be 1.2 KW at 30 mA and 6 GeV beam. Therefore the temperature difference can reach about 1000℃, but can not explain whether the temperature can reach the melting point of molybdenum. The cooling pipe around the head was changed so as to reach the solid molybdenum. Similar cooling structure for cooling mask for extracting and injecting windows were also changed as mentioned above.

Maintenance

Troubles when the different works were proceeded at a same time or when the work was related different area (different group) were sometimes occured. A person responsible for the works should instruct status to the workers for former ones and should exchange information of other group for latter ones. An order list to proceed a work is helpful to carry out the work without mistake.

Expectation, often misunderstanding, accelerated influence of trouble. Without confirming status of a work where an aluminum foil covered a port of chamber, a pump was started. The pieces of the foil were scattered into the chamber. Therefore flange covers made of polyethelene with a small slit have been used.

The work for both the scheduled and the unexpected power outage is necessary because the differential pumping for gate valves is used in TRISTAN. All of the valves are closed before scheduled outage and after unexpected the outage. If one of the sections were being exposed to air, leak would be transmitted to next sections (two examples). Therefore the open end is sealed and evacuated.

The power supply should have the function not to be power automatically on after power outage. If not, some of the machines could be burned by overloading (one example).

At the section S-2 in TAR where the electron injecting window made of beryllium is assembled, a sealing failure through the window was occured. Inside a small room in front of the window helium gas was flowing. Therefore the some quantity of hellium was introduced and DIPs and IPs were contaminated by hellium gas. Since then, at the section, background level of hellium leak detector has been very high (10^{-7} Torr・l/s). Many works have been applied on the section for more than one year. Recently the background level is decreasing on the order of 10^{-9} Torr・l/s. This is probably because many works include many nitrogen gas exposure on the section. Nitrogen gas might clean inside surface of the section. When the background level was high, neon gas leak check was tried using a quadrupole mass filter. It turned out to be effective. Hydrogen gas leak check was also discussed, but it was not tested from the view point of safety.

CONCLUSION

The first truely all-aluminum alloy ultrahigh vacuum system has been operated for four years for TAR and one year for TMR. During the period, many troubles occured. Troubles are seeds of highly motivated development and research, and the proof of challenges to open new field of the aluminum alloy vacuum system. Some of the troubles are already resolved, but repairing are being developed for others. In spite of the latter fact the aluminum alloy vacuum system has no substantial problem, and much effort will be applied to make aluminum alloy vacuum system into mature technology.

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