ALUMINUM ALLOY ULTRAHIGH VACUUM SYSTEM

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I. Introduction

I made two main dicoveries regarding aluminum properties. In 1977 the extremely low residual radioactivity of aluminum, compared with that of stainless steel, was reported[1]. If the stainless steel vacuum chamber in a high energy accelerator were replaced by an aluminum chamber, the residual radioactivity could be reduced by one or two orders of magnitude, 100-hours after machine shutdown. In 1981 an extremely low outgassing rate, less than 10^{-13} Torr ℓ/sec·cm^2 after a 150°C, 24 h bakeout, was reported[2] for a specially extruded aluminum beam chamber.

Aluminum and aluminum alloys have high thermal conductivity and low energy absorption for incident high energy particle beams, compared with stainless steel. Therefore, aluminum alloys are very good for applications with localized high heat flux.

Construction of an all-aluminum alloy accumulation ring was completed in 1983. Since then, electron beams have been accelerated and stored at 6.5 GeV, 30 mA for single-bunch mode and 90 mA in 3-bunch mode. The best pressure, on the order of 10^{-10} Torr, was obtained without any baking or discharge cleaning[3]. The pressure rise due to beam was 3 × 10^{-11} Torr/mA for a time-integrated beam current of 3.4 × 10^4 mA·h. The first truly all-aluminum-alloy vacuum system for a large electron-positron collider was completed in September 1986[4].

II. Special extrusion

Vacuum beam chambers in accelerators generally require a complicated profile, having a distributed pump and heating and cooling structures. Aluminum alloys allow easy extrusion of complicated cross sections using porthole dies, and the Al-Mg-Si alloy provides superior performance in extrusion. It has high strength and superior weldability and is suitable for use as a vacuum chamber material. Usually, during extrusion, the end of the aluminum alloy chamber is open to the contaminating atmosphere. Therefore the active inner surface, at a high temperature, is immediately covered with a porous aluminum oxide-hydride film about 125 A thick. For ultrahigh vacuum performance, a special extrusion technique is therefore applied to prevent this growth of a porous aluminum oxide film with trapped contamination that later causes desorption of gases. An oxygen and argon atmosphere is maintained in the parts during both extrusion and tempering processes[5]. Both ends of the extruded chamber are sealed vacuum-tight. As result, the inner surface of the extrusion is covered by a fine, non-porous, dense oxide film about 30 A thick.

III. Outgassing

A. Specially extruded chamber

The following cleaning procedure was adopted for a 4 m long test vacuum chamber made by the special extrusion process: degreasing in acetone at room temperature and ethyl alcohol rinse at room temperature. A typical outgassing rate after a 24 hour initial evacuation was about 2 × 10^{-11} Torr ℓ/s cm^2. The outgassing rate following a 24 hour bake at 150°C was several times 10^{-14} Torr ℓ/s cm^2, as measured[6] by the throughput method, i.e. the vacuum chamber is separated from a turbomolecular pump by an orifice of known conductance and the pressure on either side of the orifice is measured. From a pressure of order 10^{-10} Torr, the chamber was then vented to atmospheric pressure using an oxygen and argon mixture. The chamber can now be exposed to atmospheric pressure several times and it still reaches ultrahigh vacuum, without baking. A typical outgassing rate after exposure to atmospheric pressure of an oxygen and argon mixture, without baking, is several times 10^{-12} Torr ℓ/s cm^2 after 24 hours of pumping. An aluminum vacuum chamber made by ordinary extrusion techniques does not have such an extremely low outgassing rate.

Five measurements were performed, three for a 6063-EX chamber and two for a tube of 6063 clad inside with 1050 material. The former chamber had been exposed to air for 1.5 years and was then filled with pure water for 1 day and later filled with water for 1 week. The volume of water inside the chamber was about half the total chamber volume. After each step, the outgassing rate measurement was performed. For 1050, the virgin clad chamber, and the clad chamber exposed in air for 1 day were measured.

No chemical process was used to clean the samples, except the virgin samples of 1050 and the first test of the 6063-EX chamber. In these two cases, toluene was used as a degreaser. Initially, the chambers were pumped down at room temperature for 24 hr, then the chambers were baked at 150°C for 24 h using heater tapes. The turbomolecular pump was also baked, using a heating jacket. Room temperature was controlled during the whole experiment at about 20°C.

The outgassing rate of the 1050 clad material reached the 10^{-11} Torr ℓ/s cm^2 range 24 h after pump-down at room temperature and reached the 10^{-14} Torr ℓ/s cm^2 range 24 h after a 1 day bake at 150°C. The 6063-EX chamber outgassing rate after being filled with water for one day was about four times higher than before; however, the outgassing rate quickly entered into the 10^{-14} Torr ℓ /s cm^2 range after re-baking. Even after having been filled with water for 1 week, although the outgassing rate was 17 times higher during pumpdown at room temperature, the low 10^{-13} Torr ℓ /s cm^2 range was reached within 1 day after re-baking.

B. Specially surface finished chamber[7]

A special aluminum alloy chamber with a volume and inner surface area of approximately 240 ℓ and 2.5 × 10^4 cm^2, respectively, was constructed. The surface area ratio of flange (2219) to body (1050) is 68 % and 32 %. The outgassing rate of the aluminum alloy chamber was measured with the following vacuum system: The aluminum alloy chamber is fitted with a 90° elbow and a gauge port, an orifice (diameter 6 mm), a T piece with gauge port, and a turbomolecular pump (270 ℓ/s). These parts are all made of aluminum.

The gas throughput from the experimental chamber was estimated by measuring the pressure on both sides of the orifice, which had a calculated conductance of 3.3 ℓ/s at room temperature. The pressures were measured using two Bayard Alpert gauges.

The bakeouts were done at 156°C for 25 hrs. Compared with the evacuation curves for the specially-extruded chambers, the evacuation before baking is like that of 1060-EX and after baking is like that of 6063-EX. Outgassing rates were measured through a cycle which consisted of about 100 hours of evacuation, followed by baking and cooling. This cycle was performed for the initial evacuation, then repeated after venting the chamber to one atmosphere of N_2 gas for one hour, then performed a third time after venting the chamber to air for one month. In all cases, the outgassing rate before bakeout was in the low 10^{-11} Trr ℓ/s cm^2 range, or better, and after bakeout was low 10^{-13} torr ℓ/s cm^2 or better.

IV. Surface characterization

To investigate the extemely low outgassing rate of a specially extruded chamber and a specially surface finished chamber, various surface characterization techniques have been applied, such as Auger electron spectroscopy (AES), ion microprobe mass analysis (IMMA), Scanning transmission electron microscopy (STEM), and the Hunter and Fowl method. The depth profile of the specially extruded surface by AES, IMMA and STEM were in reasonable agreement. The oxide layer of the specially extruded surface and the specially finished surface were nearly the same, about 30 A thick. The layer for an ordinary extruded surface or an ordinary finish (produced with oil lubrication) were more than 120 A thick. The Hunter and Fowl method results differed from the AES, the IMMA and the STEM analysis. The specially-treated surface appears to be covered with a fine, non-porous, dense oxide film, as are the surfaces of the specially-extruded aluminum beam chamber.

V. Welding

The prominent characteristics of aluminum are its large thermal diffusion rate, its high heat of fusion and the oxide film covering the aluminum surface. In welding flanges to pipes by hand, the AC-TIG welding method is usually employed. To weld a flange and a pipe, a filler metal is required to obtain adequate beads. The filler alloy, 4043, which has excellent resistance to welding cracks, was used. Further attention was given to joint designs to avoid heat damage and weld distortion. Automatic welding equipment for an elliptical chamber was developed which is small in size, light in weight, easy to handle and ensures uniform penetration. It employs a straight polarity (DCSP) welding source[8]. To prevent the growth of a porous aluminum oxide films, the chamber is back-filled with argon. Micro-holes were not observed in welding beads.

VI. Components

A. Flanges

An aluminum alloy flange system has been developed[5]. A basic feature of the system is the use of 2219-T87 aluminum alloy for the flange material. This alloy has mechanical properties similar to stainless steel. At elevated temperatures, 2219-T87 has the highest strength among aluminum alloys, as well as superior weldability and stress corrosion cracking resistance. Therefore, 2219-T87 was the best choice as an aluminum alloy flange material for ultrahigh vacuum equipment that requires bakeout. The aluminum alloy flange detail is nearly the same as the traditional Conflat type flange. The knife edge is a superfinished surface processed by a flat diamond tool. A CrN or TiC coating is applied to the surface of the aluminum alloy flange by ion-plating. The thickness of the coating is about 2 μm. The surface of the aluminum gasket (1050-H18) is polished to a nearly mirror-like finish to obtain reliable sealing. Anodized aluminum alloy bolts (2024-T4), non-anodized nuts (6061-T6) and hard-anodized washers (2017-T3) are used without lubrication to tighten the flange. All the usual types of flanges have been prepared, eg. blank-offs, flanges for pipes, rotatable flanges, etc..

B. Bellows

Aluminum alloy (3004) seamless bellows are produced by hydraulic forming of a seamless tube. They have a life time of more than 5000 cycles for a 10 % expansion and contraction. If an aluminum alloy bellows is made thin, to obtain better elastic performance, welding of the bellows to its flange or chamber becomes difficult, especially for a thickness less than 1 mm. However, if it is made thicker, for the purpose of easy welding to the flange, the elastic performance of the bellows is degraded. Therefore, in our design, the length of seamless tube has thick walls near the ends, but is thin-walled everywhere else. The thickness of the corrugated part is reduced to 0.3 mm while the welding-edge parts have a thickness of 2 ∿ 4 mm. This contributes to both getting sound welds and better elastic performance of the bellows.

A seamless corrugated bellows cannot be used in applications which require large expansions and contractions with good operational life time. It is highly desireable to have a bellows which is as flexible as possible. A new welded type bellows has been developed. The structure of the welded type aluminum bellows is shown in Fig. 1. Thin aluminum alloy (6951) sheets are brazed in a nitrogen furnace. After brazing, chemical cleaning and tempering processes (T6) are performed.

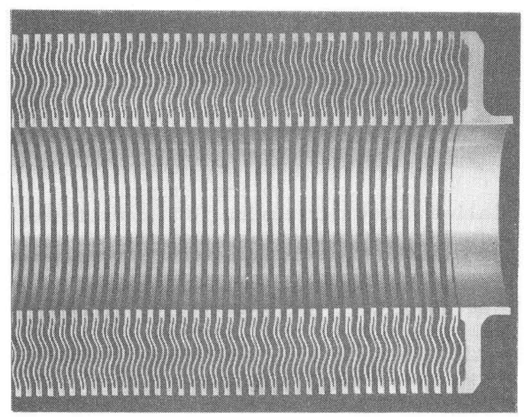

Fig. 1 Welded type aluminum alloy dynamic bellows.

C. Ion pump

I have developed a new structure for the built-in distributed sputter ion pump which works in the field of a bending magnet. Its anode consists of five layers of a polished, perforated aluminum (1050) plate. Compared with the cylindrical anode of ordinary ion pumps, the present structure is effective in making both the conductance and the active pumping surface large. The cathode consists of rods 3 mm in diameter, and is insulated from the vacuum chamber. The insulated cathode makes it possible to measure the Penning discharge current.

Stand-alone ion pumps have also been developed. The ion pump shell is an extruded aluminum alloy. Perforated and stacked anode cells have been used with the aim of increasing the conductance and the active pumping surface. The anodes have been assembled from five layers of thin perforated aluminum sheets stacked with a spacing of 6 mm. The intermediate anode sheet is 1 mm thick and the other two are 0.5 mm. The anode hole is 12 mm in diameter. The pump electrodes are chemically cleaned and electropolished. An Al-SHV feedthrough for the high voltage is electron-beam welded directly to the pump shell. An aluminum sheath heater, 10 mm diameter, is pressed into a groove on the pump shell. The maximum magnetic field of the permanent magnet is 1.5 KG. These ion pumps (10 ℓ/s, 30 ℓ/s and 500 ℓ/s) have an extremely short pump-down time; to an ultrahigh vacuum of order 10^{-9} Torr after only 24 hours of initial operation and to 10^{-10} Torr after a 150°C, 24 hour, initial bakeout procedure. The pumping speed for nitrogen, with the 500 ℓ/s model, at pressures below 10^{-8} Torr, decreases rapidly. The pumping speed before bakeout is reduced by nearly 60 %. The pumping speed for argon and hydrogen, after bakeout, is about 40 % and 160 % of that for nitrogen, respectively.

D. Ti sublimation pump

A new kind of titanium sublimation pump has been developed. This pump has an aluminum liquid trap. The trap is a cylindrical cryopanel, formed using the roll-bond technique. The merits of this pump include light weight and freedom to install in any orientation. The trap can also be used as a cryoshroud in the system. It is called a nude type titanium sublimation pump. The nude type titanium sublimation pump has efficient pumping conductance. The chamber temperature is kept at room temperature during the titanium sublimation pump operation with liquid N_2.

A Ti sublimation pump using a titanium cup was mounted on an Al-Conflat flange with an Al-ceramic feedthrough as shown in Fig. 2. The titanium cup was heated by radiation using a small filament in the titanium cup.

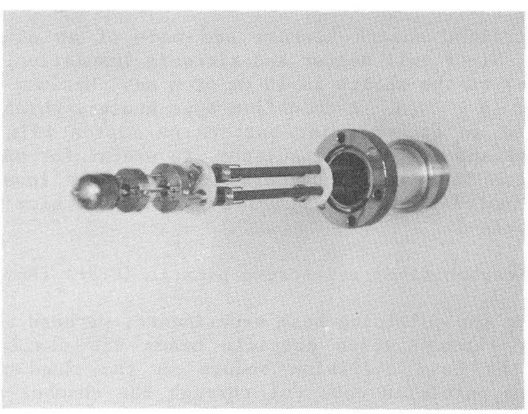

Fig. 2 Ti-sublimation pump head mounted on an Al-flange.

E. Non-evaporable getter (NEG)

Three kinds of NEG pump are useful for an aluminum alloy ultrahigh vacuum system. The cartridge type NEG-ST-101 was mounted on an Al-Conflat flange with an Al-BNC feedthrough. A molybdenum wire heater was installed inside the cartridge type NEG. The linear type NEG-ST-707 was mounted in an aluminum frame, isolated from the frame. The power feed was made using a copper ribbon connected to a 125 A vacuum feedthrough. The module type NEG-ST-707 was also mounted on an aluminum frame. The power feed was the same as for the linear type NEG.

F. Turbomolecular pump

50 ℓ/s and 200 ℓ/s turbomolecular pumps are made of aluminum alloys. The flange is an Al-Conflat type and the body is also an aluminum alloy (6063-T6). The 200 ℓ/s pump has oil free magnetic bearings. These turbomolecular pumps have an extremely short pump-down time to ultrahigh vacuum; less than 10^{-9} Torr after a 100°C, 24 hour initial bakeout procedure.

G. Valve

By relying on differential pumping between dual flat face seals, I developed a gate valve which has no gaskets or knife edges. The sealing surfaces of the isolating plate are polished to a smooth mirror-like finish and coated with CrN for hardening. The valve seats, which are 0.1 mm thick aluminum, are forced by compressed air against the sealing surfaces. A close-contacting metal seal is obtained. The aperture of the gate valve has the same elliptical cross section as the vacuum beam chambers. When the valve opens, the bellows assembly closes on the aperture of the gate valve to assure smooth flow of the wall current.

Another gate valve has an 800 mm aperture, is 3505 mm minimum to 4455 mm maximum high, is 1270 mm wide, and is only 250 mm long. It was developed for the neutral beam injector of a fusion apparatus. Its weight is 800 kg.

This new sealing concept[9], super mirror-like flat-face seals with differential pumping, has the following advantages: (1) large diameter apertures (800 mm) are possible, (2) non-circular apertures are possible, (3) insensitive to fine dust, (4) bakable at 150°C in both closed and opened positions, (6) unneccessary to have a very precise actuator, (7) insensitive to thermal and external stress, (8) long lifetime for stable sealing, and (9) able to obtain beam impedance matching.

All-aluminum alloy right angle valves are developed using the sealing principle of the Helicoflex gasket. If the surface of a flange and the Helicoflex are sufficiently smooth, repeated sealing of this combination is possible under a nearly constant tightening force. The finished surface can be further hardened by CrN coating. A valve based on this sealing principle was tested with a helium leak detector and found to have a leak rate of less than 10^{-10} Torr ℓ/s during 100 opening and closing cycles, with a constant torque of about 150kg-cm for an Al-L-valve ICF-114 type.

H. Feedthoughs

A variety of electrical feedthoughs is required, all in aluminum alloy housings. The outer shield is aluminum alloy (3003). The center conductor and a washer are made of Kovar. The insulator is ceramic (95 % alumina). The outer shield and metallized ceramic are brazed with aluminum-alloy solder (BA4047) in a vacuum furnace. During the brazing procedure, a carbon jig outside the outer sleeve is nesessary to limit the gap between the aluminum sleeve and the metallized ceramics. At the high temperature required for brazing, the gap tends to increase due to the difference in thermal expansion coefficients of the aluminum alloy and the ceramics. The metallization procedure is Mo-Mn with Ni plating. The feedthrough was tested on a helium leak detector and was found to have a leak rate of less than 10^{-10} Torr ℓ/s at room temperature. Aluminum alloy-ceramic and Kovar-ceramic seals of this type can safely withstand baking cycles from room temperature to 150°C and cooling cycles from room temperature to liquid nitrogen temperature.

Aluminum-ceramic feedthroughs such as SMA[10], BNC, SHV, LEMO, N, 8 pin, 22 pin, 48 pin and 14 pin-BNC are welded directly to an aluminum alloy flange or into the aluminum alloy vacuum chamber using electron beam welding.

I. Ceramic chamber

A ceramic chamber is bonded to aluminum-alloy bellows pieces (3003) with a brazing sheet (4043-3003-4343) in a vacuum furnace. The metallization is Mo-Mn with Ni plating. The ceramic chamber with bellows is welded directly to the aluminum alloy chamber or to a flange.

J. Window

The optical window developed consists of an aluminum alloy (3003) sleeve and a sapphire disk. The aluminum alloy sleeve and the metallized sapphire are brazed with aluminum alloy solder in a vacuum furnace. The diameter of the sapphire is 30 mm ∿ 80 mm. The thickness of the sapphire is 3 mm. The window was helium leak tight. An aluminum alloy-sapphire window was directly welded to an Al-Conflat flange using electron beam welding[11].

An X-ray window is made using beryllium and aluminum foil. The Be window is mounted on an aluminum alloy base flange. The Be foil (15 mm × 27 mm × 0.2 mm) is welded to the flange by electron beam welding[12]. The Al window, 0.08 mm in thickness, is sealed with a Helicoflex gasket. The base flange is a super-mirror finished surface. A CrN or TiC coating is applied to the sealing surface. Both the Be and the Al window are protected by helium gas or vacuum from corrosion due to NOx and ozone.

K. Fittings

A seamless cross-piece, a T-piece and a 90° elbow have been made of aluminum alloys (6063-T6) using a bulging method. Al-Conflat flanges are welded to these pieces. The T-piece is also used for the angle valve body.

L. Gauges and quadrupole mass filter

A MIC gauge[13] and a new quadrupole mass filter[14] for ultrahigh vacuum are mounted on Al-Conflat flanges equipped with Al-14 pin-BNC feedthroughs as shown in Fig. 3. The mass filter is made of aluminum alloys and a newly developed technique for transmitting the RF power is used. The aluminum electrodes of the analyzer are given a special surface treatment by machining under an oxygen gas spray. The RF amplifier and the tank coil, mounted on a ferrite toroidal core, can be separated by a 120 meter long coaxial cable. Because the parts fitted on the analyzer head are small and simple, the system has high stability and is also resistant to radiation and heat. A newly-developed ion source is used with a closed hemispherical mesh anode. This mass filter has a high sensitivity, 3 mA/Torr, at 2 mA emission current without a secondary electron multiplier and a resolution over 100 at a 2.5 MHz frequency.

An inverted magnetron-type cold cathode gauge has been made of aluminum alloys. The cold cathode gauge is mounted on an Al-Conflat flange with an Al-BNC feedthrough. A Pirani gauge with three filaments is mounted on an Al-Conflat flange with an Al-8 pin feedthrough.

M. Driving mechanism

Bakable driving mechanisms and manipulators were made of aluminum alloys. Small linear and rotary motion feedthroughs utilize stainless steel dynamic bellows and Al-SUS transition pieces. For larger sizes, the welded type aluminum alloy dynamic bellows was used.

Since bakable multi-axis driving mechanisms, such as an X-Y table, are required for semiconductor processing in ultrahigh vacuum, it is highly desireable to have elements such as: a stepping motor, a ball screw, a ball bearing, and electric-cable. We built a stepping motor using mineral insulated cable with a thin stainless steel sheath and silver-plated ball bearings, as shown in Fig. 4. Then all the materials of the stepping motor which are exposed to the vacuum are metals. We do not use any organic or inorganic materials for insulation and lubrication. We built an aluminum alloy (2219-T87) ball screw. The ball screw was polished to a supermirror surface by a combination of electropolishing and buff-polishing and then CrN or TiC coated to obtain a smooth motion, as shown in Fig. 5. The balls against the ball screw were silver coated by ion plating.

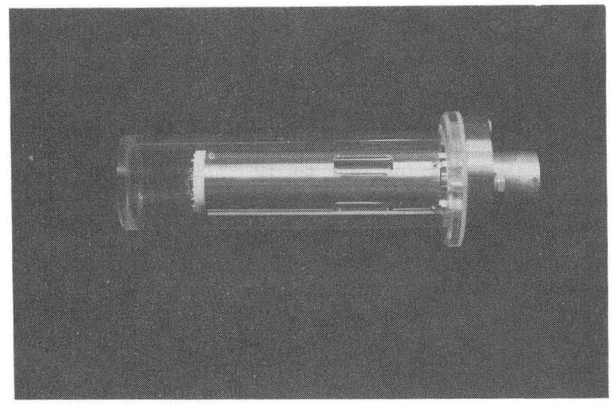

Fig. 3 New quadrupole mass filter made of aluminum alloys, mounted on an Al-flange.

N. Heater and insulation

Straight sheath heaters are made of an aluminum sheath, Ni-Cr coil heater and zirconia insulation. The diameter of the sheath is 10 mm or 6 mm. Maximum power density is 1 KW/m. A thin-film type heater, which consists of an etched print pattern on Kapton film with adhesive and a thermal insulator, is useful for uniform heating. The vacuum chambers are thermally insulated by laminated Kapton film (25 μm) which is aluminized and embossed.

O. Al-carbon fiber reinforced plastic (CFRP) chamber

For the colliding-beam experiments, we need a beam chamber through which particle beams can easily go. Since the beam collision occurs in the chamber and produced particles come out through the chamber wall, it is highly desirable to have the chamber wall as thin as possible to minimize the interactions of particles with the wall.

We built the first prototype Al-CFRP composite chamber[15]. Its inner diameter is 180 mm and its length is 800 mm for a thin Al-CFRP chamber. The thickness of the Al is 0.1 mm and CFRP is 1.2 mm. The outgassing rate was measured and it reached several times 10^{-13} Torr ℓ/s cm^2 after degassing at 120°C, 24 hrs. A buckling test was made by applying a uniform pressure from the outside by placing the chamber in a pressure vessel. The chamber sustains an outer pressure of 1.5 atm. The Al-CFRP chamber has been exposed to the circulating beam for more than a half-year.

P. Knudsen cell

A Knudsen cell is necessary to make thin films in ultrahigh vacuum. The Knudsen cell element is mounted on a Al-Conflat flange with Al-feedthroughs, as shown in Fig. 6.

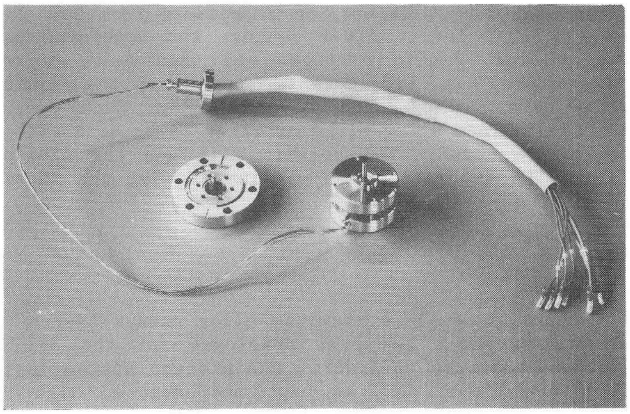

Fig. 4 A stepping motor for ultrahigh vacuum.

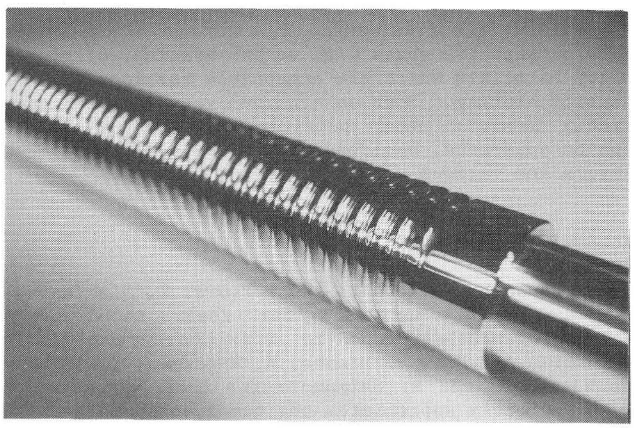

Fig. 5 An aluminum alloy ball screw.

VII. Applications

A. TRISTAN

a. Vacuum chambers

The aluminum alloy (6063-T6-EX) vacuum chambers in the bending and the quadrupole magnets are designed so as to accomodate the required beam clearance region and to allow automatic welding between the chamber and a racetrack type bellows. The bending magnet chamber has double-line pumping slits. During bending and slit-punching processes for the bending magnet chamber, the chamber was filled with an argon and oxygen mixture, to prevent the growth of an oxide-hydride film on the inner chamber surface. For the rf sections and the experimental regions, aluminum alloy circular pipes are used. Two types of insertion quadrupole magnet chambers have built-in pumps. Five sets of NEG modules are housed inside the insertion quadrupole magnet chamber.

Thirty-two gate valves with elliptical apertures and twenty gate valves with circular apertures were installed in the long straight sections. The gate valve and the beam duct are joined using automatic welding, without flanges. The ceramic chamber with bellows is welded directly to the aluminum alloy chamber. This type of ceramic chamber is used for the kicker magnet chamber, the magnetic damper, and the beam intensity monitor.

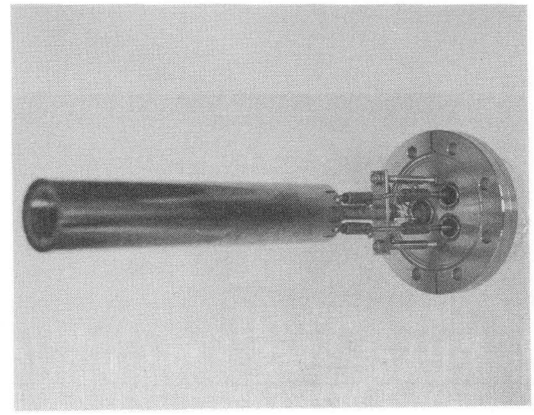

Fig. 6 A Knudsen cell mounted on an Al-flange.

For roughing pumps, 50 ℓ/s and 200 ℓ/s turbomolecular pumps were installed. Distributed ion pumps (DIP) are installed in the bending magnet chambers. 30 ℓ/s ion pumps are used for the arc sections. 125 ℓ/s and 250 ℓ/s pumps are used for the long straight sections. 500 ℓ/s ion pumps are used for the rf cavities and DC separators. Cartridge NEG's are installed in each standalone 30 ℓ/s ion pump with an aluminum alloy cross chamber. An NEG type ST-707 pump module is installed in each insertion quadrupole magnet chamber. Linear NEG Type ST-707's are installed in each weak bend vacuum chamber. All NEG pumps are operated at room temperature.

b. Assembly

Installation of the vacuum system along the ring has been completed. After installation, He leak testing and alignment of the vacuum chamber against the magnets were made. Calibration was made for all fixed frames between the beam position monitors and the quadrupole magnets. The beam transport lines from the accumulation ring to the colliding beam ring were completed for electrons and positrons[16]. The entire vacuum system with computer control was completed in September 1986.
(Fig. 7)

c. Initial operation

Each section separated by gate valves was first evacuated by a roughing pump. At a pressure of 10^{-6} Torr, NEG pumps, cartridge, module or linear types, operated in a room temperature mode, were activated. Cooling is not required for NEG pump activations. Then operation of 30 ℓ/s ion pumps was started. During the operation of the ion pumps, the pressure of the arc sections reached of order 10^{-9} Torr after several weeks evacuation. The pressure in the RF cavities reaches of order 10^{-9} Torr after evacuation for 100 hours with baking and RF high power conditioning. All distributed ion pumps, which are truely virgin, have been started at a pressure of less than 10^{-6} Torr. During the starting procedure, pressures increase up to of order 10^{-4} Torr. After operating the DIP's continuously, the pressure drops to of order 10^{-9} Torr without any baking or discharge cleaning.

The entire vacuum system is controlled by computer: such as starting or stopping of various pumps, opening or closing of the valves, readout for various pressure gauges, and temperatures of the vacuum chambers, cooling water and compressed air. Fig. 8 shows the vacuum status display of the TRISTAN ring.

B. Semiconductor processing

a. Special surface finish

Aluminum alloy ultrahigh vacuum systems have re-

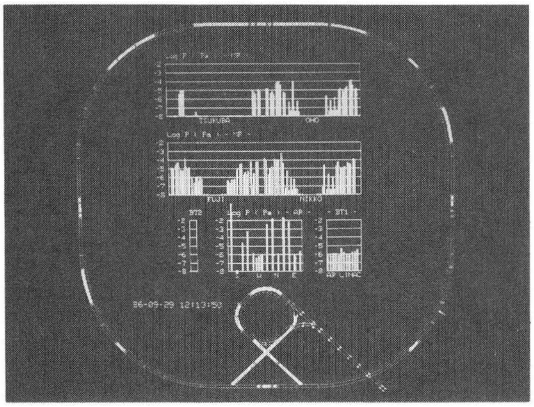

Fig. 8 A computer display of the TRISTAN vacuum status.

cently aroused considerable interest. Aluminum alloy vacuum chambers are usually made by extrusion processes. The diameters of extruded chambers are too small to use in a molecular beam epitaxy (MBE) systems, and it is difficult to make larger chambers by this process. As a research project for an aluminum alloy MBE system, a large aluminum alloy chamber with a special surface finish was constructed. The aluminum alloy chamber is 1000 mm long and 580 mm in diameter. The main flanges are made of 2219-T87, 700 mm in diameter and 40 mm thick. The chamber was placed in a larger chamber which was used in production of the special surface finish. After evacuating this larger chamber, it is back-filled with an $Ar+O_2$ mixture, without heating or plasma[18]. Argon is not essential. Extremely low water content is essential for good vacuum quality. The main body inner surface is final machined in this atmosphere without liquid lubricants. Large flanges are treated in the same way.

b. MBE chamber

The chamber has a height of 1000 mm and an inside diameter of 554 mm. A turbomolecular pump, an ion pump, and a titanium sublimation pump were used. When liquid nitrogen was introduced into the system to cool down an aluminum shroud, it also acted as a pump. The system was pumped down from 1 atm by the turbomolecular pump and then baked at 120°C for about 15 h. After the gauges were degassed, LN_2 was introduced into the shroud and the titanium sublimation pump was also fired. The lowest pressure achieved by this process was $\sim 3.5 \times 10^{-11}$ Torr without LN_2. Insufficient bakeout and considerable outgassing from the Ti layer on the shroud were thought to be the reasons why the pressure was limited at such a high value. Therefore, a pressure 3.2×10^{-11} Torr without LN_2 and 7.5×10^{-12} Torr with LN_2 were reached by applying a more thorough bakeout, $\sim$ 135°C, 30 h, and without firing the titanium sublimation pump. Fig. 9 shows the all-aluminum alloy MBE system.

c. Corrosion by gallium

An important problem for an aluminum alloy MBE system is corrosion by gallium. Other elements, for example Cd, Hg, B, In, P, and As were also investigated. These elements do not corrode aluminum. The problem for gallium is solved by surface treatment. The surface treatment is an SiO_2 coating on the aluminum surface using a spark discharge in a silicate solution. Tests against gallium corrosion for various surface treatments were performed as follows: SiO_2 coated aluminum alloy specimens were coated with about a 3 µm thickness of gallium. A 1 gram drop of Ga was put on the gallium coated specimens and baked in a vacuum furnace at 200°C, 24 hrs, in a pressure from 10^{-6} Torr to 3×10^{-8} Torr. After baking, the specimens were dropped into liquid nitrogen and then held at room temperature. The SiO_2 ceramic coatings on the aluminum alloy were not corroded by gallium[18]. Such ceramic coated aluminum alloy plate or wire can be bent without separation between the ceramic film and the aluminum alloy. No separation was obtained during the thermal cycle from -196°C to 400°C.

VIII. Conclusion

Thus, a complete aluminum alloy vacuum system for ultrahigh vacuum has been developed for the TRISTAN electron-positron collider. The present system satisfied conditions such as high performance, high reliability, impedance matching, simplicity, low wasted space between magnets, small size, light weight, low residual radioactivity, completely nonmagnetic, and low cost. New concepts from the research and development at KEK are as follows: 1. aluminum alloys are low residual radioactivity materials, 2. bakable Al-Conflat flanges with metal seals, 3. close-contact sealing mechanism with super-mirror finished surfaces, 4. extremely low outgassing rate in special extrusion and in special surface treatments, 5. aluminum alloy to ceramics or sapphire seals with vacuum brazing, 6. aluminum alloy materials which are acceptable for localized high density heating. Such an aluminum vacuum system can be widely used in other particle accelerators, nuclear fusion apparatus, semiconductor processes, surface analyzers and various ultrahigh vacuum systems.

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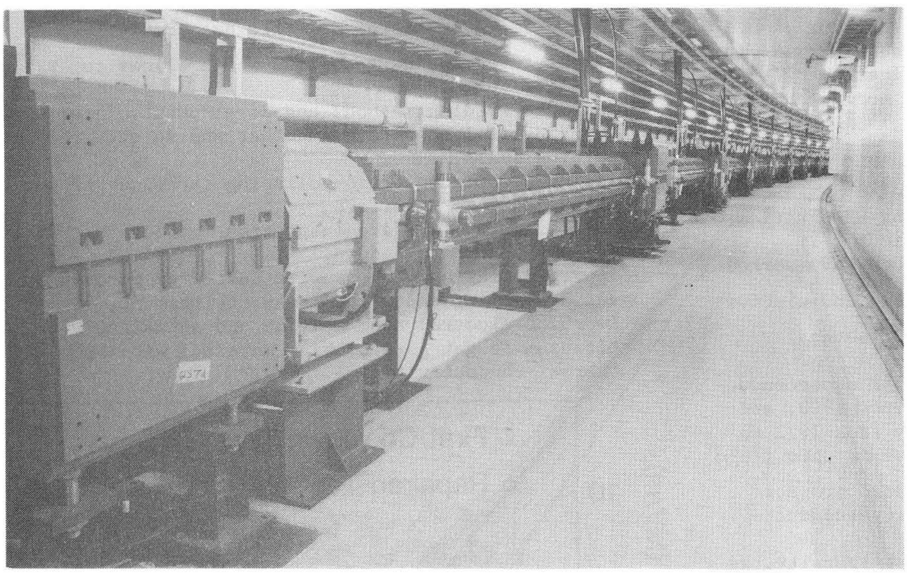

Fig. 7 Arc section of the TRISTAN electron-positron collider.

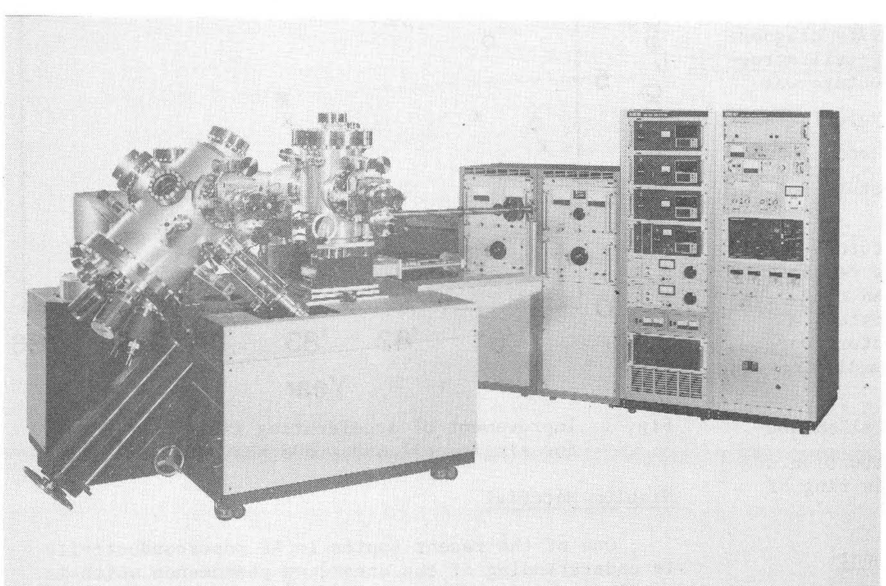

Fig. 9 All-aluminum alloy MBE system.