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CONCEPTUAL DESIGN STUDY FOR ALUMINUM RECYCLER RING VACUUM CHAMBER IN FERMILAB

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§1. INTRODUCTION

The purpose of this study is to propose an aluminum chamber with superior performance and high reliability at low cost for the recycler ring[1] in Fermilab. Key performance advantages of aluminum chamber and components in comparison to stainless steel are provided with the requirements needed for developing the recycler ring. Analysis and actual case experience indicates that when stainless steel components are irradiated by antiproton beams, melt-down can occurs, but not aluminum as it has a very high tolerance.

It is understood that the antiproton storage ring has basically noeffect of dynamic outgassing. However, for high current proton storage ring such as CERN-ISR had dynamic gas desorption effect. Antiproton ring has negative potential, then ionized ion is trapped within antiproton beam.

§2. BENEFITS OF ALUMINUM[2]

Extrusion is possible to make elliptical chamber with heater groove as shown in Fig.1.

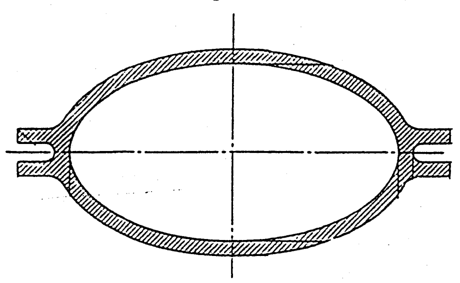

Fig.1 Cross section of beam chamber for bending and quadrupole magnets.

Clean extruded pipe has very low specific outgassing rate, Q_0 at 150℃, 24 hours baking[3] with following performance: Torr ℓ/s cm^2

- 99.99% high purity aluminum: 2 X 10^{-14}
- guaranteed high purity aluminum: 10^{-13}
- without bakout of aluminum: part in 10^{-10}
- originally proposed stainless steel: 10^{-12}

Based on the aluminum vacuum system performance charactristic, the major advantages are:

1) Reduce pumping speed of ion pumps.
2) Extend distance between ion pumps.
3) Before baking residual gas is mainly water after baking residual gas is mainly hydrogen. If bakeout by chemical process[4] of COF_2 is employed, a vacuum of 10^{-10} Torr region can be achieved with a mild bakout 80℃ instead of the normal temperature of 150℃.
4) Energy loss dE/dx is proportional to material density, ρ and atomic number squared of the material, z^2. The localized high heat flux for aluminium was more than several ten of times higher than stainless steel material against melt-down and the fine leak from the flanges. Temperature distribution of localized heat flux irradiated flange is shown in Fig.2 due to low energy loss and high thermal conductivity characteristics.

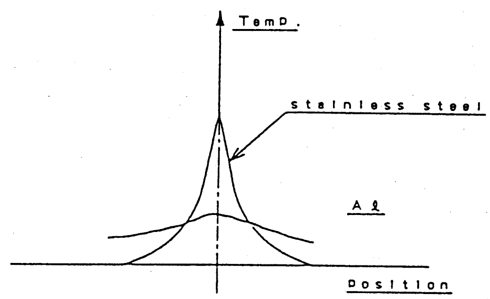

Fig.2 Temperature distribution irradiated from localized high heat flux against stainless steel and aluminum.

§3. VACUUM BEAM CHAMBER

A. Beam chamber

Circumference of the ring is about 3,300 m long. Since the bending angle for half cell is less than 1°, it is not necessary to provide a bending process for bend beam chamber. Extruded aluminum tube with elliptical aperture and heater groove are used for bending magnet and quadrupole magnet chambers. Length of the unit beam chamber is about 17 m long. Thickness of the elliptical chamber is 4 mm. Total number of 17 m long beam chamber is about 200 pieces along the entire ring. Using automatic welding beam chamber, beam position monitor and bellows can be joined without flanges as shown in Fig.3.

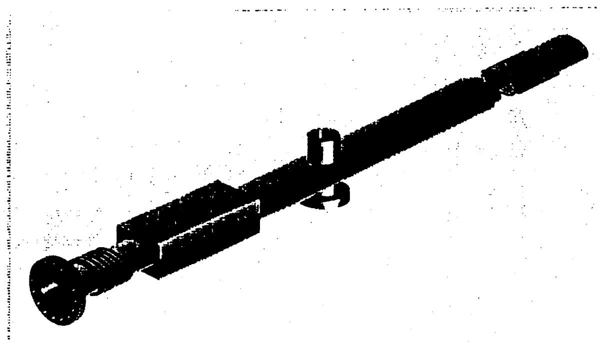

Fig.3 Half cell beam chamber of 17 m long consists of bellows, beam position monitor joined automatic welding without flanges.

End of the chamber against gate valve has flange. The design and construction of bellows for 17 m long vacuum beam chamber require thermal expansion and contraction of about 34 mm for 100℃ temperature rise during baking procedure.

Flanges for the pumping manifold ICF-114 and the gauges ICF-70 are adopted on the vacuum chamber. Gate valve will be used aluminum alloy products. The distance of the gate valve is about 150 m long.

B. Beam chamber material

The high purity 99.99% aluminum should be used to minimize adsorption and desorption from the chamber wall. The high purity aluminum are produced by gas bubbled flushing of argon and halogen mixture to reduce the internal hydrogen to less than 0.05 $cm^3/100gr \cdot Al$[5]. A special extrusion process[2] using an oxygen and argon mixture with water content in the 10 ppm range is used in the chamber to keep the surface clean. Depth profiles of the oxide layer of the EX extruded surface were analyzed by Auger electron spectroscopy. It was found that the oxide layer for the EX extruded surface was about 30Å thick. On contract, the oxide layer for an ordinary extruded aluminum surface is 120-180Å thick.

C. Beam position monitor

Beam position monitors are required for every quadrupole magnets. Total number of the beam position monitors are about 200 pieces. Primary candidate for beam position monitor is electrostatic pickup type. The cut electrodes which as elliptical aperture same as beam chamber are installed in aluminum housing. The electrodes are made from titanium plate. Assembled electrode is mounted on aluminum flange using ceramic insulators. Output signals are fed using non-magnetic SMA coaxial feedthroughs. The housing utilize extruded aluminum tube. After installation of electrode inside the housing and calibration using wire as beam position monitor, the flange and the housing assembly are welded by electron beam welder.

D. Clean machining and surface treatment

Beam chambers, flanges, beam position monitors are machined using clean machning system, namely EX plasma process. EX plasma process means machining in clean oxygen and argon mixture environment with Corona discharge, thus producing ozone. The Ozone is extremely active with strong oxydization and cleaning effect. After the surface has been cleaned, high density non-porous oxide layer is formed with extremely low outgassing rate.

To eliminate additional carbon contamination, ozone treatment[6] was applied on metal surfaces. The surface of aluminum without any treatement were exposed to ozone using dry air including ozone. No carbon was detected in the sputter profiled layer using Auger electron spectroscopy.

E. Flange, bellows and feedthrough

The aluminum alloy flange is compatible system for stainless steel CF type flanges. A basic feature of the system is the use of A2219-T87 die forged aluminium alloy. The knife edge is a mirror-finished surface, processed by a diamond tool. A titanium carbide coating is applied to the surface of the knife edge by ion plating. TiC treatment on the knife edge provides nearly perfect ptotection fron sticking between the knife edge and the gasket, and against surface scratches. The machined gasket is A1050-H24. The combination system of an aluminum alloy and an ordinary stainless steel CF flanges using aluminum gasket and aluminum alloy bolts are leak-tight during thermal cycles.

Aluminum alloy A3004 seamless bellows are produced by hydraulic forming of a seamless tube and provides the most uniformed wall thickness with the longest fatigue life. The thickness of the corrugated part of the bellows is 0.3 mm while the thickness of the welding edge is 4 mm. This bellows has life time of more than 1,000 cycles for +5 mm expansion and 35 mm contraction. RF shield is not necessary inside the bellows due to long beam bunches.

SMA type feedthrough has good RF characteristics over a frequency range of DC-4 GHz. These coaxial types made of aluminum and ceramic brazed are useful for beam position monitor. The outer shield can be welded using electron beam welder to aluminum housing.

F. Automatic welding assembly

Automatic welding equipment for an elliptical chambers were developed for small size, light in weight, easy to handle, and ensures uniform penetration. This equipment is designed to move the TIG welding torch along the elliptical cross section of the vacuum chamber by adopting orbits. The arc torch is supported by automatic arc voltage controller with servo mechanism. Guide orbit of the automatic welder can separate two, and can adopt fixed beam chambers installed in bending and quadrupole magnets. Moving area of automatic welder is inside of 500 mm in diameter circle.

§4. PUMPING SYSTEM

A. Pumping system

Given the criterion of an average vacuum 10^{-10} Torr range, the distance of lumped ion pumps of 30 ℓ/s is determined on the assumed value of the specific outgassing rate Q_0. Fig. 4 shows pressure distribution along the beam chamber against three kinds of specific outgassing of chamber and pump distance.

a) Staniless steel chamber: $Q_0 = 10^{-12}$ Torr ℓ/s cm^2 and pump distance: 8.5 m long.
This value approximate given in reference 1 and not acceptable.

b) Aluminum chamber: $Q_0 = 10^{-13}$ Torr ℓ/s cm^2 and pump distance: 17 m long.
This value is acceptable against requirement.

c) Aluminum chamber: $Q_0 = 10^{-14}$ Torr ℓ/s cm^2 and pump distance: 34 m long. This value is expected as a margin.

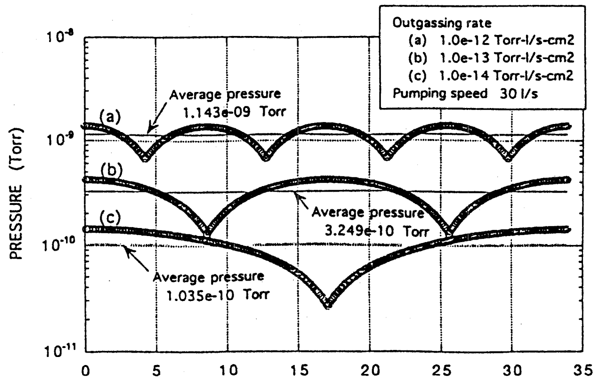

Fig.4 Pressure distribution along the beam chamber.

To reduce a cost, new type controlled power source for ion pumps which one-tenth in size compared to the standard is recommended. A D-shaped I-V charactrictic (fold-back over current protection) ion pump power supply[7] was used in the TRISTAN without any problems.

Roughing pump system are transportable cart station. After starting ion pumps, roughing pump station of turbomolecular pump and dry-pump combination will be separated from the metal seal right angle valve with manual operation. Dry-pump consists of diaphragm type and drag pumps combination. This combination is oil-free pump system. Distance of the roughing pump is about 70 m long. Two roughing pump stations are adopted inside section with 150 m separation by gate valves.

B. Operations

Estimated pumping time will be about several hours from atmospheric pressure to operating pressure of turbomolecular pump. Upon reaching to 10^{-6} Torr range using chemical process at 80℃ instead of ordinary 150℃ baking, sputter ion pumps operation is activated by a single ON switch for many of the ion pumps along the storage ring.

§5. PROTOTYPE BEAM CHAMBER FOR EVALUATION

The prototype beam chamber is two 17 m long with elliptical shape joined aluminum alloy bellows without flanges. Total length is 34 m long. The unit chamber of 8.5 m long has dummy beam position monitor, pumping manifold of ICF-114 and gauge port of ICF-70 flanges as shown in Fig.5. Ends of beam chamber are flanges of ICF-152. These flanges are only use for connect and disconnect for transportation. Two 30 ℓ/s ion pumps are installed. A 50 ℓ/s turbomolecular pump and dry-pump combination as a roughing pump is installed. All-metal seal right angle valve installed between the beam chamber and turbomolecular pump. Distance of the ion pump is 17 m or 34 m long. The expected ultimate pressure on the ion pump is 10^{-10} Torr range during the 150℃, 24 hours baking period.

The chemical process using COF_2, and fast pump-down process[8] using super-dry nitrogen will be applied for the test chamber.

§6. KEY RECOMMENDATIONS

1) Construct extruded aluminum beam chambers, each 17 ,m long. The unit chamber installed with bellows, beam position monitor, pumping manifold.
2) Using automatic welding, beam chamber, beam position monitor and bellows can be joined without flanges.
3) Install ion pumps at a distance 17 m or 34 m apart to achive the predicted ultimate pressure of 10^{-10} Torr range.

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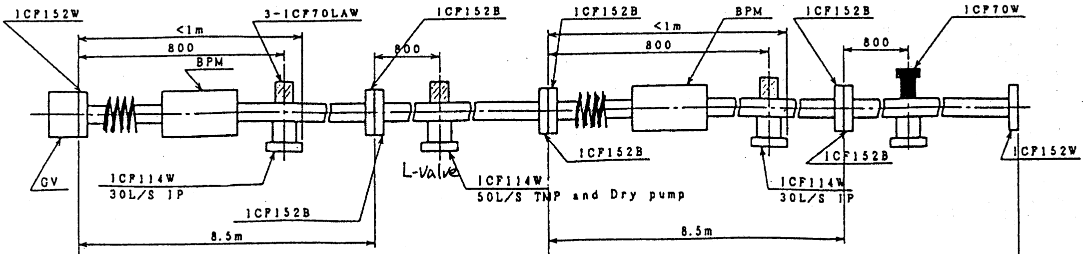

Fig.5 A prototype beam chamber consists of dummy beam position monitors, pumping ports, gauge ports and bellows.