DESIGN, FABRICATION, AND TESTING OF UHV COMPATIBLE ALUMINA CERAMIC CHAMBERS FOR KICKER MAGNETS OF Indus-2

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Abstract

Ultra High Vacuum (UHV) compatible alumina ceramic chambers are used as vacuum envelopes inside the four injection kicker magnets in Indus-2 (a 2.5 GeV, 300mA electron storage ring). These are necessary to avoid the effects of eddy current induced by the pulsed magnetic field generated by the kicker magnets. For up-gradation of UHV system of INDUS-2, new alumina ceramic chambers with improved design features were designed and developed. Salient design features of this development are: monolithic flanged alumina tube, improved ceramic-to-metal joint, RF continuity, free from stress concentration, safety during handling, reduced tightening torque for leak tight metal sealing and UHV compatibility. Alumina tubes made of 99.7% purity alumina powder were molded by isostatic pressing followed by sintering at high temperature for achieving optimum mechanical strength. Sintered and ground tube was subjected to Mo-Mn metallisation followed by protective Nickel plating of areas to be brazed with Kovar. Vacuum brazing technique was used to braze metallised alumina to Kovar joint using BVAg-8 brazing alloy. Inner surface of alumina tube was coated with Titanium to provide conducting path to image current. Helium leak rate of the ceramic-to-metal joint was < $2X10^{-10}$ mbar l /sec before and after bake-out at 150°C for 24 hours. After bake-out ultimate vacuum ~$5X10^{-10}$ mbar was achieved. As expected, RGA spectrum of ultimate vacuum after bake-out shows abundance of mainly H_2 gas. This paper describes detail engineering design, fabrication processes and ultimate vacuum testing results of these chambers.

INTRODUCTION

Injection section of Indus-2 consists of four identical ferrite kicker magnets (Fig. 1) for generating compensated bump[1] for beam injection. To avoid effects of eddy current induced by pulsed magnetic field and to provide conducting path to beam induced image current, UHV compatible alumina ceramic chambers with Ti coating inside are installed as UHV envelopes inside these magnets. For up-gradation of UHV system of Indus-2, new alumina chambers with improved design features were developed.

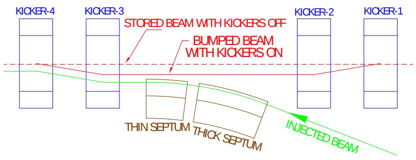

Fig. 1: Layout of storage ring injection

ENGINEERING DESIGN

Various design requirements for these chambers are: stability of structure against atmospheric pressure loading at baking temperature of 150ºC, UHV compatibility (Pr ≤ $5X10^{-10}$ mbar), non-magnetic metallic flanges for metal gasket sealing, RF continuity, geometrical compatibility with magnet aperture, bake-ability, corrosion resistance, & Ti coating on inside surface. Improved design features of this development are: monolithic flanged alumina tube with race-track inner profile, lap (shear) geometry of ceramic-to-metal joint, free form stress concentration, safety during handling, reduced tightening torque requirement for He leak tight demountable joints. Geometry of the chamber assembly is shown in Fig. 2.

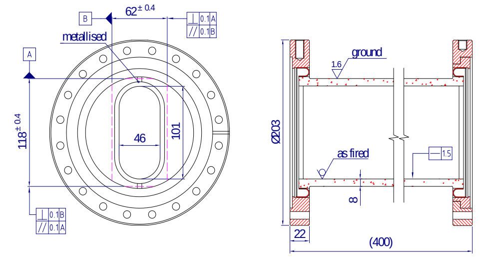

Fig.- 2. Schematic of alumina chamber assembly

Alumina Tube Design

Monolithic flanged alumina (99.7% purity) [2] tube is having race-track inner profile due to beam dynamics requirement and rectangular outside for geometrical compatibility with magnet aperture. Geometrical compatibility with magnet aperture requires very good flatness and perpendicularity of the mating surfaces. Surface finish of outer mating surface was specified to 1.6 µm for minimizing high voltage related problem.

Ceramic- to-Metal Joint Design

Difference in coefficient of thermal expansion (TCE) between ceramic and metal leads to substantial residual thermal stress at the brazed joint. The residual stress lowers the tensile/bending strength of the brazed interface significantly[3]. For successful ceramic-to-metal brazed joint optimisation of various parameters like brazing alloy, metallic components & its thickness at the braze joint, the joint configuration, and the amount & position of the braze must be considered for minimising the resulting residual stress. EN1.3981 grade of Kovar was selected as interface material for ceramic-to-metal braze joint due to its close TCE matching with F99.7® grade alumina(Fig. 3-a), weldability with SS316LN and low specific out-gassing rate. Ceramic-to-metal joint geometry was designed to avoid direct tensile/ bending stress due to inherent brittleness of the alumina to Mo-Mn interface[4]. Salient features of this ceramic-to-metal design (Fig. 3b) are: lap joint, convoluted geometry of Kovar sleeve for stability against atmospheric loading, flexibility during temperature change[5] and higher tortional moment of inertia.

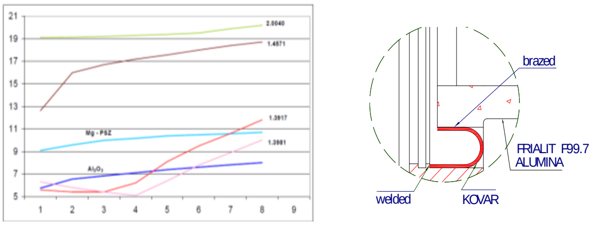

Fig. 3 (a) Graph of TCE ~Temp (b) Ceramic-to-metal Joint

FABRICATION PROCESS

Various stages for manufacturing these chambers are as follows: isostatic pressing of alumina tube, green machining, sintering, diamond grinding, ultrasonic cleaning in Acetone, Mo-Mn metallisation, Ni plating, forming stress relieving of Kovar tube, vacuum brazing of metalised alumina tube to Kovar tube, TIG welding of SS 316LN flange with Kovar tube, Helium leak testing, ultrasonic cleaning in acetone, Ti coating and ultimate vacuum testing. Geometrical tolerances and surface finish of outer surfaces of Alumina tube were achieved by diamond grinding followed by diamond polishing.

Isostatic pressing & sintering

In order to get zero porosity and high strength these chambers were moulded by isostatic pressing [2] the specially prepared alumina powder. Hydrostatic pressure ~ 1000 bar was applied during isostatic compaction of these tubes. Polished mandrel of stainless steel was placed inside for getting smoother inner profile. Sintering

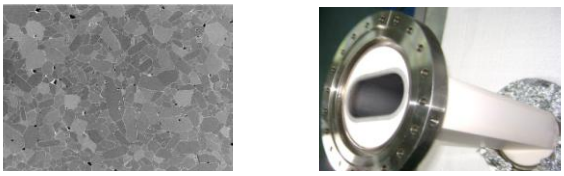

Fig 4 (a) Microstructure of sintered tube (b) Ti coated chamber

was carried out at 1800°C for densification and increase in strength. Fig. 4(a) shows microstructure of as sintered alumina tube.

Metallisation

Dissimilar nature of atomic bonding in alumina and metal makes it imperative to first metalize the alumina surface that is wettable by some suitable brazing alloy. Suspension of Mo-Mn was applied on the desired surfaces of alumina followed by firing at 1475º C for 30 min in wet hydrogen mixture atmosphere. Firing produces transition from vitreous phase to metallic phase across the layer. Subsequently, galvanic nickel plating ~3 µm was applied to protect this Mo layer from oxidation and to get suitable surface wettable by copper-silver eutectic brazing alloy.

Brazing

In order to get degassed and contamination free assembly brazing of metallised alumina tube to Kovar was carried out in vacuum furnace. Copper-silver eutectic alloy (BVAg-8) was used as brazing alloy that wets surfaces of Kovar as well metallised alumina tube and provides sound mechanical bonding. Brazing temperature and time were 820ºC and 8 minutes respectively.

Ti Coating

Ti coating ~ 2 µm was done by DC sputtering using Ti wire electrode. Pure Ar (99.999 %) gas at 5 X 10^{-2} mbar pressure was used for creating ions for sputtering. Photograph of Ti coated chamber is shown in fig. 4(b).

UHV TESTING

Schematic of UHV test set up is shown in fig. 5(a). He leak rate was < 2X10^{-10} mbar l /sec before and after bake-out at 150°C for 24 hours. After bake-out ultimate vacuum ~5X10^{-10} mbar was achieved for Ti coated chamber. RGA spectrum (fig. 5b) after bake-out of coated chamber shows abundance of mainly H_2 gas.

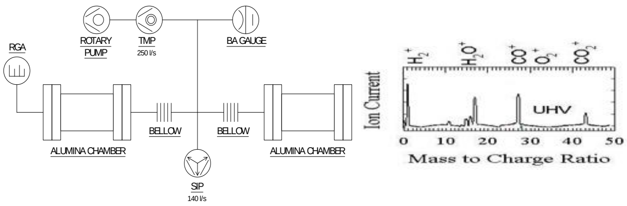

Fig.5 (a) Schematic of UHV test setup (b) RGA spectrum

CONCLUSION

Design objectives were achieved due to proper design and quality assurance at every stage of fabrication. For structural application of ceramic-to-metal joints lap (shear) type joint should be preferred over pure butt joint. RGA spectrum confirms the absence of any high Z gaseous species.

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