

Development of UHV Compatible Machined Diamond Profile Gaskets For INDUS-2

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Abstract. Ultra High Vacuum (UHV) compatible demountable joints are needed in Indus-2 (2.5 GeV, 300mA) electron storage ring for connecting Al-alloy vacuum chambers (homogeneous joints) as well as Al-alloy vacuum chambers to well proven stainless steel components like beam diagnostic components and RF-shielded bellow assemblies (heterogeneous joints). Bakeable & reliable diamond profile Al-alloy gaskets have been developed for Helium leak rate less than 2×10^{-10} Std. CC/sec, which eliminated the need of any Al to SS transition pieces onto the Aluminium vacuum chambers. Salient features of these gaskets are: high reliability, low cost, reduced flange thickness, self alignment, ease in installation, less torque requirement, formability to non-circular shape & ultra cleanliness. These diamond profile gaskets were machined from extruded Al-alloy 6061-T5 pipes using specially developed high-speed steel formed cutting tools. Thermal cyclic tests were carried to check the reliability of these gaskets. No leaks were found even after several bakeouts at 150°C. Non-circular metallic gaskets like the one used in UHV gate valve bonnet seal can also be manufactured using specially developed formed toolings. This paper describes basic design philosophy, manufacturing process and testing details of these gaskets.

1.Introduction

Indus-2 (2.5 GeV, 300 mA) is a dedicated synchrotron radiation source (SRS) up to X ray region for basic research. Its circumference is 172.43 m. UHV of the order of 1×10^{-9} mbar with stored electron beam is required for beam lifetime more than 20 hours. Al-alloys 5083-H321 and 603-T6 have been used as material of construction for dipole and straight section chambers respectively. Conventionally well proven SS316L material has been used for RF-shielded bellows, beam diagnostics devices, sputter ion pumps and Titanium Sublimation pumps etc. There are nos. of homogeneous (Aluminium to Aluminium) and heterogeneous (Aluminium to SS) demountable joints around the ring. It was imperative to develop reliable & low cost gaskets compatible with both types of above joints and bakeable up to 150°C within a stipulated time schedule. Important boundary conditions were: Compatibility to UHV environment, limited space in the ring, differential thermal expansion caused by dissimilar flange materials at elevated temperature, resistant to radiation and corrosion. Metallic gaskets are conventionally used in demountable joints of UHV systems because of low specific out-gassing rate and bakeability considerations. Very low vapour pressures and lower gas permeation rates at higher temperatures also favour their selection. In order to get helium leak tight joints with leak rate

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$< 2 \times 10^{-10}$ Std CC / sec large sealing load is needed in case of metallic gaskets. This is because of plastic deformation caused to metallic gaskets to fill up the hills and valleys on the surfaces of flanges. This applied tightening load is function of permissible helium leak rate, gasket material, circumferential length and sealing interface width of gasket, surface finish of flange sealing surface and pressure difference across the seal. This paper describes basic design philosophy of gaskets based on permissible helium leak rate, mechanical design, manufacturing process and test results.

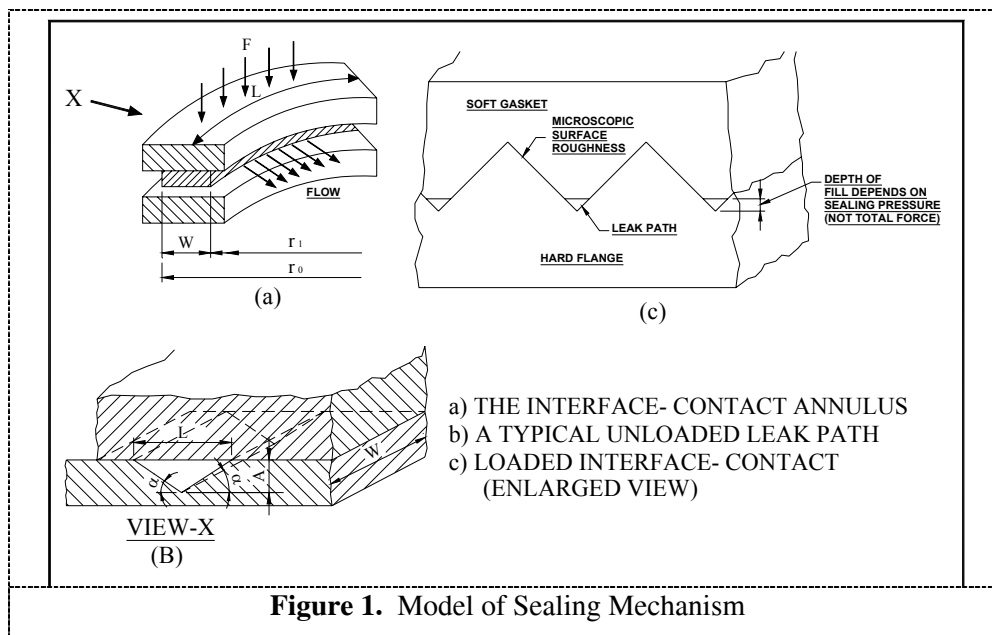
2. Theoretical model of gasket sealing

The basic sealing mechanism for a gasket seal involves forcing soft gasket material into the microscopic grooves on a hard sealing surface through which gas may flow (figure 1) As sealing pressure is progressively increased gasket material is pressed deeper into the grooves reducing the cross-section and thus, the conductance of the leak paths. Conductance of loaded interface for any gas is given by [1]:

$$C = 4 (T/M)^{1/2} A^2 L/W e^{-3F/LWR} \text{ l/sec} \quad (1)$$

Where,

- C = Conductance of loaded interface in l/sec
- T = Ambient Temperature in K
- M = Molecular weight of gas in gm
- A = Surface roughness of flange sealing surface in cm
- F = Total sealing force in Kg
- L = Mean circumferential sealing length in cm
- W = Radial width of loaded sealing interface of gasket and flange surface
- R = Gasket sealing factor in Kg/cm²



2.1. Tightening index, gasket sealing factor, and leak rate

Denoting sealing pressure ‘P’ = F/LW, and tightening index ‘K’ = P/R, equation (1) can be written as:

$$C = 4 (T/M)^{1/2} A^2 L/W e^{-3K} \text{ l/sec} \quad (2)$$

Gasket sealing factor ‘R’ is the property of gasket material, which is defined as the amount of applied sealing pressure which produces decrease of the conductance (or leak rate) by a factor of $e^{-3} \sim 0.05$. An instrument called sSealometer is used for measurement of this factor for a given gasket material. This factor is different from y factor (joint contact surface unit sealing load) for gasket seating

condition as mentioned in Appendix-2 of ASME Boiler and Pressure vessel design code Sec-VIII, Div-I.

Practical values of ‘R’ for various gasket materials:

- Lead = 70 Kg/cm²
- Teflon = 150 Kg/cm²
- Al (Annealed) = 300 Kg/cm²
- Cu (Annealed) = 500 Kg/cm²

For Helium at 25°C, leak rate ‘Q’ through the loaded interface is given as:

$$Q = C \Delta P = 34 [A^2 L/W e^{-3K}] \Delta P \text{ Torr l/sec} \quad (3)$$

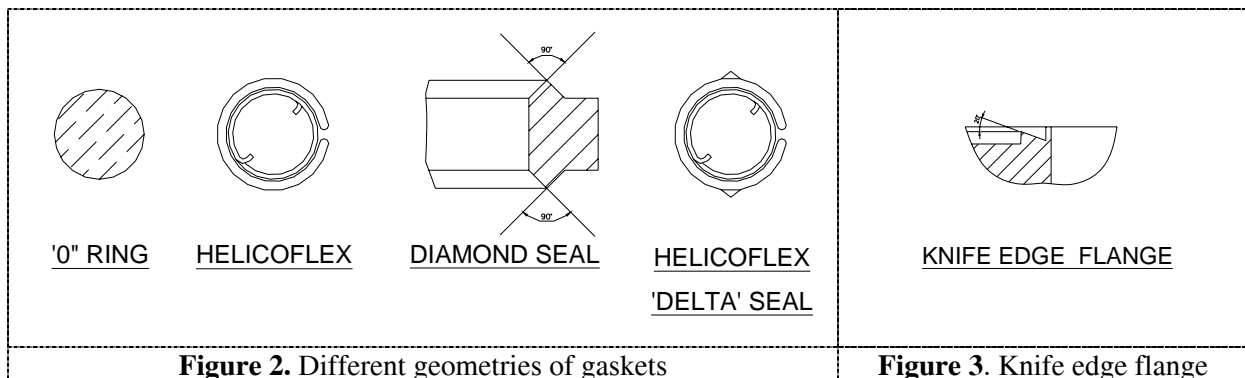
3. Practical considerations for vacuum gasket geometry

From equation (3) above

$$Q \propto A^2 L/W e^{-3F/LWR} \Delta P$$

Leak rate can be minimized by:

- 1) Selecting a gasket material having lower value of ‘R’ : i.e proper selection of gasket material.
- 2) Designing for minimum possible sealing width ‘W’ at the interface between gasket and flange surface, which may be practically attained by one of the following designs :
 - A. O-ring design: As in elastomer O-ring, metal wire seal, helico-flex and helico-flex delta metallic seals (figure 2).
 - B. Knife-edge design : This design is adopted on flange (figure 3) and gasket is flat.
 - C. Diamond shape design: This design is generally adopted on gasket and flange-sealing face remains flat (figure 2).
- 3) Maximizing the surface smoothness of sealing surfaces i.e decreasing the value of ‘A’ : This takes account of the significant impact of the surface roughness of sealing surface of flange.
- 4) Minimizing ΔP. Using differential pumping design does this.



4. Mechanical Design

4.1. Sealing Pressure

Re-arranging equation (3) for leak rate, the sealing pressure required to achieve a desired leak rate may be estimated as follows [2]:

$$P = R/3 \ln[34 A^2 L \Delta P /QW] \quad (4)$$

Using this equation, the sealing pressure, sealing load per unit sealing length and total sealing load can be calculated for a given leak rate, gasket material its geometry, surface roughness of flange sealing surface and pressure difference. This sealing pressure P from equation (4) is equivalent to factor Y of Appendix-2 of ASME Pressure vessel code Sec-VIII, Div-I.

4.2. Design of flanges

Once the sealing load is known, the detailed flange design is based on strength of material calculation for stress and stiffness. Appendix-2 and Appendix-S of ASME Pressure vessel code Sec-VIII, Div-I

give guidelines for designing bolted flanges (loose type, integral type and optional types) with ring gasket under external pressure load. Spacing of bolts should be as close as possible for uniform loading. This is decided by considering minimum inter-bolt spacing required for torque wrench. Bolt circle diameter should be as close as possible to gasket in order to reduce the moment arm of flange, which in turn minimizes flange thickness. UG-11, 34, 44 give guidelines for bolted blind flanges with ring type gaskets.

4.3. Tightening Torque

Tightening torque required for tightening the bolts can be calculated using following formula:

$$T = 1/1000 [W \tan (\alpha + \phi)d_p/2 + \mu_1 W r_1] \text{ Nm} \quad (5)$$

Where,

T = Torque applied on bolt in Nm

W = Bolt load in N

α = Helix angle ($\alpha = \text{pitch}/\pi d_p$)

ϕ = Friction angle ($\tan \phi = \mu/\text{Cos}\beta$)

μ = Co-efficient of friction between the mating surfaces of nut and bolt

μ_1 = Co-efficient of friction between the mating surfaces of nut and washer

β = Half of included angle of thread (For Metric thread $\beta = 30^\circ$)

d_p = Pitch diameter of bolt thread

r_1 = Mean nut bearing radius

5. Development of diamond shape gaskets

5.1. Geometrical Design

Profile of the gasket was kept as diamond-edge type because of the obvious reason as explained earlier. Cross-section of a typical diamond gasket developed in RRCAT is shown in figure 4. Photograph of these diamond gaskets is shown in figure 5. The geometrical details of a typical joint [3] are given figure 6. This gasket sits in a recess of flange faces, which allows a desired plastic compression [4]. Its design is such that it can absorb differential expansion between two flanges of dissimilar materials during the bake-out.

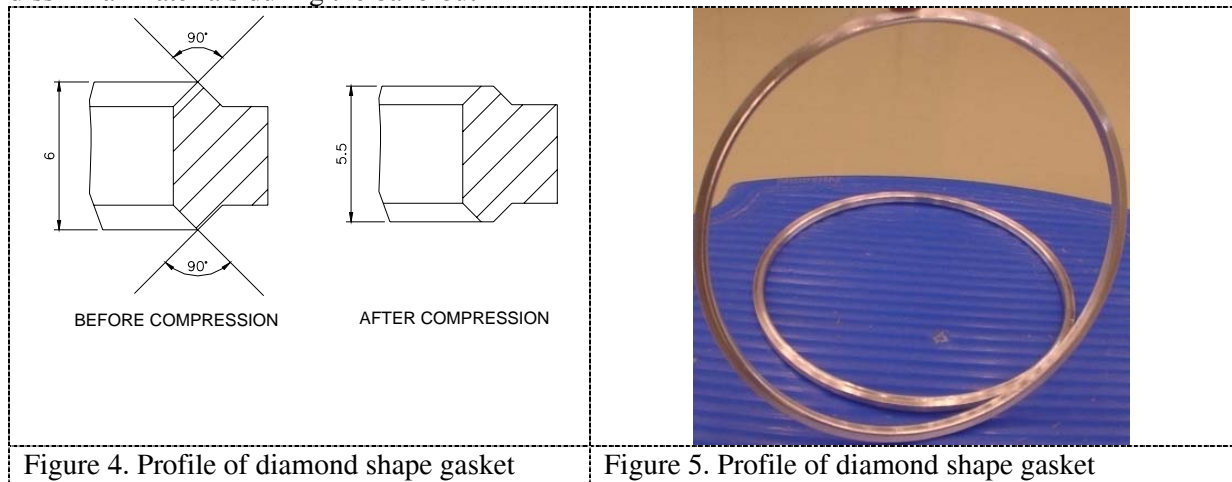


Figure 4. Profile of diamond shape gasket

Figure 5. Profile of diamond shape gasket

5.2. Mechanical and physical properties

The material of the gasket was adapted to the operating conditions of INDUS-2 with particular emphasis on: the thermal stability of the material up to 150°C, resistant to corrosion and radiation, UHV compatibility and mechanical strength. These requirements could be met with a Al6063-T5 Al-alloy. The material properties of the components used for design and testing are summarized in Table-1. Co-efficient of thermal expansion plays an important roll in selection of bolt material. Table-2 shows the effect of co-efficient of thermal expansion on sealing performance of various alternative material of construction of bolts. Table-1 shows that choice of stainless steel bolts lead to almost zero probability of leaks and hence they were selected for the demountable joints in INDUS-2.

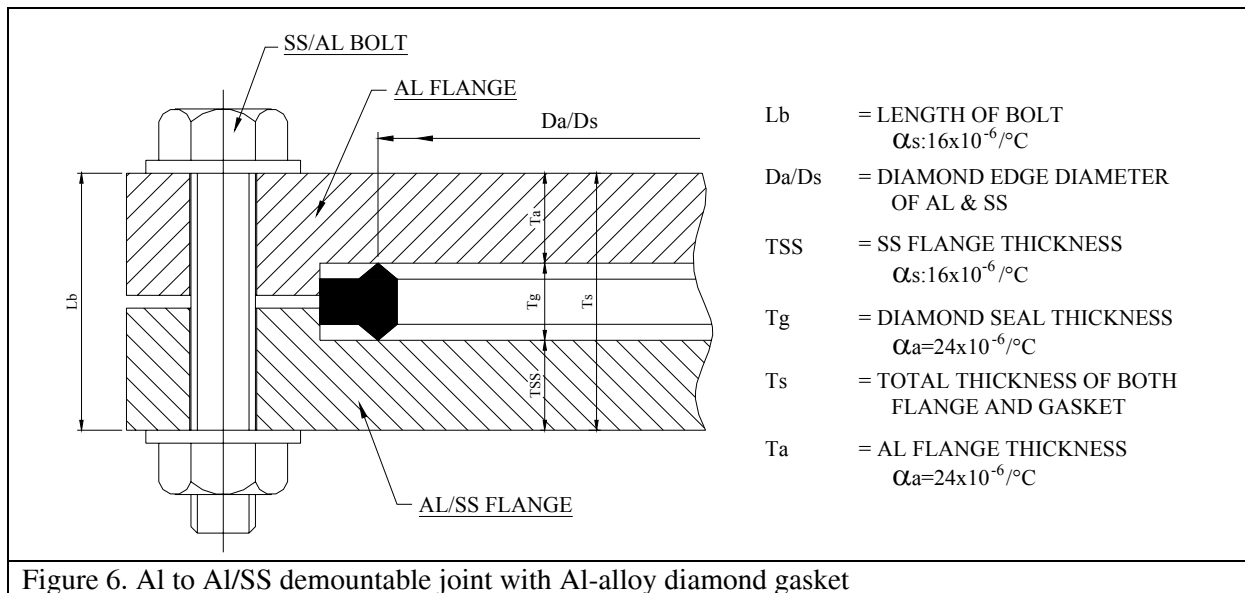


Figure 6. Al to Al/SS demountable joint with Al-alloy diamond gasket

5.3. Torque ~ Compression Characteristics

Torque ~ compression curve of diamond gasket as shown in figure 7 shows linear behaviour. Testing started with 10 Nm torque due to the starting value of range of the torque wrench available with us. Slope of the curve shows the compression of 25 micron/Nm.

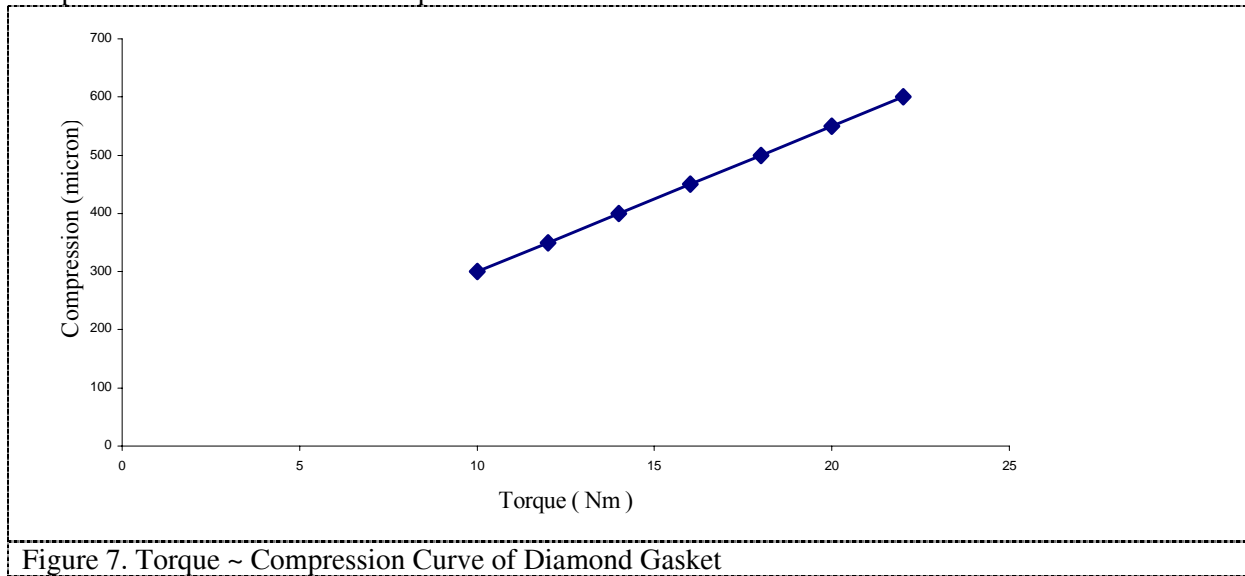
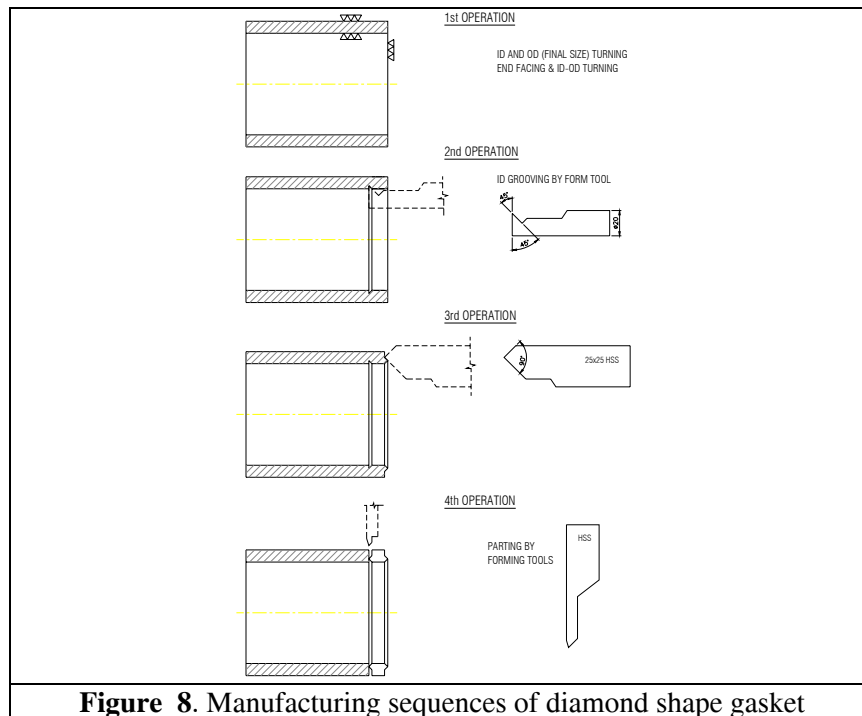


Figure 7. Torque ~ Compression Curve of Diamond Gasket

5.4. Manufacturing Process

Lay of the mating sealing surfaces plays vital role to increase further reliability of these seals against sealing. Conventionally, vacuum flanges are turned on lathe to give better surface finish. Microscopically the lay (tool path) on these surfaces is in circumferential direction. To match the same pattern of lay on gaskets, it was decided to machine these gaskets on lathe machine. After prototype testing, manufacturing process was standardized and the batch production of the diamond shape Al-alloy gaskets was taken up. This facilitated interchange-ability of gaskets within close tolerances. High-speed steel form tools were developed to produce these gaskets. Good machine-ability of Al-alloy selected for gasket material renders excellent surface finish. First the pipe stock was machined from inner and outer sides to remove the skin of the material to get the virgin core of the material. Each gasket is turned in four stages as shown in figure 8.



Material Properties	Flanges		Gasket	Bolts
Mat Grade	SS316L	Al 2219	Al 6063	A4
Mat temper	Annealed	T87	T5	80
Yield Strength	200	350	140	600
Hardness (BHN)	150	130	55	> 300
Thermal expn (°C ⁻¹)	16 X 10 ⁻⁶	24 X 10 ⁻⁶	24 X 10 ⁻⁶	16 X 10 ⁻⁶
Young Modulus (Map)	2,00,000	70,000	65,000	2,00,000

DS Flange Design	Outside dia of flange (mm)	Diamond edge dia.	Difference of diamond edge radius during baking	Length of bolt in mm (L _b = T _s)	Change in length during baking (ΔL) in mm			
					SS/Al With SS bolts	SS/Al With Al bolts	Al/Al With Al bolts	Al/Al With SS bolts
DSF 203	203	157.5	0.082	40	-0.023 NL	0.0182 PL	0 NL	-0.0416 NL
DSF 203	152	111.3	0.058	32	-0.019 NL	0.014 PL	0 NL	-0.033 NL
DSF 203	114	73.2	0.038	14	-0.008 NL	0.007 PL	0 NL	-0.014 NL
DSF 203	70	42.2	0.022	10	-0.005 NL	0.004 PL	0 NL	-0.010 NL

Note: ΔL = (ΔL_b - (ΔT_s), NL – No leak, PL- Probability of leak

6. Testing & observations

Large numbers of gaskets were tested for repeated baking cycles at 150° C. There were no leaks even after repeated baking. We used hundreds of diamond gaskets for ex-situ and in-situ assembly in the ring. All the joints were qualified for He leak rate < 2X10⁻¹⁰ Std CC / sec. Statistics shows that there were no leaks except few cases. After evaluation it was revealed that those leaks were not because of

gaskets rather due to problem in sealing surfaces of flanges either poor flatness or radial scratches and gap between flange surfaces etc. An important consideration for using this gasket is that there should not be any gap between flange surfaces after tightening i.e the joint operates as single body during baking. It is worth mentioning here that thorough check-up of the sealing surface of flanges before tightening the gaskets minimizes probability of leak.

7. Conclusion:

Gasket material and geometry for given permissible He leak rate and flange surface finish governs the equivalent γ factor for gasket seating condition for the design of vacuum flanges. Development of machined Al-alloy diamond gaskets for INDUS-2 proved highly reliable, cost effective and easy to install. Their compatibility for both homogeneous and heterogeneous joints makes it more versatile. Important fallout of this development is that non-standard gaskets can also be formed or directly machined from material stock. These special gaskets can be used for dual purpose of sealing as well as RF-contact in case of accelerator vacuum system.

8. References:

- [1] A. Roth, Vacuum Technology, 2nd revised edition, page no. 397
- [2] Dorothy M. Hoffman, Baba Singh and John H. Thomas, Handbook of Vacuum Science & Technology, page no. 513
- [3] Yadav. D.P, Ram shiroman, Shukla S.K and Rao Raja. A.S, Development of UHV demountable joints for Al alloy chambers of INDUS-2, IVS Bulletin, vol 4, no 3, pp 21-25, Sept. 2001
- [4] W Unterlerchner, Non-standard vacuum hardware for an accelerator vacuum system, Vacuum, volume41, numbers 7-9, pp 1920 –1923, 1990

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