Analysis of RFQ Vacuum System for HINS Tests at MDB

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The arrangement of RFQ vacuum system is briefly described. The vacuum level with assumed standard out-gassing rates of the RFQ major components is projected and compared with measurements. The permeation of water through Viton O-rings of the LCW manifold mounted inside the RFQ vacuum vessel is analyzed and compared with data taken at various ambient temperatures. The rate of hydrogen gas spill from the Ion Source and LEBT into the RFQ vacuum space is also projected. Suggestions to improve RFQ vacuum system are presented and discussed.

1. Brief overview of the RFQ vacuum system arrangement

As indicated in figure 1, RFQ consists of accelerating vanes made of solid copper embedded in a cylindrical (0.46m diameter x 3 m length) vacuum vessel of stainless steel. On the top of the vessel there are two 6 inch ports for the HV lines providing the RF power to the vanes, and two 8 inch ports for the LCW cooling flow of these vanes. At the bottom of the vessel there are three 10 inch ports for the vacuum pumps. On the vessel sides there are twelve 2-3/4 inch ports, for the RF signal pick-up, and four 2-3/4 inch ports for the vacuum instrumentation (Pirani Gauge, two Ion Gauges and the RGA). All ports on the vacuum shell use CF flanges with copper seals. The large front and back flanges of the vessel are sealed using the Viton O-rings. The Viton O-ring seal is also used in 24 feed-through lines to pick-up the RF signal, and in 48 VCO fittings of two LCW manifolds mounted at the top of the vessel interior.

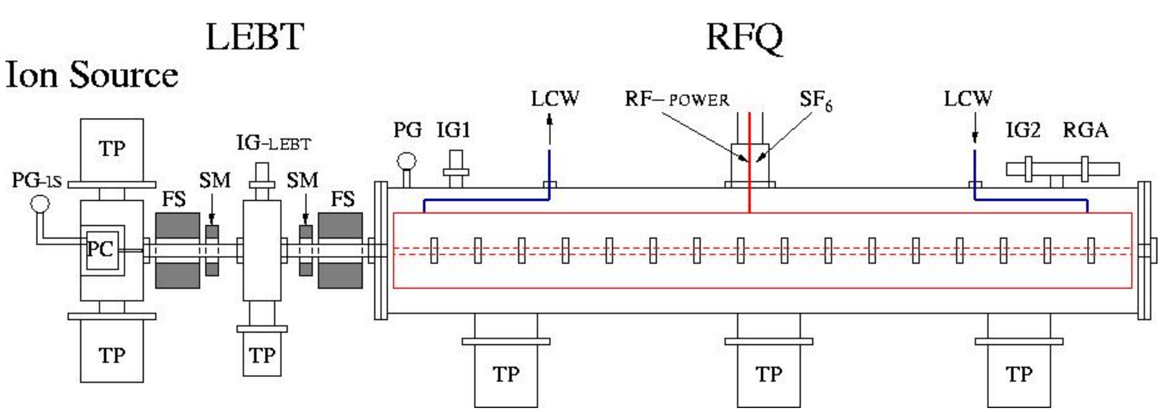

Fig.1 Arrangement of RFQ vacuum system with its connection to Ion Source through LEBT. PC- plasma chamber, FS- focusing solenoid, SM- steering magnets, PG- Pirani gauge, IG- ion gauge, TP- turbo pump.

All turbo pumps are Varian TV-1001 Navigator with the exception of the LEBT pump which is TV-301 type. The hydrogen gas pumping speed of the TV-1001 is 900 l/s while that of the TV-301 is 200 l/s. The Ion Gauges are the Granville-Phillips, Bayard-Alpert Nude 274 type, and the RGA is the Extorr 200 gas analyzer.

2. Expectations for the RFQ vacuum

The RFQ cross-section is shown in figure 2. The body of RFQ vanes constitutes a nearly closed object with small orifices through-out the center of the vanes as well as in their front and back flanges (not shown for clarity) to allow passing the accelerated beam. The pumping from the interior of the vanes is primarily through the15 slots, each 0.95 cm x 4.14 cm of cross-section and 2.20 cm in depth, evenly spread along the length of each quadrant. It is technically not possible to have a vacuum ion gauge inside the vanes space, so the vacuum level there has to be determined using an extrapolation of a measurement outside the vanes into the interior of the vanes. The conductance of the slot can be precisely calculated due to its regular and simple shape, but the conductance of both the interior and the exterior of the vanes is more complicated and will be estimated only. Due to very small dimensions of the slot, however, its conductance is by more than an order of magnitude smaller than that of a neighboring space in the either interior or exterior of the vanes, and therefore primarily determining the overall conductance. This makes the estimating the conductance in all other spaces of the RFQ acceptable. This is especially true for the determination of the relative conductance of the various gas species which does not depend on the geometry of the vacuum system. At the end we will use the actual RFQ vacuum measurements to normalize, if needed, the projected both total and relative conductance for various gas species.

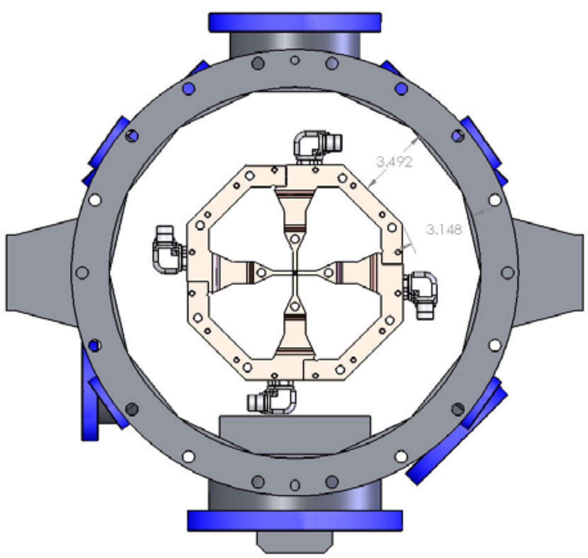

Fig. 2 RFQ cross-section: copper vanes are in the center of the stainless steel vacuum vessel. The shown bottom and top ports are for a turbo pump and the LCW connection, respectively. The placement of fraction of fittings of the LCW manifold is also shown.

We divide molecular path in the interior and exterior of the vanes into sections so the conductance in each of them can be approximated using formula for a cylindrical or a rectangular tube [1]:

Cylindrical tube: $C = ¼\ 478\ (T/300)^{½}\ (28/M)^{½}\ \pi R^2\ [1 + 3/8\ L/R]^{-1}$ (1)
Rectangular tube: $C = ¼\ 478\ (T/300)^{½}\ (28/M)^{½}\ ab\ [1 + 3/8\ (a + b)L/ab)]^{-1}$ (2)

T – temperature (K), M –atomic mass, R – radius of the pipe,
L – length of the pipe, a and b dimensions of a squared pipe cross-section

The selected sections are: (1) – space between two neighboring slots of vane interior, (2) – vane slots, (3) – space between RFQ body and vacuum shell, and (4) – entry into the turbo pump. The conductance is calculated for H2 and H2O, two major outgassing species from steel and copper, and for N2, O2, CO, CO2, C3H8 and SF6 which represent air and other gases potentially leaking and/or permeating through the Viton O-rings. In addition, a conductance of the hydrogen gas spilled from the LEBT beam pipe into, and then through, the interior of the RFQ vanes is also estimated. Finally, we project pumping speeds for the gases originating in the interior and/or the exterior of the RFQ vanes, and then project the partial and the total pressures inside and outside of the RFQ vanes space, both without and with hydrogen spill from the LEBT section.

The interior of the vanes is naturally divided into 4 quarters, and we approximate the molecular flow in each quarter with 3 separate flows in a cylindrical tube of a cross-section equal to that of a ¼ of the vanes interior, and of a path length equal to the ½ of 1/3 length of vanes (representing 5 neighboring slots) as the molecules reaching a slot from further distances can be neglected. The space in the exterior of the vanes is more irregular, but as conductance there is expected to be high due to a rather large distance between the walls of the vanes and the vacuum shell, we also approximate that space with a cylinder of a cross-section equal to that of the total area between the vanes surface and the vacuum shell. As the pumps are symmetrically distributed along the RFQ vacuum shell we use the geometrical sum of a ½ distance between the RFQ ends and a ½ of mean path from the top and the bottom rows of slots to the pumps as an average distance of the molecular flow. Again, this procedure leads to underestimation the overall conductance in the exterior space of the vanes. The assumed geometries of the RFQ vanes interior and exterior sections for the estimation of the conductance are listed in Table 1.

Table1. Assumed geometry of various sections of RFQ for conductance calculation

Section	<R> [m]	a [m]	b [m]	<L> [m]
¼ Vane within area of 5 slots	0.042	-	-	0.25
Vane slot	-	9.525 e-3	4.14 e-2	2.3 e-2
Vanes to vacuum shell space	0.19	-	-	0.7
Turbo pump entrance	0.1	-	-	0.1

The mass coefficients ($¼\ 478\ (T/300)^{½}\ (28/M)^{½}$) for the selected gases at 10^0 C and 30^0 C are given in Table 2, and the summary of the estimated partial and total conductance for various gases emitted from the interior and the exterior of the RFQ vanes surfaces at 30^0 C is given in Table 3. The conductance from the interior of the RFQ, $C_{RFQ-INT}$ is defined as:

$$1/C_{RFQ-INT} = 1/C_{VANES} + 1/C_{SLOTS} + 1/C_{VAC-SPACE} + 1/C_{TP} \quad (3)$$

The conductance from the surfaces outside the RFQ vanes (including vacuum shell) is defined as:

$$1/C_{RFQ-EXT} = 1/C_{VAC-SPACE} + 1/C_{TP} \quad (4)$$

The C_{VANES} is a sum of the conductance in 4 vanes, and the C_{SLOTS} in all 60 slots.

Table2. Mass coefficients for conductance calculation

Gas specie	H2	He	H2O	N2	O2	CO	CO2	C3H8	SF6
Coefficient @ 10^0 C	1736	1228	579	464	435	464	414	414	207
Coefficient @ 30^0 C	1877	1328	626	502	470	502	448	448	224

Table3. Estimated partial and total conductance for various gases in the RFQ

RFQ COMPONENT	Conductance [L/S]						
	H2	He	H2O	N2 / CO	O2	CO2/ C3H8	SF6
Inner vane, 1/3 length	804	569	269	215	201	192	96
1 slot	87	62	29	23	22	21	10
Space outside vanes	22310	15785	7440	5968	5586	5323	2655
Turbo pump inlet	3430	2427	1144	918	859	818	408
Inner vanes to pumps	3269	2312	1090	875	819	780	389
Outside vanes, or vac. shell to pumps	7046	4985	2350	1885	1764	1680	839

The pumping speeds, $S_{RFQ-INT}$ and $S_{RFQ-EXT}$ are projected using the equation (5) for the interior and the equation (6) for the exterior of the RFQ vanes (this one includes also vacuum shell) where S_{TP} is the nominal pumping speed of all three turbo pump:

$$1/S_{RFQ-INT} = 1/S_{TP} + 1/C_{RFQ-INT} \quad (5)$$

$$1/S_{RFQ-EXT} = 1/S_{TP} + 1/C_{RFQ-EXT} \quad (6)$$

We apply the nominal 900 L/s pumping speed of hydrogen in TV-1001 Varian pump to all other gases. This is certainly incorrect as the pumping speed for the heavier gases is likely 20 % lower, but in the absence of data we have no other choice. This assumption, however, is valid as long as hydrogen remains a dominant gas as expected.

Table4. Projected pumping speed for various gases emitted inside and outside vanes

RFQ COMPONENT	Pumping Speed [L/S]						
	H2	He	H2O	N2 / CO	O2	CO2/ C3H8	SF6
Inside vanes space	1479	1245	776	660	628	605	340
Outside vanes space	1952	1750	1256	1110	1067	1036	640

In order to project the vacuum level in the RFQ we must know the surface areas of the vanes and the vacuum shell, and we have to assume the out-gassing rates. The surface areas were very precisely determined [2] using a solid modeling analysis, but the assumptions of the out-gassing rates is rather uncertain. Nevertheless this exercise is useful as at a very minimum it helps understand relative contributions of the different gas species emitted from various areas of the RFQ internal structure.

The RFQ has been pumped and remained under vacuum for many months now. The vacuum state, however, was interrupted multiple times to allow installation of RF couplers and some instrumentation. During these periods a pure nitrogen gas was purged through the RFQ system. The out-gassing rates are very strong function of the surface quality (e.g. machined versus polished) and cleanliness that may effectively change those rates by orders of magnitude. As we have no knowledge of the way the RFQ surfaces were prepared we assumed standard out-gassing rates for the clean but unbaked surfaces of stainless steel and copper after 100 h of pumping as reported in [3]. We note, however, that typically warm vacuum level is stabilized with a minimal rate of gas desorption only after some 100-200 days of pumping.

The most common gases from the stainless steel and the OFHC copper are hydrogen (57%), water (37%), and CO + CO2 (6%) with the out-gassing rates from the copper being typically factor 2 higher than those from the steel. As the pumping goes on the relative rate of H2O gets smaller and hydrogen becomes dominant gas specie. Using these assumptions we made projections for partial and total pressures inside and outside spaces of the RFQ vanes. The surface areas of the copper and steel, the assumed out-gassing rates for the H2 and H2O, and the projected partial and total pressures are given in Table (5). Partial pressures inside the vanes, $P_{RFQ\text{-}INT}$, and outside the vanes, $P_{RFQ\text{-}EXT}$, are calculated using the equations (7) and (8), respectively:

$$P_{RFQ\text{-}INT} = C_{RFQ\text{-}INT} / S_{RFQ\text{-}INT} \qquad (7)$$

$$P_{RFQ\text{-}EXT} = C_{RFQ\text{-}EXT} / S_{RFQ\text{-}EXT} \quad (8)$$

Table5. Projected partial and total pressures of H2 and H2O in the RFQ vacuum spaces

	Units	Inside Vanes		Outside Vanes			
Material		Cu		Cu		SS	
Area	[m^2]	7.14		2,47		4.73	
Gas Species		H_2	H_2O	H_2	H_2O	H_2	H_2O
Outgassing Rate	[Torr_L/S/ m^2]	$1.3\ 10^{-6}$	$8.6\ 10^{-7}$	$1.3\ 10^{-6}$	$8.6\ 10^{-7}$	$6.7\ 10^{-7}$	$4.3\ 10^{-7}$
Outgassing	[Torr_L/S]	$9.3\ 10^{-6}$	$6.1\ 10^{-6}$	$3.2\ 10^{-6}$	$2.1\ 10^{-6}$	$3.2\ 10^{-6}$	$2.0\ 10^{-6}$
Pumping Speed	[L/S]	1479	776	1952	1256	1952	1256
Partial Pressure	[Torr]	$6.3\ 10^{-9}$	$7.9\ 10^{-9}$	$1.6\ 10^{-9}$	$1.7\ 10^{-9}$	$1.6\ 10^{-9}$	$1.6\ 10^{-9}$
Total Pressure	[Torr]	$1.4\ 10^{-8}$		$0.7\ 10^{-8}$			

We observe that projected pressure inside the vanes is twice that of the outside one. This is due to both the assumed double out-gassing rate for the copper and a smaller conductance from the interior of the vanes to the pumps. The projected pressure outside the vanes is $0.7\ 10^{-8}$ Torr to be compared to the measured ones with IG1 and IG2 ion gauges at $1.5\ 10^{-8}$ Torr with RF couplings uninstalled and the LCW water not flowing in the vanes cooling channels. At the time this measurement was conducted the IG readings still continued to fall. Therefore, we view this comparison as satisfactory, and as a vindication of the assumptions used for estimation of the conductance as well as for the out-gassing rates. In this situation we are not introducing any “normalization” factor for the further analysis of the RFQ vacuum system.

3. Air and water permeation in the Viton O-ring seals of the RFQ

Although the RFQ vacuum system was intended to operate in a UHV range there is rather a large number of Viton O-ring seals used. The list of these Viton seals is given in Table 6. In Table 7 we present permeation factors [4] of various gases in Viton O-rings

Table6. Length of RFQ Viton seals

Location	OD [inch]	Mean Length [mm]	Count	Total Length [cm]
LCW Manifold	0.625 0.75	50 75	32 4	160 30
Total LCW Manifold				190
Vacuum Shell	18 0.375	1466 30	2 10	293 30
Total Vacuum Shell				323
Total RFQ				513

relative to helium at 20^0 C and at 1 bar differential pressure. We also show the actual permeation value for air [5] under the same conditions. The permeation strongly depends on the temperature, e.g. it typically (but varying with gas specie) increases by a factor of two from 20^0 C to 40^0 C [4], and for well soluble gases it rises linearly with a rise of the differential pressure.

Table7. Relative permeation of gases through Viton (20^0 C, 1 bar differential pressure)

Gas Specie	He	H2O	H2	N2	O2	CO2	Ar	Air
Relative Permeation	1	23	0.2	0.047	0.13	0.16	0.13	0.065
Permeation per Linear Inch of Ring								$1.5\ 10^{-8}$ Torr-L/S

For a total of 202 inch length of Viton rings in the RFQ vacuum vessel we expect ~ $3\ 10^{-6}$ Torr-L/S of air permeation rate. With the projected air pumping speed of 1100 L/S in the outer space of the vanes air permeation would then contribute about $2.7\ 10^{-9}$ Torr pressure to the RFQ vacuum. As the actual vacuum was measured to be ~ $1.5\ 10^{-8}$ Torr the air permeation constitutes less than 20% of the RFQ vacuum level. The air permeation factor given in [5] is for a free-standing Viton ring. In the vacuum chamber, however, Viton rings are placed inside the grooves, which if properly designed and machined, allow for a complete closure of the mating halves of the flange, and in this way strongly minimizing the effective permeation rate. In order to determine the strength of this effect we will use the detection of helium from the permeating air performed under the same conditions. The helium flow rate from air was measured using a very sensitive ($7.5 10^{-12}$ Torr-L/S, Alcatel Model 182 leak detector, and it was found to be 4.8 10^{-11} Torr-L/S. As there is 5 ppm of helium in the air at atmospheric pressure we can project the permeation rate of air to be:

$$\text{Perm (air)} = 2\ 10^5 \times 0.065 \times 4.8\ 10^{-11} = 0.6\ 10^{-6}\ \text{Torr –L/S} \quad (9)$$

Comparing this result with the air permeation prediction of 3 10^{-6} Torr-L/S based on data from [5] we find that in the RFQ vacuum system the permeation of air through Viton seals is suppressed by about a factor of 5. Using this suppression factor (1/5) we can estimate the permeation rate for the water vapor through the Viton rings of the LCW manifold. As the water circulates under 3 bar pressure we add additional factor 3 and a factor of 0.38 for the LCW manifold fraction of all RFQ Viton seals:

$$\text{Perm (H2O)} = 1/5 \times 3 \times 0.38 \times 10^6 \times 23 \times 4.8\ 10^{-11} = 2.5\ 10^{-4}\ \text{Torr-L/S} \quad (10)$$

With the H2O estimated pumping speed of 1256 L/S in the outside vanes space we project then the partial pressure due to H2O permeation to be: P (H2O-perm) = 2.0 10^{-7} Torr. As shown in figure 3, within few minutes after the LCW flow has begun in the LCW manifolds the vacuum level has risen to about 2.1 10^{-7} Torr. As the initial reading

(IG1) was ~ 2.5 10^{-8} Torr the excess pressure caused by the LCW flow is ~1.85 10^{-7} Torr, thus being in an agreement with the expectation.

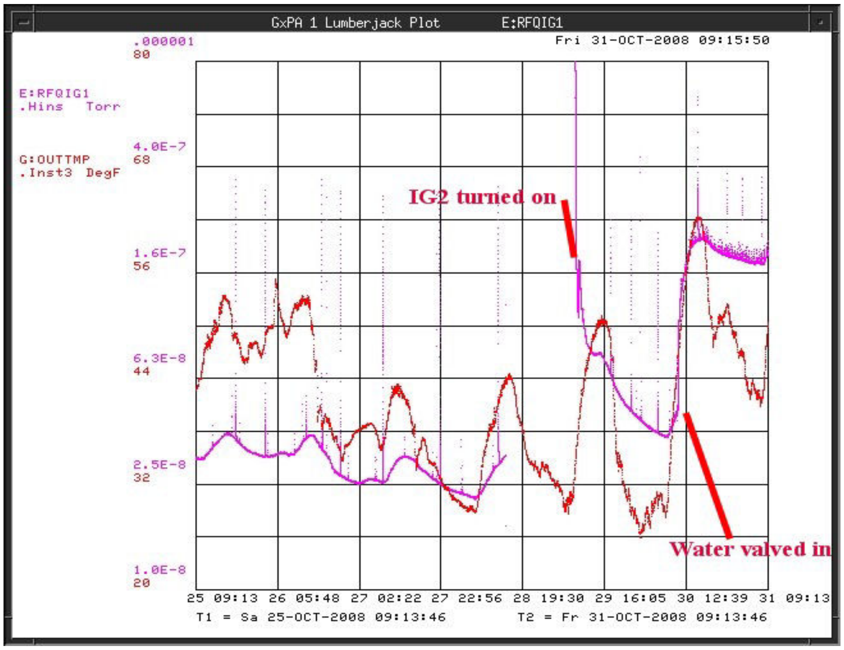

Fig.3 Pre-LCW flow RFQ vacuum level (IG1), and rise (IG2) with LCW flow

The LCW manifold is outside of the vanes structure so the water vapor spreads into the internal space of the vanes primarily through 60 slots with a total H2O conductance of 1740 L/S. As the conductance in the outside space of the vanes is 7440 L/S we expect that only some 23% (1740/7440) of these water molecules enter the inner space. The water molecules which got inside the vanes space bounce between the walls as other molecules from the out-gassing process, and then they are pumped-out at 776 L/S rate. Due to a very high solubility of water molecules in copper (typically twice of that in the stainless steel), however, a considerable fraction (perhaps (1740 – 776)/1740 = 55%)) of these “external” H2O molecules will actually stick to the inner vanes surfaces re-filling the outer molecular layers of copper up to possibly a saturation level. When the RF power is applied to the RFQ vanes the rapidly rising temperature of the vanes surfaces forces very quick release of rather large amount of water vapor, leading in this way to a possibility of HV discharges.

4. Effect of ambient temperature on the RFQ vacuum

We observe a strong dependence of the RFQ vacuum level with change of ambient temperature. The main reason is that the water vapor constitutes a dominant gas component in the RFQ vacuum space. The water molecules are chemisorbed to the metal surface, and their desorption rate from the surface is temperature dependent. The average length of time water molecule resides on the metal surface constitutes most important factor affecting the overall pumping speed. It turns out that the average residence time increases by some 10 orders of magnitude [3] between 450^0 C and 22^0 C. If the rate of the rise and/or fall of the residence time was independent of the temperature range than the residence time would be approximately changing by a factor of 10 per 40^0 C interval. This is not likely to be the case, however, for the temperature range closer to the freezing point at 0^0 C when the water molecules will reside on the surface (for practical purpose) for an infinitive time. Scaling from the $(22 - 450)^0$ C temperature range, the rate of desorption would be slowed down by a factor of 5 between 30^0 C and 10^0 C. With the observed 2 10^{-7} Torr partial pressure of water in the RFQ outer vanes space at 30^0 C one should then expect "improvement" of the vacuum level down to about 4 10^{-8} Torr with the RFQ vessel external walls cooled down to10^0 C. The actually measured RFQ vacuum level at 10^0 C was found to be 1.5 10^{-8} Torr, nearly a factor 3 lower. We believe that the lower than expected vacuum level is possibly due to the acceleration of the residence time length as the surface temperature gets closer to 0^0 C. One may also anticipate that at lower temperatures, when the formation of multi-molecular layers is more likely to occur, there is an increase of absorption of water molecules on the in-homogeneous vacuum vessel inner surfaces.

A typical residual gas mass spectrum of the RFQ vacuum taken at 10^0 C is shown in figure 4. Even at this low temperature water constitutes about 80%, while hydrogen only about 13% of all gas species. After some 5 months of pumping of the RFQ vessel, one should expect hydrogen to be a dominant gas, especially at such a low temperature.

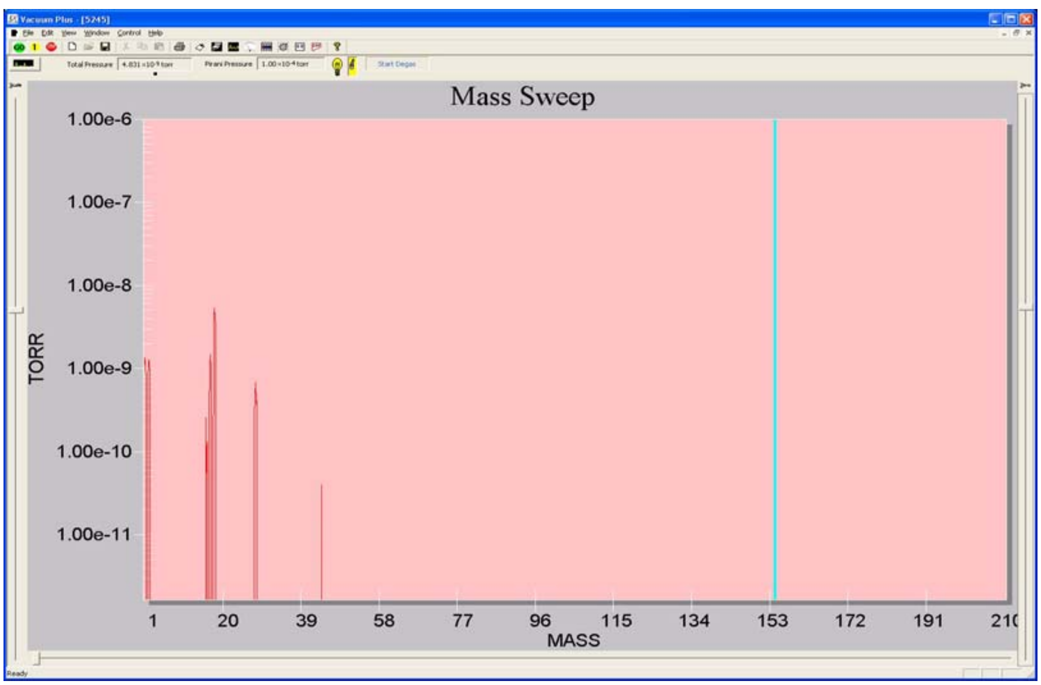

Fig. 4 RFQ residual gas mass spectrum at 10^0C: in addition to H2 and H2O there is ~6% of N2 and ~1% of CO2/C3H8, both could come from LCW water as well

The interior of the RFQ vanes is nearly closed and well protected from the ambient temperature changes due to the separating vacuum space as well as due to the continuing flow of the LCW water of constant temperature through the RFQ vanes.

5. Spill of hydrogen gas from the Ion Source into the RFQ space

In proton source operations hydrogen gas is continually fed into the plasma chamber, and its flow rate is adjusted to keep hydrogen pressure at (50 – 100) mTorr. As only a minute fraction of this gas is actually converted to positive ions a set of three turbo pumps of 2700 L/S total pumping speed is mounted around the accelerating column to remove the bulk of the excess gas. Another turbo pump of 200 L/S pumping speed is mounted at the LEBT section. At 100 mTorr pressure in the plasma chamber the vacuum level in the LEBT section is ~ 4 10^{-6} Torr. In figure 5 we show the vacuum connection between the LEBT exit beam pipe and the RFQ vacuum space. The RFQ entrance orifice

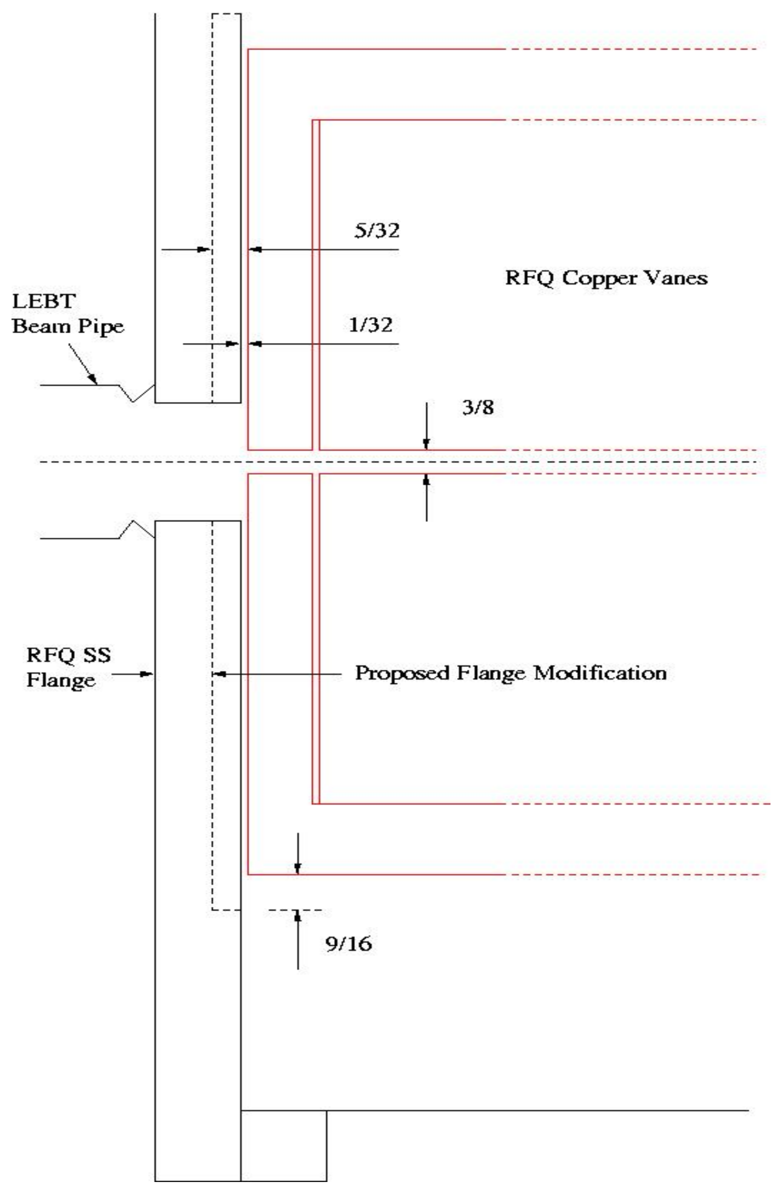

Fig. 5 Present arrangement and proposed modification of the space between the vacuum shell and the vanes flanges (all dimensions in inches)

is 9.5 mm in diameter and 17.46 mm in length giving a conductance for H2 gas at 5.8 L/S. There is, however, a 0.8 mm space between the vacuum and the vanes flanges at a circumference of 125.6 mm giving a surface area of ~ 100 mm^2 for the gas flow there. As the cross-section area of the orifice is ~ 70 mm^2, only 42% of hydrogen from LEBT will pass through the orifice, and so the H2 spill rate into the inner space of the vanes is: 0.42 x 4 10^{-6} Torr x 5.8 L/S = 9.8 10^{-6} Torr-L/S. If this gas spill was uniformly distributed along the entire length of the vanes (as the out-gassing is) it would be pumped out at 1479 L/S (Table 4) leading to a partial pressure of 6.5 10^{-9} Torr. Unfortunately, this H2 gas source is at the entrance to the RFQ, so the conductance is strongly diminishing along the vanes length, e.g. the area of the last slots will see only ~6% of the hydrogen spill in the area of the first slot. Naturally, this leads to a gradient of H2 pressure along the RFQ length with projected pressure in the first $1/15^{th}$ RFQ section to be ~10^{-7} Torr. This LEBT induced partial pressure may be too high for proper RFQ operations when contributions from the system out-gassing (and other sources) are added. A possible solution to this problem is shown in Fig. 5. We propose to make a circular, counter-board cut-out in the central portion of the SS flange. This will allow some 90% of LEBT hydrogen gas spill enter the outside space of the vanes where it will be pumped out at a speed of 1952 L/S. A fraction (~23%) of this gas, however, will be back-filled into the inner vanes space suppressing somewhat the expected gain. In figure 6 a comparison of the LEBT induced H2 pressure expectations with both present and proposed arrangement of the RFQ flange is shown. A possible pressure suppression factor at the RFQ entrance is ~ 3.6, and ~ 2 at the exit.

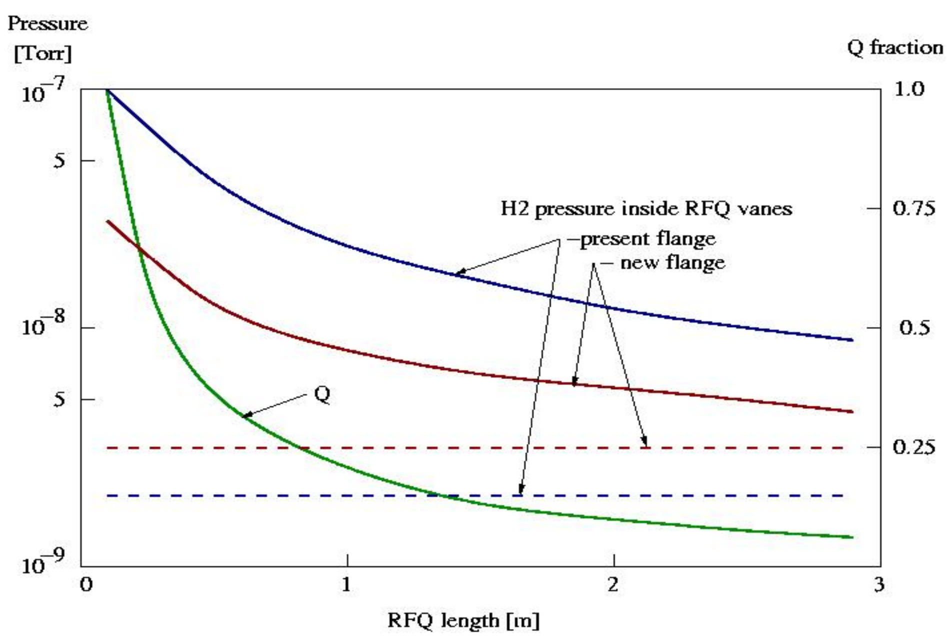

Fig. 6 Projected pressure due to H2 gas spill from LEBT into the inner space of the RFQ. Green line indicates a fraction of hydrogen load, Q, as a function of its path along the RFQ. The solid blue and brown lines indicate pressure projections in the inside space of the vanes for present and proposed RFQ flange arrangements, respectively. The dotted lines represent partial pressure due to H2 back-flow from the outer RFQ vacuum space to the interior of the vanes.

The RFQ vacuum flange is large but it is used only in the 1 bar differential pressure range application, so the counter-board cut-out should not affect its required strength. The strength analysis should be done, however, and if necessary a set of few radial ribs could be welded-in.

Naturally, a better solution to the excess hydrogen flow into the RFQ space would be to install a restrictive orifice near the end of the LEBT beam pipe. In such a case the flow both inside and outside space of the RFQ vanes would be strongly suppressed. This option, however, requires good knowledge of the beam phase space in the last section of the LEBT beam pipe to make sure that the beam intensity will not be reduced in the same time.

6. Potential leak in the RF couplers

There are two RF couplers mounted on the top of the RFQ vacuum shell. Their HV connections use ceramics joints to isolate from the ground potential. The main body of the coupler is sealed to the vacuum shell with a CF flange, but there are also O-rings used to seal the coupler's pressurized at 6 psi protective gas (SF6). If the brazed or welded joint of the coupler ceramics fails than this gas will leak into the RFQ vacuum space. As the pumping speed for the SF6 released into the RFQ vacuum space is 3 times lower than that for the hydrogen even a small leak may cause problems. A frequent RGA runs should be used to detect any presence of the SF6 in the RFQ vacuum space.

7. Summary and recommendations

We presented a model for the RFQ vacuum system which reasonably reproduces measured vacuum levels and their changes with the ambient temperature. The analysis of the Helium Leak Detector data agrees well with predictions based on the known permeation factors for helium, air and water through the Viton seals. With properly sealed RF couplers water constitutes ~ 80% and hydrogen ~ 13% of all gas species detected in the outer space of the vanes. After some 5 months of pumping of the RFQ vessel, one should expect the partial pressure ratio of water to hydrogen to be reversed. Our analysis suggests, however, that the permeation of the LCW water through the Viton O-rings, and not the water out-gassing of the RFQ inner surfaces, most likely constitutes dominant source of this gas specie inside the RFQ vacuum space.

1st recommendation

Replace the Viton seals of the LCW manifolds inside the RFQ space with welded joints. Based on the analysis in Chapter 4, one may expect that in the internal space of the RFQ vanes the ratio of water vapor to other gas species to be even higher than that in the outer vanes space. When the RF power is applied one should then expect rapid release of water vapor. This situation may compromise performance and possibly longevity of the RFQ.

2nd recommendation

Machine a counter-board cut-out in the stainless steel flange which connects the RFQ vacuum shell to the LEBT beam pipe. This will allow redirect most of the Ion Source hydrogen gas flow into the RFQ vanes outer space minimizing in this way the partial pressure of hydrogen in the beam path of the RFQ. In the future this will help as well to suppress the H^- source associated Cesium gas flow into the internal space of the RFQ vanes.

3rd recommendation

Minimize vacuum level swings caused by the ambient temperature changes. In the warm vacuum systems, such as the Ion Source, LEBT and RFQ, swings of the ambient temperature have considerable effect on the vacuum level due to significant changes in the out-gassing rates. In such a situation it is rather difficult to control vacuum system at the desired vacuum level. Therefore, it would be very helpful to install a simple enclosure covering the Ion Source, LEBT and the RFQ area. This enclosure would be outfitted with the air conditioning system comprising of both a heater and a chiller. The air conditioning would also help to stabilize the Ion Source which is operating under the 50 kV potential and being very prone to the destructive discharges in the HV electronics embedded in a humid air.

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