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Vacuum System Model and Measurements at New H⁺ RFQ Ion Beam Injector

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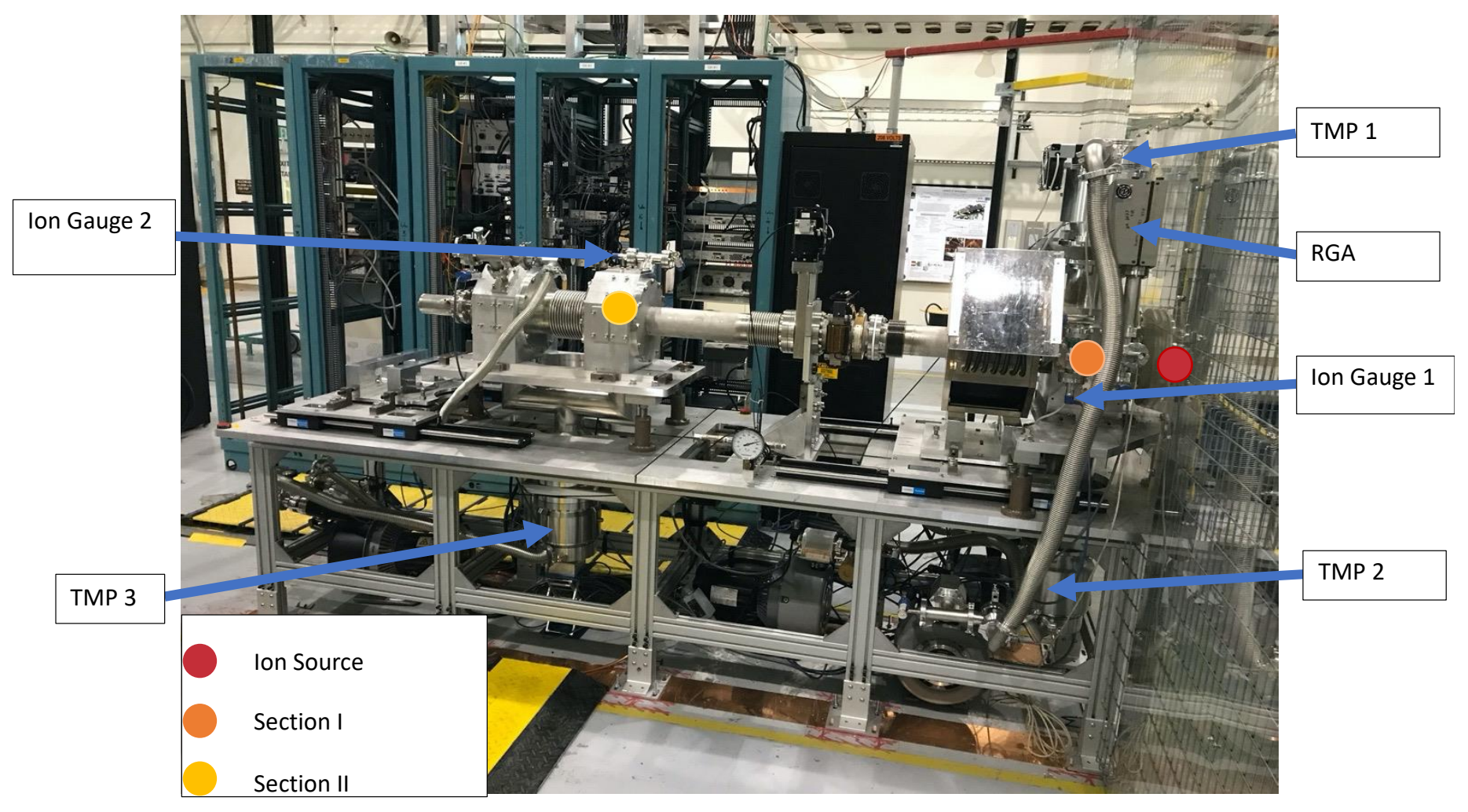
Abstract: A Radio Frequency Quadrupole (RFQ) accelerator is being developed to replace the H⁺ Cockcroft-Walton(CW) injector. The injector upgrade will significantly reduce the long term operational risks and improve existing LANSCE beam production for the Isotope Production Facility and future 800 MeV proton beam user systems [1].In this study, we evaluate the vacuum model of the new RFQ injector system. Vacuum components, hydrogen gas injection system and low energy beam transport line for new H⁺ ion beam injector at 201.25 MHz RFQ accelerator were assembled and tested. We will present first vacuum pressure measurements and compare them with simplified high vacuum system model. We will discuss: a) optimization of the vacuum pressures inside a duoplasmatron ion source versus various hydrogen gas mass flow rates, b) high voltage extraction chamber vacuum conditions for different vacuum pumping speed configurations, c) proton beam current attenuation for high injection of hydrogen gas and d) maximal voltage limits in the three electrode extraction column.

System and Outline

Understanding the vacuum of the low energy beam transport was the goal of this study, to achieve this end, experiments were conducted, correction factors applied, and a model of the vacuum created.



Low energy beam transport with labels of key elements

Low energy beam transport system and the focus of this study.

RFQ (Radio Frequency Quadrupole) this is a component that will be incorporated later.

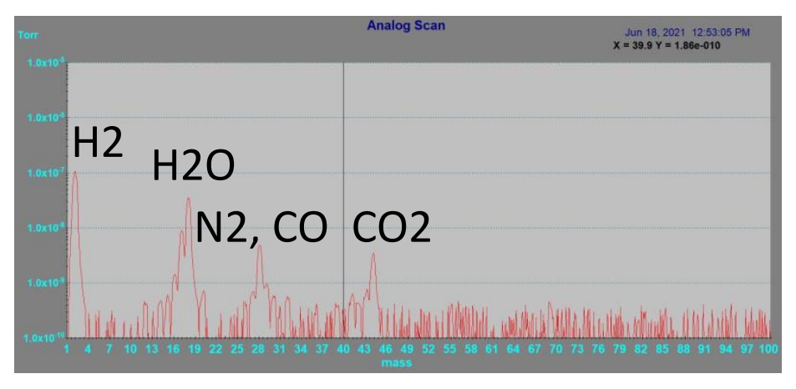
Low energy beam transport and RFQ

Experiment Overview

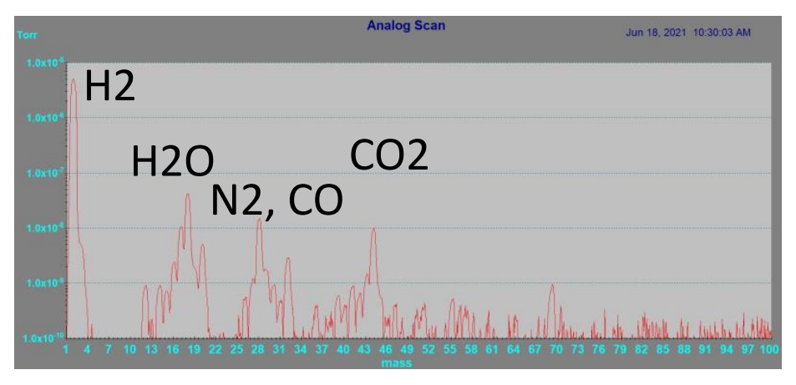
Experiments were conducted to determine the efficacy of the vacuum system. In total, there were two experiments run, and they differed only by the type of gas injected. The first experiment used H_2 (the gas of interest), while the second used N_2. Each experiment consisted of two trials, one trial with three turbo molecular pumps (TMP) active and one with two TMP active. The experiments consisted of injecting the gas of interest in increments until a threshold was reached. Afterward, the gas injection was reduced until zero. The partial pressure of the components as well as the total pressure in three sections was determined.

Mass Spectra

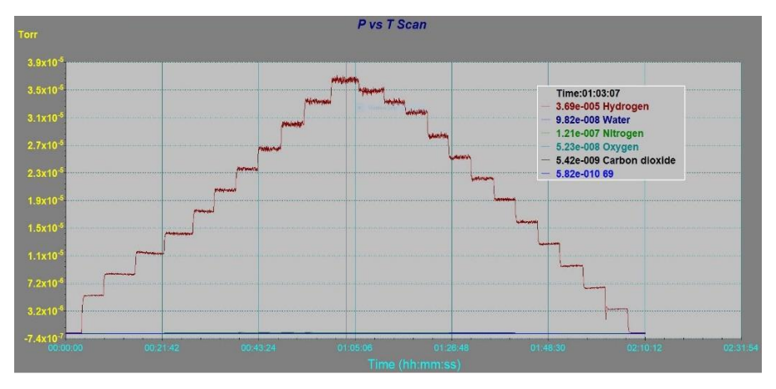
The abundances of different species in the gas was important in understanding the efficacy of the vacuum system. This spectra showed that the gas was 98.8-99% hydrogen by partial pressure. H2, H20, O2, N2, CO2, amu 69, and for the nitrogen run N were species of interest.



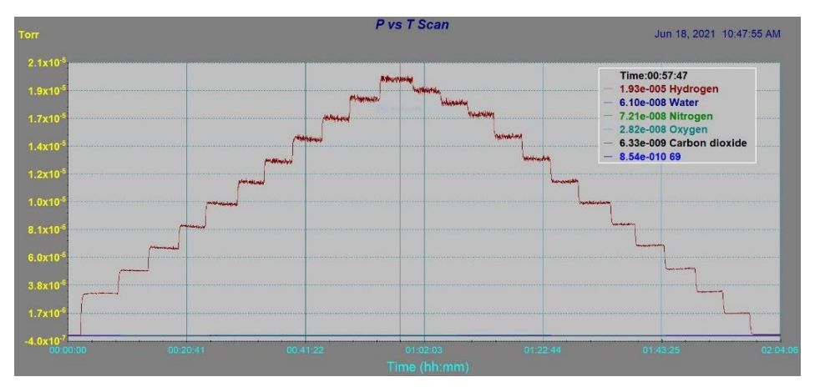
Prior to H2 Injection



After H2 Injection

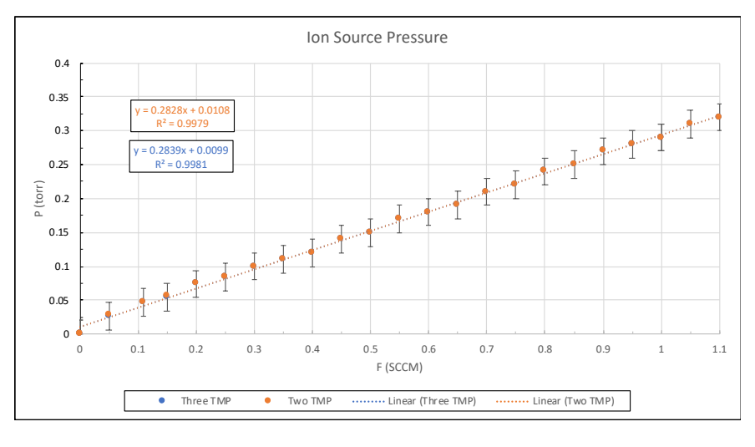


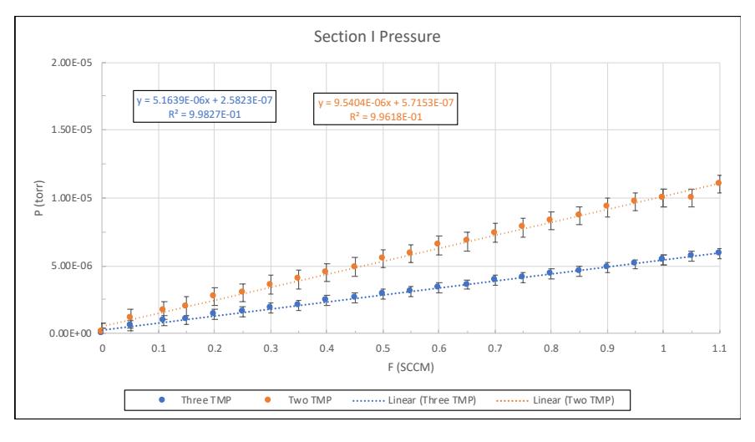
Operational spectra with three pumps

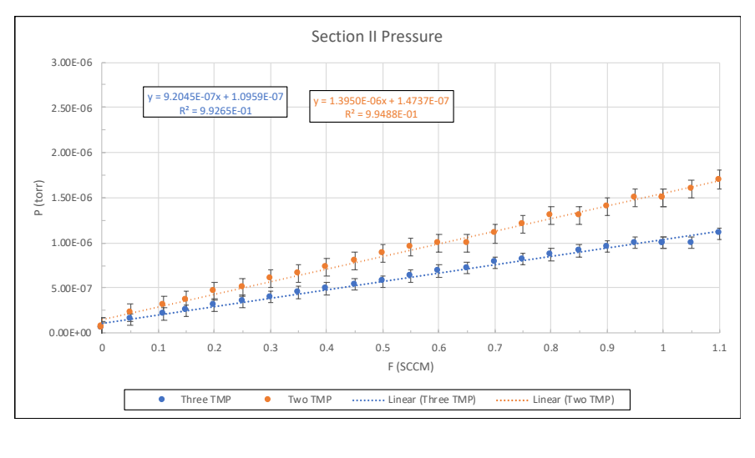


Operational spectra with two pumps

Raw Pressure





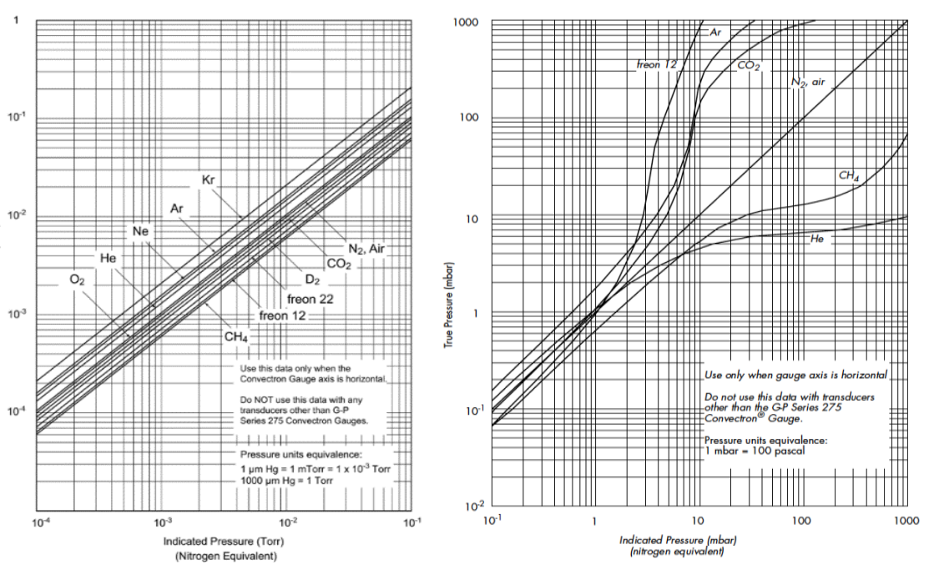


The pressure data was collected in three locations by a Convectron gauge (Ion source) and two ion gauges (section I and II). For three and two pumps active.

Correction Factors

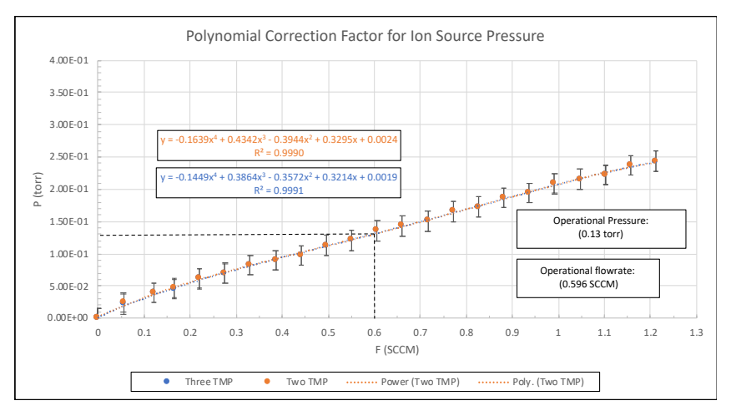
Correction factors are necessary for the flow meter, Convectron gauge, and ion gauges because the dominant gas is hydrogen and these devices are calibrated for nitrogen by default.

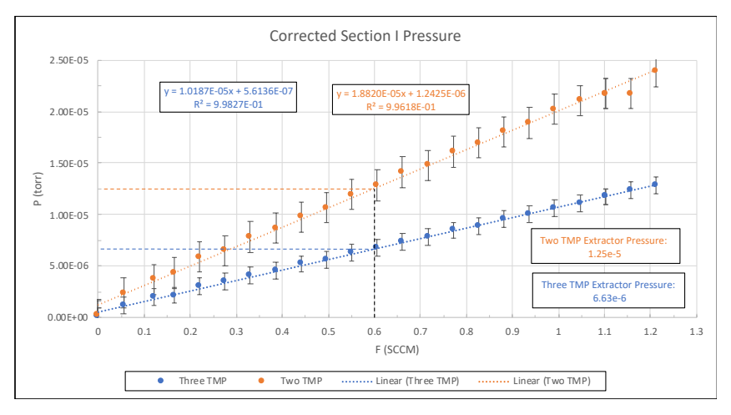
Correction Factors		
Flow:	**Convectron Gauge:**	**Ion gauge:**
F*1.102	0.1584*(P)^3 - 0.3264*(p)^2 + 0.8487*P + 0.0001	P/0.46

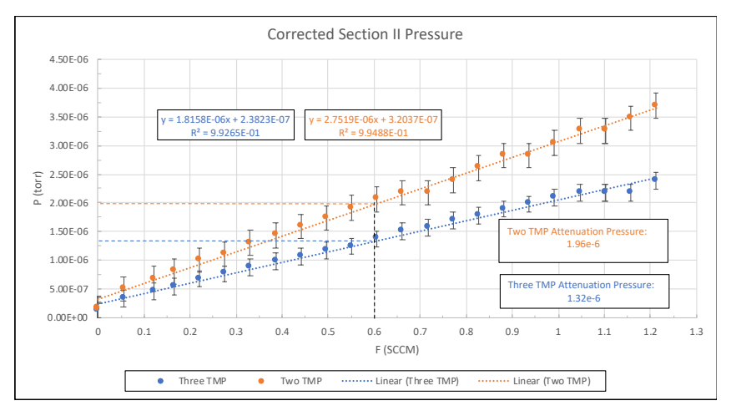


To the left are some graphs that were used to determine the polynomial correction factor for the Convectron gauge.

Corrected Pressure and Operational Parameters







The operational flow shown by the dial is 0.54 SCCM. Operational pressures are shown for other sections. The operational flow is the same for two or three TMP active.

Vacuum Model

The vacuum system was represented as a system of three parallel pumps. When the experiment was run using two pumps, pump two was removed and the calculations repeated with minor adjustments. To the right are the equations that were used.

$$P = Q/S$$

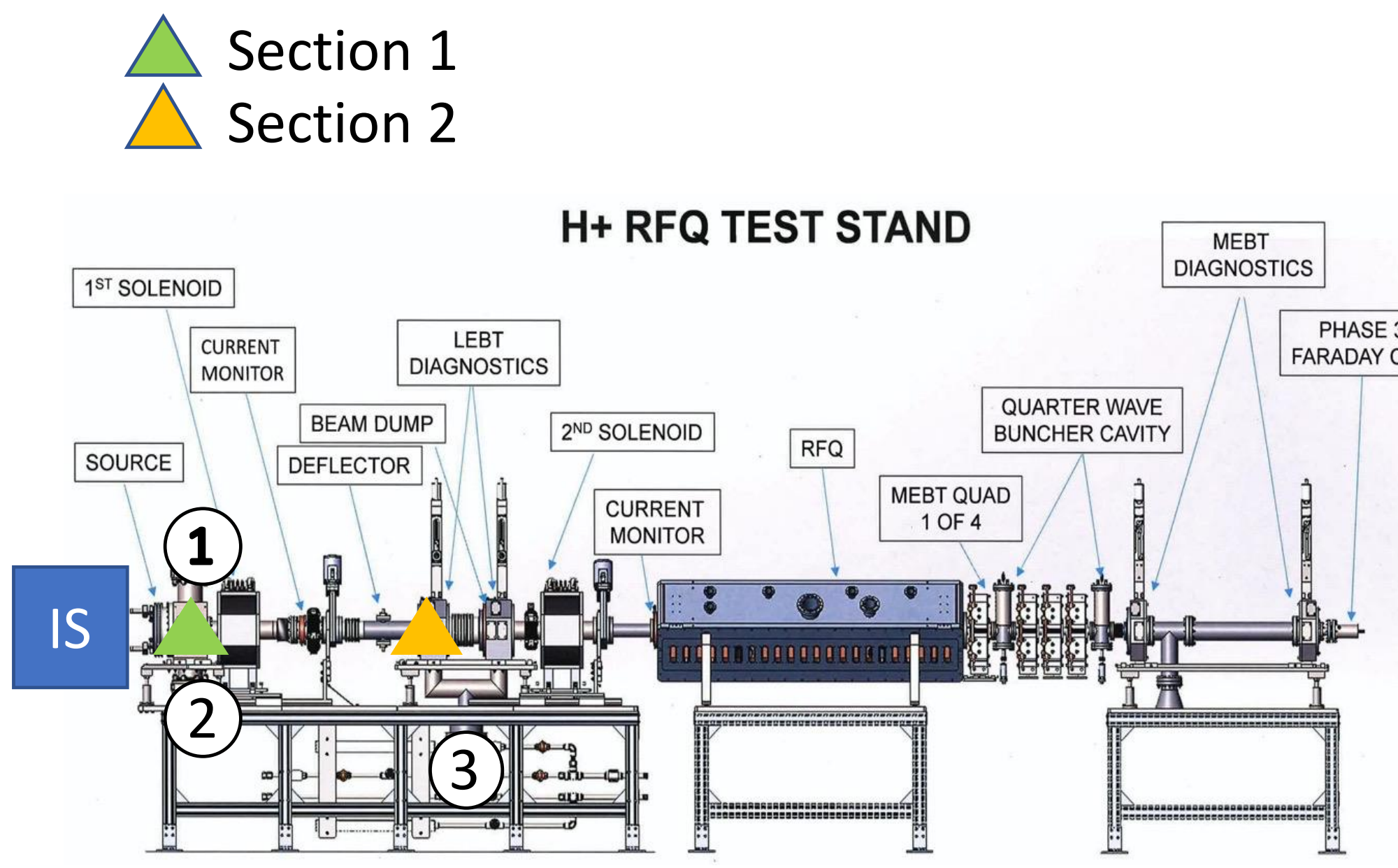
$$\frac{1}{S_{eff}} = \frac{1}{C_T} + \frac{1}{S}$$

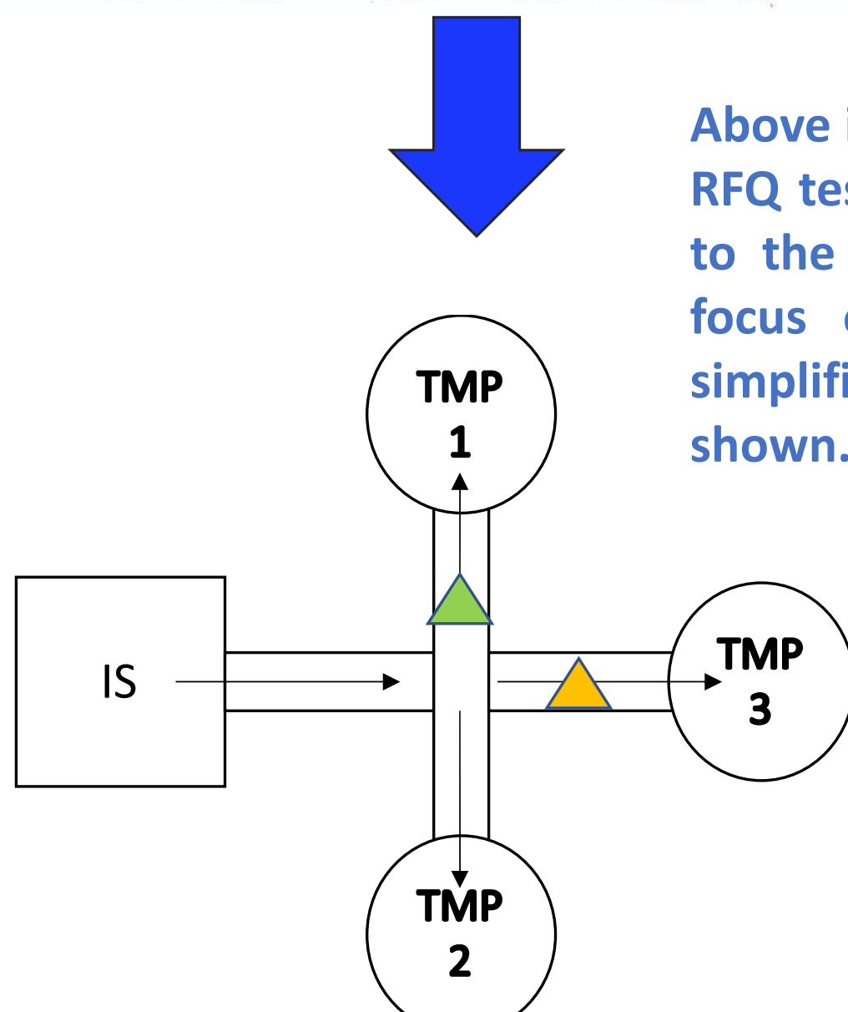
$$\frac{1}{C_T} = \sum_{i=1}^{i} \frac{1}{C_i} \text{ series}$$

$$C_T = \sum_{i=1}^{i} C_i \text{ Parrallel}$$

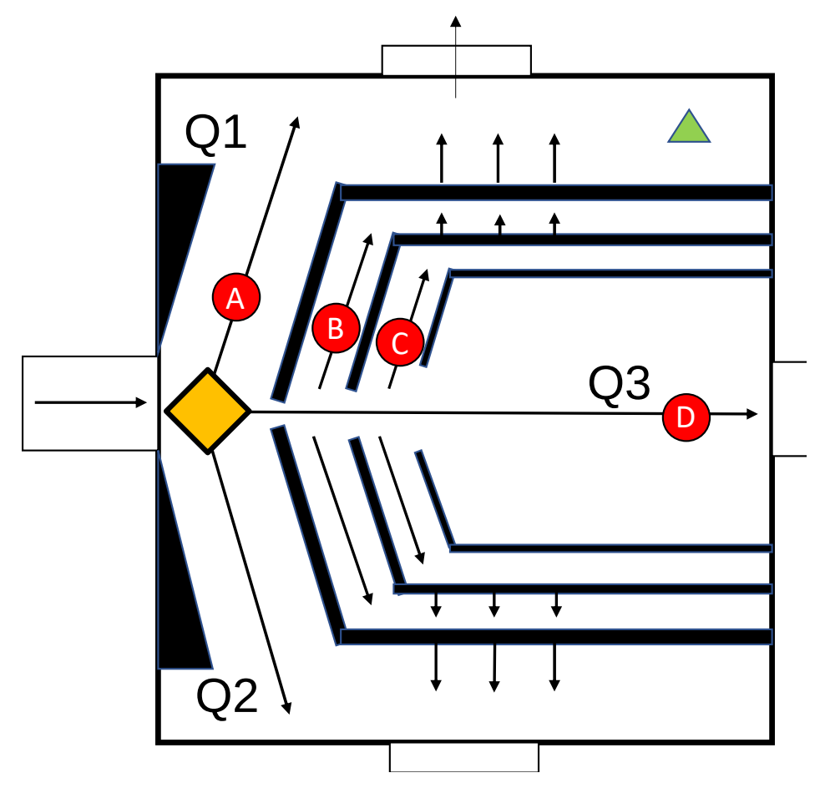
$$Q_n = Q_0 \times \frac{S_{eff,n}}{S_{Net}} \text{ Parrallel}$$

$$S_{Net} = \sum_{n=1}^{n} S_{eff,n} \text{ Parrallel}$$





Above is the diagram of the completed RFQ test stand. Currently, the area up to the LEBT is assembled and is the focus of this study. To the left, a simplified diagram of the system is shown.



Above is a diagram of the extraction chamber. A,B,C, and D are regions of interest for future calculations.

Calculation at yellow rhombus for three TMP:

$S_{eff,1}$= 209.507789 L/s

$S_{eff,2}$= 28.4091679 L/s

$S_{eff,3}$= 209.507789 L/s

Q1=46.825%

Q2=46.825%

Q3=6.35%

Two TMP:

$S_{eff,1}$= 209.507789 L/s

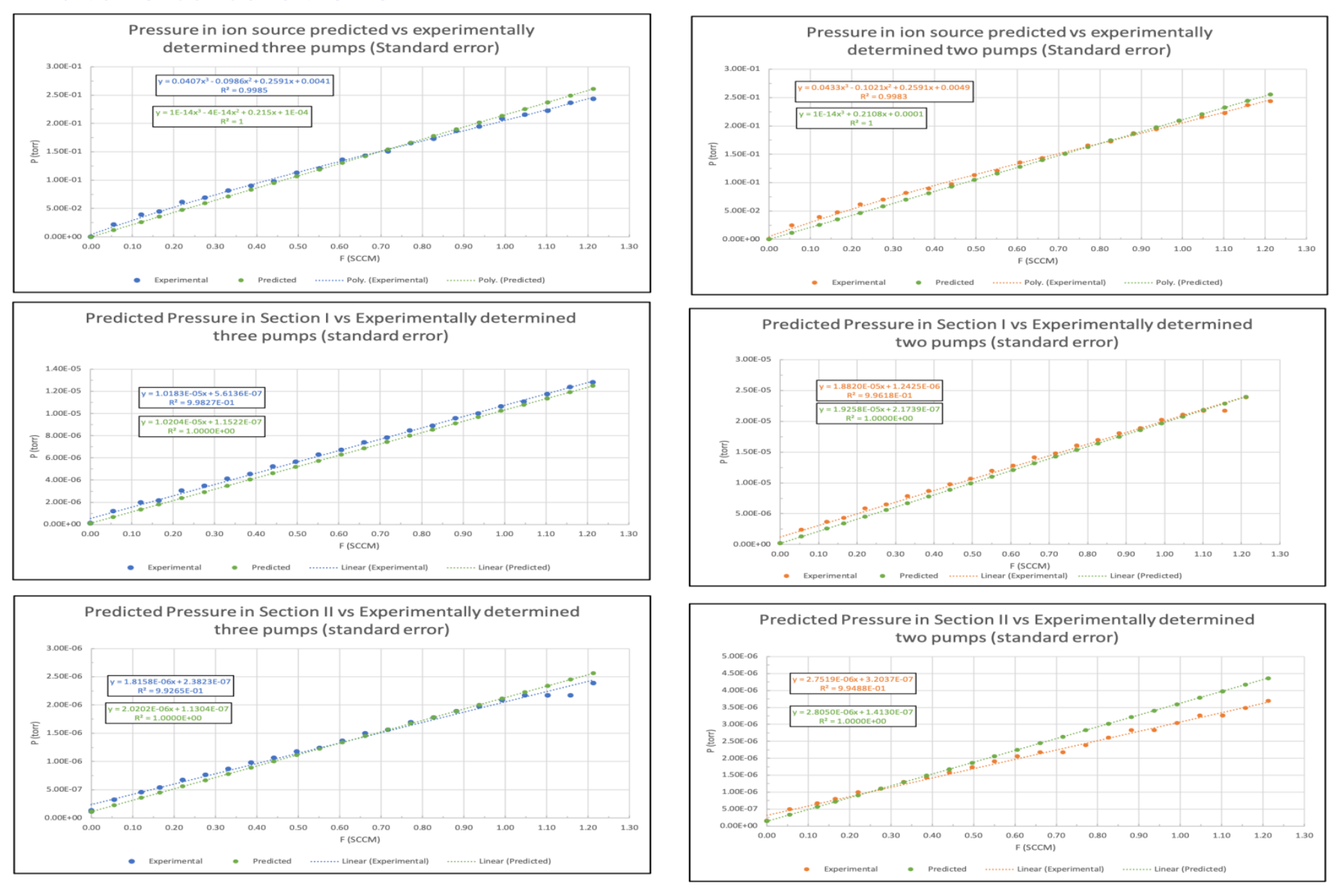
$S_{eff,2}$= 28.4091679 L/s

Q1=88%

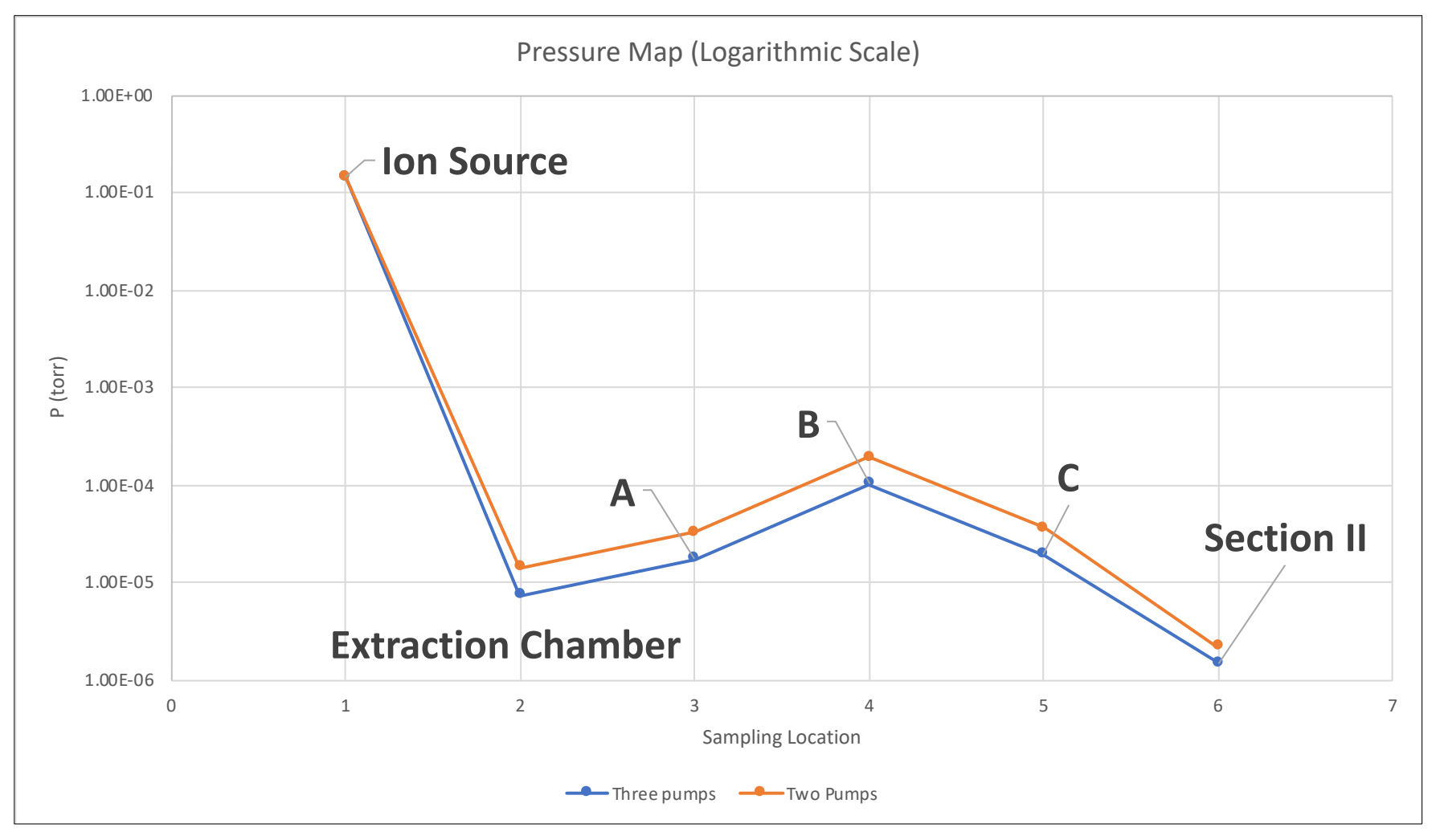
Q3=12%

2TMP Q1/ 3TMP Q1= 1.879

2TMP Q3/3TMP Q3=1.889

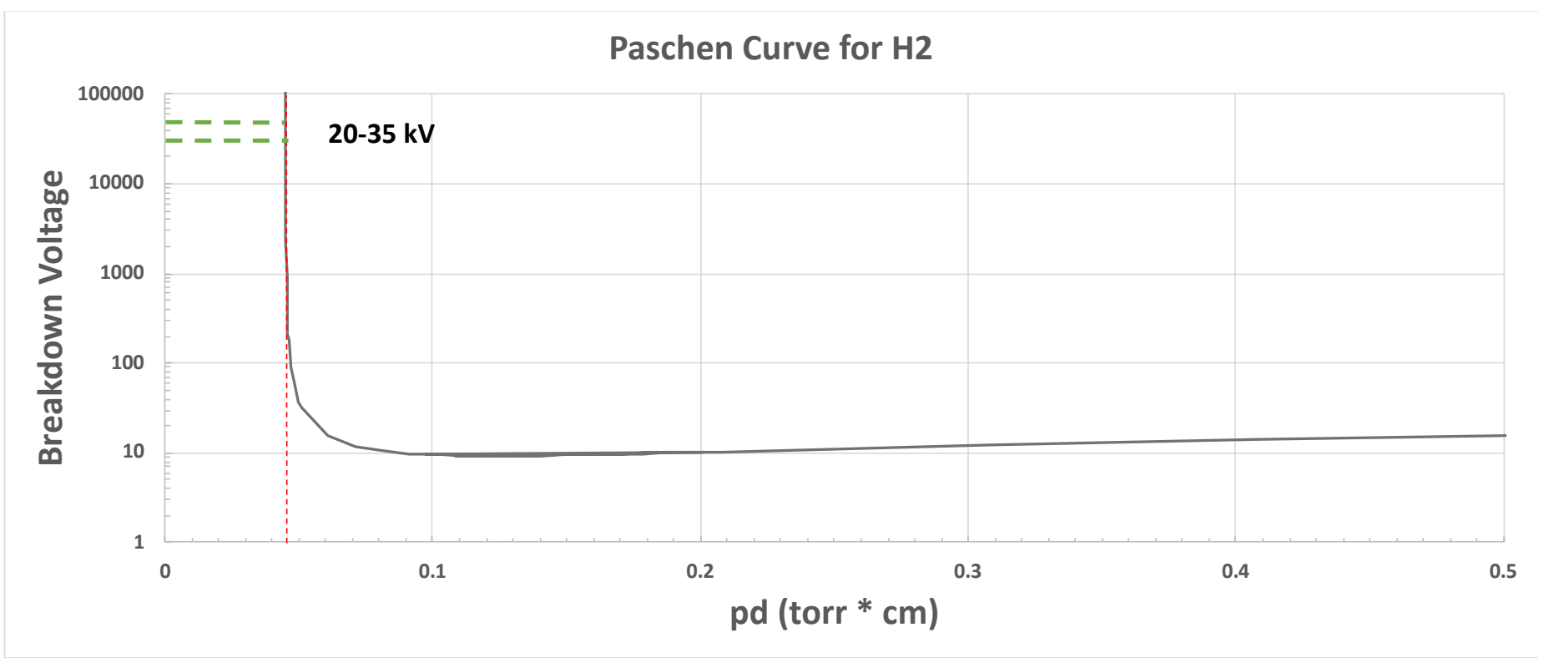


Above the model is compared to the experimentally determined pressures. Where green indicates the model. Below is the pressure distribution predicted by the model in several key locations.



Breakdown Voltage

The extraction column operates at higher pressures than the surroundings and at extremely high voltages. Thus it is necessary to determine if electrical breakdown is possible. In this case, a Paschen curve is constructed using the parameters of the system and used to determine if breakdown is possible. Below is that curve.



Minimum for breakdown in specified region: 0.045191154 torr cm

A. Highest Pd was 7.42e-5 torr cm
B. Highest Pd was 5.43e-4 torr cm
C. Highest Pd was 1.06e-4 torr cm

Therefore, according the curve, breakdown is impossible in critical regions.

The only exception would occur if a new source of ions / electrons is present. Such as thermionic emission.

Below the calculation of the curve is shown.

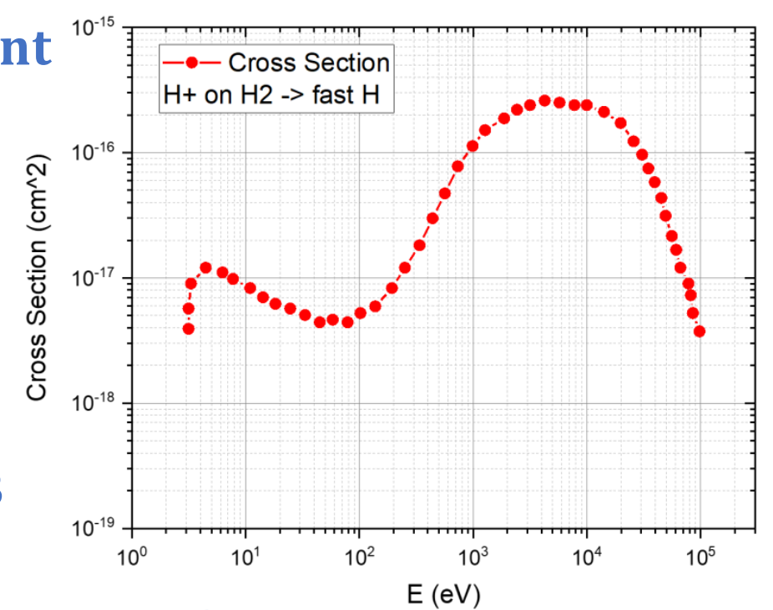
1. $A = \frac{\sigma}{K_B \times T} = 4.938$ Constant
2. $B = \frac{\epsilon_i \times \sigma}{K_B \times T} = 76.250$ Constant
3. γ_{se} = 4, secondary electron coefficient [Proton on Stainless steel]
4. ϵ_i=15.44 Ionization energy
5. $\sigma=1.527 \cdot 10^{-16}\ cm^2$ cross section
6. $\text{lower bound} = \frac{\ln(1+\frac{1}{\gamma_{se}})}{A}$ =0.045185 torr cm
7. Note that conversions are necessary for A and B

$$V_B = \frac{Bpd}{\ln(Apd) - \ln\left[\ln\left(1 + \frac{1}{\gamma_{se}}\right)\right]}$$

Beam Attenuation

Beam attenuation is the loss of beam due to interactions with ambient particles in the vacuum. Therefore, the worse the vacuum the more beam loss. The dominant process for the beam attenuation should be $H^+ on\ H_2 \rightarrow fast\ H$.

1. $\Delta I = -I\eta\sigma\Delta x$, change in current
2. $\frac{\Delta I}{I} = \eta\sigma\Delta x \cdot 100\%$, percent lost current
3. I=20 mA, beam current
4. $\eta=\frac{P}{RT} \cdot 6.022 \cdot 10^{23}$, density
5. $\sigma=1.527 \cdot 10^{-16}\ cm^2$, cross section for center of mass 22.333 keV



$H^+ on\ H_2 \rightarrow fast\ H$ cross section graph [5]

Attenuation Calculation at 0.596 SCCM							
Region	**X (cm)**	**Pressure (torr)**		**Denssity (cm^-3)**		**Attenuation**	
		Three TMP	Two TMP	Three TMP	Two TMP	Three TMP	Two TMP
A	1.25	1.55E-05	2.91E-05	5.01E+11	9.42E+11	0.010%	0.018%
B	1.53	9.30E-05	1.75E-04	3.01E+12	5.65E+12	0.070%	0.132%
C	1.61	1.73E-05	3.25E-05	5.59E+11	1.05E+12	0.014%	0.026%
D	194.11	1.50E-06	2.17E-06	4.85E+10	7.03E+10	0.144%	0.208%
						0.24%	0.38%

Beam loss is below 0.5% for two or three pumps, indicates that there is no risk of losing the beam and that the vacuum is favorable.

Conclusions and Discussion

Experiments were conducted, the vacuum was determined to be sound, a model was created and employed to determine the pressures in areas of interest, breakdown voltage was investigated, and finally the beam attenuation was estimated. In the future, beam neutralization and thermionic emission both need to be investigated to improve the understanding of the vacuum.

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