Fermilab

Particle Physics Division
Mechanical Department Engineering Note

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Project: PRECAM

Title: PRECAM – Vacuum Analysis

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Abstract Summary:
Outgassing rates and required vacuum pumping speeds are calculated for the PRECAM vacuum vessel.

Applicable Codes:

The PRECAM Vacuum Vessel is less than 1 cubic foot volume, so it does not meet the requirements as a FESHM vacuum vessel. No Engineering note for the vessel is required.

Introduction

The PRECAM vessel is used to test up to 6 CCDs at one time. A desired vacuum pressure of 1e-6 Torr is required in the vessel to prevent water vapor from condensing onto the CCDs during operation. The CCD operating temperature is -100C. To achieve the required vacuum, a turbo pump and dry rougher pump are used to initial remove most of the gas. Once the ultimate pressure of the turbo pump has been achieved, the turbo pump is valved out and cryo pumping and charcoal getters take over to maintain the desired pressure. The turbo pump is isolated from the system using an isolation valve. The turbo pump is isolated from the system since there is not enough space on the telescope to carry the turbo pumps backing pump.

Gas loads, required pumping speeds, and required getter volume are calculated for the PRECAM Vessel.

Vessel Description

The PRECAM vessel is approximately 8 inch diameter, 10 inch long vacuum vessel. The vessel is used with up to 6 CCDs at one time. Kapton cables approximately 2 cm wide by 40 cm long are used to readout the detectors. One G-10 board 10 cm tall by 20 cm long is used inside the vacuum as an electronic signal feed thru board. The vessel has copper walls and back cover. The front window is sapphire and is 100 mm in diameter. The window, the window aluminum mounting flange, Cryocooler, vacuum interface board flanges, vacuum gage, and vacuum pump all use o-ring seals.

PRECAM Vessel Outgassing Rates

Out-Gassing Materials:

Material	Number	Surface area Each	Total surface area	150 hr Outgassing rate	Expected gas load
		cm2	cm2	Torr.L/(s.cm^2)	Torr.L/s
Kapton cables	6	212	636	7.5e-8	9.54e-5
G-10 Feed thru board	1	200	200	1.05E-09	2.10e-7
Cu vessel wall	1	2682	2682	4e-11	1.07e-7
Alum. Cover	1	243	243	1.00E-10	2.43e-8
Alum. Focl Plate	1	270	270	1.00E-10	2.7e-8
Silicon Surface	6	18	108	4.00E-09	4.32e-7
Glass window	1	78	78	4.00E-09	3.14e-7
Total					9.65e-5

Outgassing rates from BTEV 150 hr test.

Permeation thru O-rings:

Material	Number	Linear Inch of seal	Total linear inches	Air Permeation rate	Expected gas load
		in	in	Torr.L/(s.inch)	Torr.L/s
Viton End cover flanges	2	25	50	2.5e-8	1.26e-6
Viton VIB flange	1	9.4	9.4	2.5e-8	2.36e-7
Viton window	1	12	12	2.5e-8	3.14e-7
Viton KF-50	1	8	8	2.5e-8	1.96E-07
Viton KF-25	1	4.5	4.5	2.5e-8	1.10E-07
Total					2.11E-06

Permeation reference: Vacuumlab.com

TOTAL GAS LOAD = 9.86e-5 Torr.L/sec

Calculate the Required Turbo Pumping Speed:

The turbo pump speed is calculated for the initial warm pump down. A minimum of 2e-4 torr is needed before energizing the PolyCold cryocooler to ensure no contaminates are condensed on the CCDs.

Required System Pumping Speed:

Required pumping speed assumes no pumping restriction to the vessel, or the pump is mounted directly to the vessel. If the Turbo pump is mounted to a KF50 flange that is 5 inches long, the conductance of the tube restricts the overall pumping speed. A 5 inch length is chosen as a conservative length for the isolation valve and related mounting flanges for the turbo pump.

Conductance of a short 5 inch long, 1.75 inch inner diameter (KF-50) tube on the turbo pump:

$$= \frac{\text{sqrt (Pi * 1 * 8.314 * Gas Temp (K))}}{\text{Sqrt (18 * 0.14 Kg/mole air)}} * \frac{(\text{diam})^2}{\text{Length / diam} + 4/3 * 1\text{-diam}^2/(\text{diam}*1.2)^2}$$

= 0.0022 m^3 / sec = 3.4 L/sec conductance

With a 30 L/sec turbo pump the overall pumping speed is

= 1 / (1/ 30 L/sec + 1/ 3.4 L/sec) = 3.0 L/sec

A Turbo pumping speed of 30 L/sec attached to an isolation valve and short nipple will achieve a Vessel Vacuum Pressure of:

Ultimate pressure = Gas load / Pumping speed
= 9.86e-5 Torr.L/sec / 3.0 L/sec
=3e-5 Torr

An ultimate pressure of 3e-5 Torr is sufficient to cool down and start cryopumping.

Calculate Cryopumping Speed:

Once the vessel has been pumped down to below 2e-4 torr with the turbo pump, the vessel is cooled down using the cryocooler. Cryopumping on the cold surfaces begins. Cryopumping will remove the water vapor and other gases heavier gasses that freeze out on the cold surfaces.

Calculating the required Cryopumping Surface area:

The cold surfaces are internal to the vessel volume so there is no additional pumping restriction due to lengths of piping.

Cryo pumping Speed:

= 140,000 L/sec. per square Meter of cold surface area for cryo pumping surfaces at 77K
There is about a 30% penalty for cryopumping at 143K (Ref Barron, Cryogenic Systems)
=100,000 L/sec. per square Meter of cold surface area

Required Cold Surface area:

1e-6 torr = desired ultimate water vapor pressure
Required pumping speed = gas load/ ultimate pressure
Required pumping speed = 9.86e-5 Torr.L/sec / 1e-6 torr
Required pumping speed = 98 L/sec

Required cold surface area =
= 98 L/sec / 100,000 L/sec .m^2
= 0.000098 square meters
= 9.8 square cm. of 143K temperature surface

The cryocooler head surface area:

$=\pi*(3.3cm/2)^2 + \pi*3.3cm*0.5cm = 13.7$ square cm

There is enough cold surface area to maintain the water vapor pressure below 1e-6 torr.

Calculating the volume of Getter Required:

Noncondensing gases can be captured using a getter material instead of an ion pump. Charcoal based getters are passive in nature and can be located inside the vessel so that pumping conductance issues can be avoided. When the vessel warms up, it is important to pump with a turbo pump to ensure the outgassing from the charcoal is removed from the vessel.

Gas load of non cryopumped gases

= 9.86e-5 Torr.L/sec * 1%
= 9.86e-7 Torr.L/sec

Required Charcoal Pumping Speed:

= Gas Load / Desired Ultimate vessel pressure
=9.86e-7 Torr.L/sec / 1e-6 Torr
= 1 L/sec

Pumping Speed of Charcoal per unit Volume:

This data is really for molecular sieve from varian – not activated charcoal.
Typical values (Reference Varian –Performance Criteria for Sorption Pumps) are 1e-3 Torr.Liters per gram of carbon at pressures near 1e-6 torr.
The gas load in one month is 2.5e6 sec * 9.83 e-7 Torr.L/sec = 2.6 Torr.liters
The gas load in one day is 86e3 sec * 9.83 e-7 Torr.L/sec=0.084 Torr.liters
The gas load in one hour is 3600 sec* 9.83 e-7 Torr.L/sec=3e-3 Torr.liters

So 1 gram would last 1 hour at -195C

Measurements:
Activated charcoal (15 grams) purchased from Spectrum Inc. is used as the getter material. The charcoal was covered using a 0.1 micron Teflon membrane to prevent dust from contaminating the CCDs. Previous testing showed that 15 grams is enough volume to maintain the vacuum for extended periods.

Current operations have shown that the vacuum achieved is e-5 torr when warm, and e-6 torr when cold. At this time, operations have maintained good vacuum for at least a week.

Ref: Tests of the Activated-Charcoal Getter, Spartan IR Camera for the SOAR Telescope
B. Lein and E. Loh

Comments about the proposed pumps and pumping speeds:

The proposed pump sizes for the vessel are a Drytel 1025 Turbo pumping station, 15 grams of activate charcoal, and internal cryopumping surface greater than 9.8 cm^2. Space requirements on the camera vessel do not permit huge pumps or huge pump out ports to be mounted to the vessel. To achieve the required vacuum in the vessel, any preconditioning of the vessel would be helpful. For example storing the cables in a dry environment, or pre-baking the vessel at a temperature slightly above room temperature could greatly improve the ultimate pressure and also the pump down times.

Pumping speeds:
Turbo Pump, 30 L/sec or more
Minimum 143K Cryo pump surface area, 9.8 cm^2

Achievable ultimate pressures for the Vessel when the pumps are mounted with a KF50 flange:
Turbo Pump can achieve 3e-5 torr
Minimum 143K Cryo pump surface area to achieve 1e-6 torr = 9.8 cm^2

Methods to further improve the vacuum quality:

Although the gas load is dominated by the kapton cables, all possible flanges should be conflat to reduce permeation rates. If possible, store the kapton cables in dry nitrogen to prevent water abosption before mounting inside the dewar.

Use as the largest reasonable cold surface area.

Note: Electrical isolation is provided between the vessel and vacuum pumps and instrumentation. This is performed using Boc Edwards or equivalent plastic o-ring retainers and clamps on KF flanges.