ISBN: 978-3-95450-223-3 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2019-MOPLO19

TEST RESULTS OF PIP2IT MEBT VACUUM PROTECTION SYSTEM

A.Z. Chen[†], R. Andrews, C.M. Baffes, D.D. Lambert, L.R. Prost, A.V. Shemyakin, T.J. Zuchnik,
Fermilab, Batavia, IL USA

Abstract

The central part of PIP-II program of upgrades proposed for Fermilab's injection complex is an 800 MeV, 2 mA, CW-compatible H$^-$ SRF Linear Accelerator. Acceleration in the superconducting cavities begins with an injected 2.1 MeV beam produced by a Warm Front End (WFE). The first cryomodule, a Half Wave Resonator (HWR), abuts this WFE. To minimize the amount of gas that may enter the SRF linac in a case of a vacuum failure occurring in the warm front end, a vacuum protection system is envisioned to be used in the PIP-II MEBT (which is a component of the WFE). It features a fast closing valve (FV) with two sensors and a differential pumping insert (DPI). A prototype of this system was installed in the PIP-II Injector Test (PIP2IT) accelerator and successfully tested in several modes modelling a variety of vacuum failures. The report presents the design of the vacuum protection system and results of its tests.

INTRODUCTION

The Injector Test of PIP2, (referred to as PIP2IT [1, 2]) is composed of an H- ion source, low energy beam transfer section, RFQ, medium energy beam transfer section (MEBT), a cryomodule of half wavelength resonator (HWR), a cryomodule of single spoke cavity resonator (SSR1), and high energy beam transfer section (HEBT) with beam dump. The HWR and SSR1 are cryomodules with superconducting RF cavities operating under 2K.

The performance quality of superconducting cavity critically relies upon the quality of a low particulate and ultra-high vacuum environment [3]. Since the beam line vacuum space is in common for all beam devices, a vacuum failure in a warm section poses a significant risk to the SRF cavities. In case of a serious vacuum failure, the large gas flux into a cryomodule not only destroys the superconducting status, but also moves any loose particles from an adjacent area into the superconducting cavity and ruins its performance. It is necessary to equip the warm section adjacent to cryomodules, such as MEBT, HEBT with measures to preclude the propagation of gas into the vacuum of the superconducting cavities at speeds of hundreds of meters per second.

THE DESIGN OF THE VACUUM PROTECTION SYSTEM

A typical way to achieve this isolation is to utilize a fast closing valve, such as the one by VAT. A VAT's 75 series fast closing valve is specified to close with 10 ms. At PIP2IT, in order to prevent large amount of gas (and particles will move with) flux into HWR (the 1st cryomodule of PIP2) during any possible vacuum failure in MEBT. The fast closing valve is placed about 1 m upstream of HWR. The 1st sensor will be placed at the beam absorber in Fig. 1 and the 2nd sensor at the bunch cavity near HWR. The absorber was chosen as the location of the first sensor because all chopped beam (rated for 20KW CW [4]) will be placed there and a large amount of gas is produced as well as the creation of particulate. The bunch cavity was chosen as the location for 2nd sensor because of some risk of leaking cooling water into vacuum.

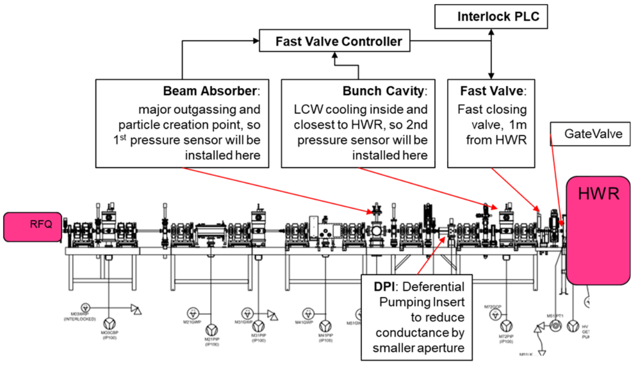


Figure 1: The configuration of vacuum protection system at MEBT.

A differential pumping insert (DPI) with a small aperture of 10mm in dia., 200mm long is placed downstream of the absorber to significantly reduce the gas flux from any possible vacuum failure in the upstream part of the Warm Front End. The DPI helps to achieve UHV in the region next to HWR.

The pressure rise detected from either sensor will trigger the fast closing valve and close it within 10ms. However, gas propagation in vacuum is very fast, closing the valve within 10ms will not be fast enough to completely prevent gas flux passing the valve before the valve is closed; especially if a failure occurs near the valve. The test for measuring this amount of gas passed by the valve before full closure was carried out to qualify the design. That is: can this design provide meaningful protection of the HWR? It should be noted that the closing time of the valve was not measured.

FIRST TEST SETUP AND RESULTS

Along with the progress of PIP2IT, the 1st measurement was carried out in less ideal configuration in Fig. 2. The 1st sensor was installed on the beam scraper near the prototype absorber, and the 2nd was on the beam scraper near a bunch cavity. The DPI was placed in between. In this setup, the vacuum space at upstream of the fast valve is 36.5 litres, and 95.1 liters at the downstream. The large volume at the

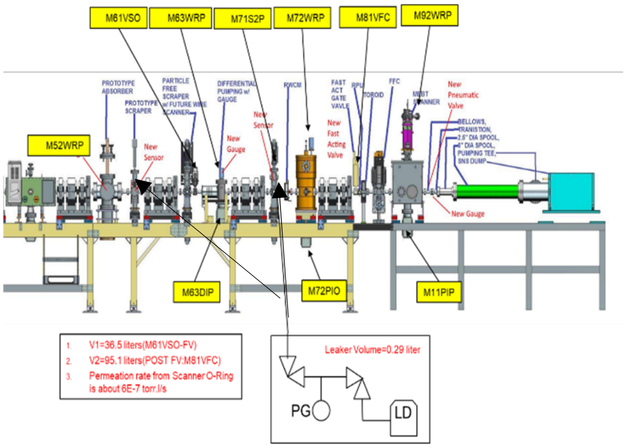
---

* This manuscript has been authored by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the U.S. Department of Energy, Office of Science, Office of High Energy Physics.

†alexchen@fnal.gov

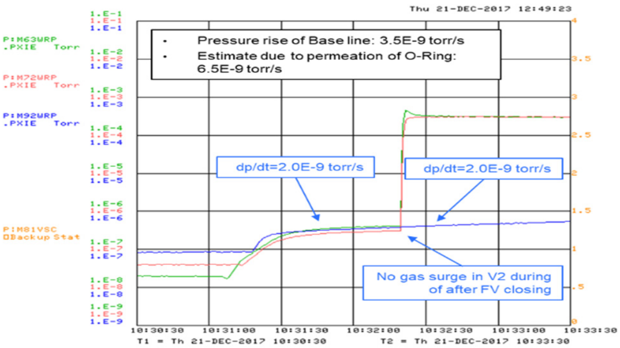
ISBN: 978-3-95450-223-3 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2019-MOPLO19

downstream, where the gas amount measured, reduced the sensitivity of the test. Furthermore, the permeation from a large O-Ring in the emittance scanner set the limit of gas flux rate to 6E-7 torr·l/s.



1. V1=36.5 liters(M61VSO-FV)
2. V2=95.1 liters(POST FV:M81VFC)
3. Permeation rate from Scanner O-Ring is about 6E-7 torr.l/s

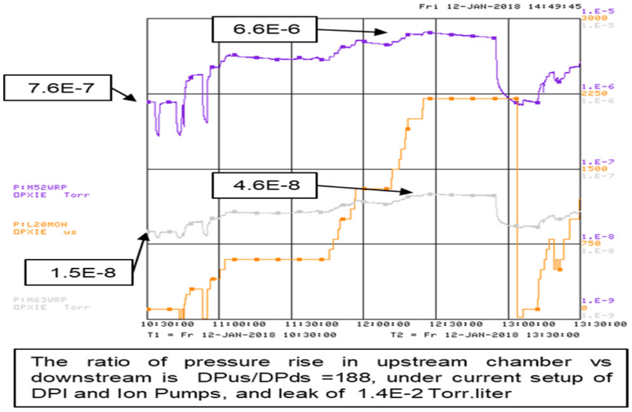
Figure 2: Setup of 1st test.



- Pressure rise of Base line: 3.5E-9 torr/s
- Estimate due to permeation of O-Ring: 6.5E-9 torr/s

Figure 3: Sample result of 1st Test with the pressure at leak reservoir 4.7E-2 torr.

The leak was simulated by a fixed volume gas reservoir (0.29 litter in 1st test) and a designated pressure. The leak was introduced by opening the manual valve into vacuum space in upstream side of the fast valve. The leak was placed at one of the two scrapers where the sensor is located, but from opposite ports.



The ratio of pressure rise in upstream chamber vs downstream is DPus/DPds =188, under current setup of DPI and Ion Pumps, and leak of 1.4E-2 Torr.liter

Figure 4: The Effect of DPI.

From the 1st test, we learned the gas amount past the fast closing valve is smaller than expected, below the permeation rate from O-Ring. In Fig. 3, blue line was pressure for downstream of FV, the other two were in upstream.

We also learned from the 1st test that the DPI efficiently restrict the gas flux. In Fig. 4, the grey line is pressure (in torr) in downstream of DPI, the purple line in upstream.

In order to improve the sensitivity of measurement, it is necessary to reduce the vacuum space at the downstream of the fast valve, even more important is to remove the device with O-Ring out of the vacuum space downstream of FV for test setup.

SECOND TEST AND RESULTS

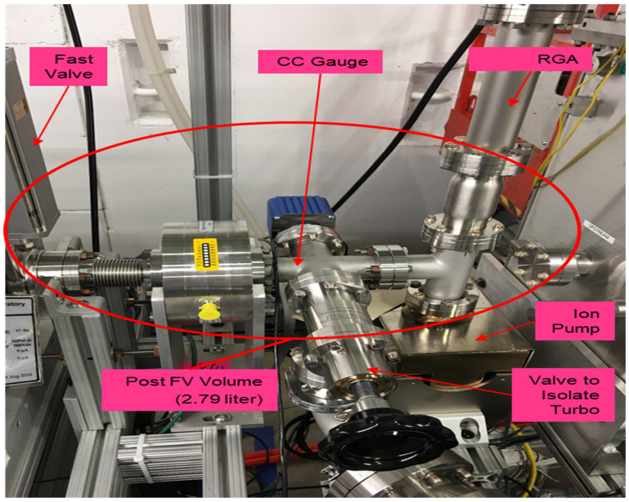


Figure 5: Vacuum space at downstream of Fast Valve.

In the 2nd test setup, the vacuum space post FV was reduced to 2.79 liters (vs. 95.1 liters in 1st test), as in Fig. 5. There is no O-ring this vacuum space so no air permeation. The ion pump was off during the leak test, and it was used only for recovering of the normal vacuum state.

Figure 6 shows the setup of simulated leaking. The dry nitrogen gas reservoir has volume of 0.33 litter. Leak size is changed by varying the pressure at the leak reservoir from 1.2 torr to 760 torr, and 760 torr with continuous supply.

Figure 7 shows two leak events with typical response from two simulated leaks. The pressure at leak reservoir indicates the size of leak since the volume of reservoir is fixed. Pressure rise response the leak promptly.

There are ten measurements taken in the 2nd test (see Table 1). Various leak sizes were simulated in both upstream and downstream of the DPI, by changing the pressure of dry nitrogen reservoir. The gas pressure in the vacuum space downstream of fast valve was reading from the cold cathode gauge for every simulated leaking. P0 was the base pressure before leak, P1 was the peak pressure right after simulated leak introduced. Pressure rise was P1 minus P0. The gas amount past the fast valve then equals the pressure rise times the fixed volume. Monolayer coverage is calculated by the amount of gas covers the surface with one molecular layer. The DPI effect of flux restriction is similar as in tests in 1st setup.

Table 1: Summary of Measurement on 2nd Test

	Pressure at Leaker Reservoir	CCG500 Reading		dP= P1-P0	Gas Amount	monolayer coverage	Leaker Location
		P0 (before)	P1 (after)				
	torr	Torr	torr	torr	Torr•liter	cm2	
23-Aug	1.7	6.2E-09	1.7E-07	1.6E-07	4.6E-07	1.3E-02	Upstream DPI
	52	7.5E-09	1.9E-07	1.8E-07	5.1E-07	1.5E-02	
24-Aug	760	7.9E-09	2.0E-07	1.9E-07	5.4E-07	1.6E-02	
	760‡	2.3E-08	2.3E-07	2.1E-07	5.8E-07	1.7E-02	
1-Oct	9.5	7.3E-09	3.8E-05	3.8E-05	1.1E-04	3.1E+00	Downstream DPI
	350	2.1E-08	1.4E-05	1.4E-05	3.9E-05	1.1E+00	
	810	1.0E-07	4.5E-05	4.5E-05	1.3E-04	3.6E+00	
8-Oct	1.2	6.1E-09	5.1E-04	5.1E-04	1.4E-03	4.1E+01	
9-Oct	130	6.0E-09	5.8E-07	5.7E-07	1.6E-06	4.6E-02	
	760‡	3.0E-08	2.5E-06	2.5E-06	6.9E-06	2.0E-01	

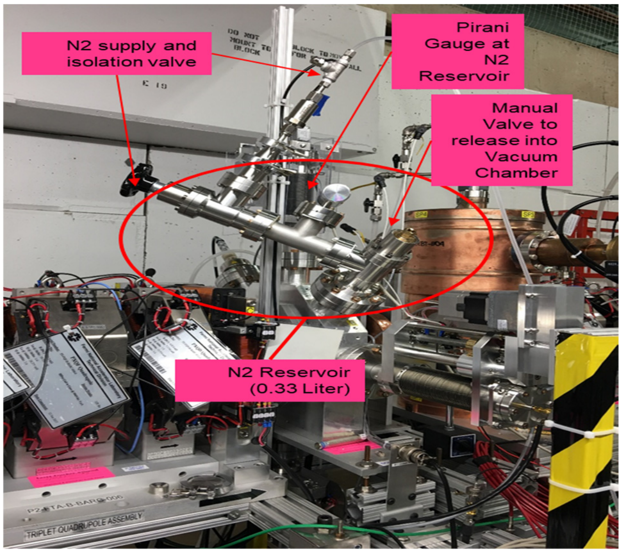


Figure 6: Simulated Leak setup.

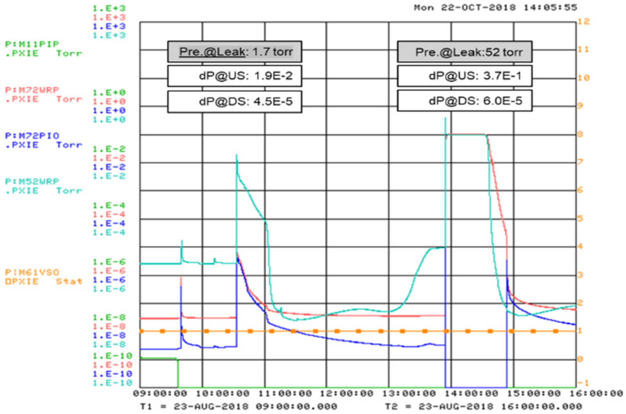


Figure 7: A sample of measurement at 2nd test.

From ten measurement results in 2nd test, we observed that 1) the size of leaks is insensitive to the amount of gas passed through the fast valve before closing; 2) the DPI plays significant role to reduce the amount of gas can pass the fast valve before it close, two groups of leak locations, upstream and downstream of DPI is clearly separated, see Fig. 8; 3) in term of monolayer coverage, the gas amount is reasonably small relative to cavity surface area.

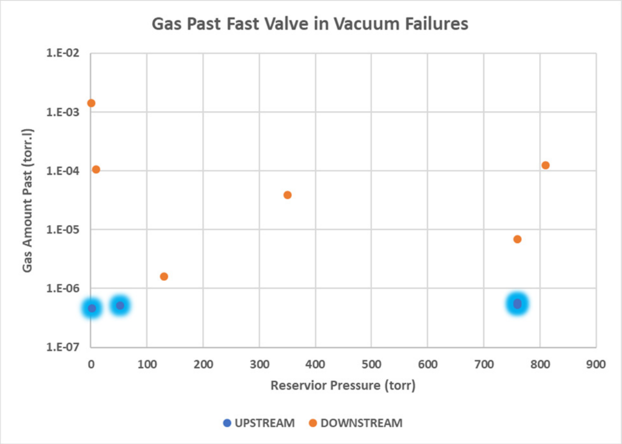


Figure 8: Gas Amount Past FV vs Leak Size at 2nd Test.

SUMMARY

With the improved sensitivity in 2nd test setup, the amount of gas passed by the FV is carefully measured. It is not directly driven by the size of leak. Differential Pumping Insert (DPI) throttled the leak significantly. The current design works as expected.

The amount of gas past FV is small enough 1) to not move particulates, 2) insignificant for surface condensation of cavities. So, we conclude that the vacuum protection system can provide significant protection to cryomodule from the risk of vacuum failure in adjacent warm sections.

ACKNOWLEDGMENT

The authors are thankful to the many people who helped with these tests, including R. Kellett, E. Lopez, C. Exline.

---

‡ Leaker reservoir was vent with dry nitrogen continuous supply.

REFERENCES

[1] PIP-II Conceptual Design Report, 2017, `http://pip2-docdb.fnal.gov/cgi-bin/ShowDocument?docid=113`

[2] L. R. Prost et al., "PIP-II Injector Test Warm Front End: Commissioning Update", in *Proc. 9th Int. Particle Accelerator Conf. (IPAC'18)*, Vancouver, Canada, Apr.-May 2018, pp. 2943-2946. `doi:10.18429/JACoW-IPAC2018-THYGBF2`

[3] R. L. Geng and H. Padamsee, "Condensation/adsorption and evacuation of residual gases in the SRF system for the CESR luminosity upgrade", in *Proc. 18th Particle Accelerator Conf. (PAC'99)*, New York, NY, USA, Mar. 1999, paper MOP136, pp. 983-985

[4] A. V. Shemyakin et al., "Design of 162-MHz CW Bunch-by-Bunch Chopper and Prototype Testing Results", in *Proc. 61st ICFA Advanced Beam Dynamics Workshop on High-Intensity and High-Brightness Hadron Beams (HB'18)*, Daejeon, Korea, June 2018, pp. 428-433. `doi:10.18429/JACoW-HB2018-THP1WC03`