VACUUM SURFACE SCRUBBING BY PROTON BEAM IN J-PARC MAIN RING

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Abstract

In J-PARC 50GeV synchrotron ring, large vacuum pressure rises above 10-4—10-3 Pa are found at 30GeV acceleration final stage in the repetition cycle with beam intensity over 1013 particles per pulse (ppp). The pressure rise are mainly occurred in the chambers of the in-vacuum electrostatic septum (ESS) magnet for the slow-extraction (SX), magnetic septum (MS) for SX, and the kicker magnet for the fast-extraction (FX); furthermore, as beam intensity goes high, the rise are occurred in the normal beam duct in arc section. This rise depends on beam intensity and peak-current, and can be reduced by continuous beam operations that work as scrubbing with proton beam and surface desorptions.

INTRODUCTION

J-PARC MR Review

Since the successfully extraction of 30GeV proton beam in December 2008 and transport to the neutrino beam line in April 2009, J-PARC 30GeV synchrotron (MR-Main Ring-) rise up the beam power and brush up the quality of beam, now we supply about 20—50 Tppp (tera particles per pulse) equivalent to 30—65 kW power to the neutrino beam line.

In MR vacuum system [1], the main pump is the titanium sputter ionization pump (IP) of pumping speed 0.5—0.6 m^3/s. In three arc sections, IP are placed about 34m intervals at the gap between quadrupole and bending magnets and at the short straight section so called “missing bend”. In three straight sections, the vacuum chambers of injection and extraction magnets individually have IP. The vacuum pressure is measured by Bayard-Alpert (B-A) gauge. In July 2009 (and also in May 2010 if the low beam power operation mode), vacuum pressure arrives below 1×10^{-6} Pa in almost all ring except injection and fast-extraction septum chamber 1×10^{-5} Pa [2].

Pressure Rise

In November 2009, as the beam intensity goes up to a few Tppp (tera particles per pulse), we found the vacuum pressure burst up and decay slowly with single beam shot at the chambers of FX kicker, SX ESS and SX MS (although latter two magnets are not in use) as shown in Figure 1. The pressure rise value is over 10^{-5} Pa at FX kicker, over 10^{-4} Pa at SX ESS and MS where the beam losses are found at the final acceleration time. Furthermore, recently the beam-power exceeds 40kW, the pressure rise in the ordinary beam duct in arc section has begun.

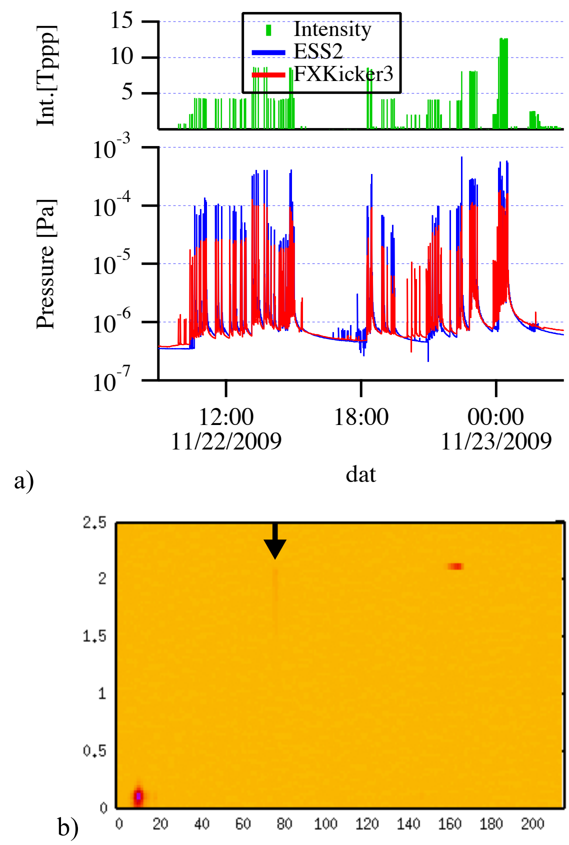

Figure 1. a) Pressure rise at SX ESS and FX Kicker chambers has began in Nov. 2009. b) Surface plot of beam loss monitor of main ring vs. acceleration period. Arrow shows the novel beam loss, observed at the acceleration time 1.5—2s of index 77, quadrupole downstream of ESS where the pressure rise to 5×10^{-4} Pa.

For continuous fast-extraction mode of repetition time of 6s or 3.52s, the pressure repeatedly rise up and down then become the equilibrium value of the rate of outgas and exhaust. With beam operation for several hours, the average pressure decrease exponentially or slowly because the amount of outgassing decrease. It is considered that the vacuum surface of chamber and in-vacuum magnet become clean by the bombardment of protons and residual gasses and secondary emission electrons.

In this paper, the surface cleaning, scrubbing effect is described.

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FX KICKER CHAMBER

Each chamber of the large cylindrical stainless steel tank of 1.2m diameter and 2.5m long has two 0.6 m^3/s IP. The magnet core is stacked ferrite blocks and cut rectangular along the beam aperture; so the proton beam looks ferrite (top and bottom) and aluminum electrode (side).

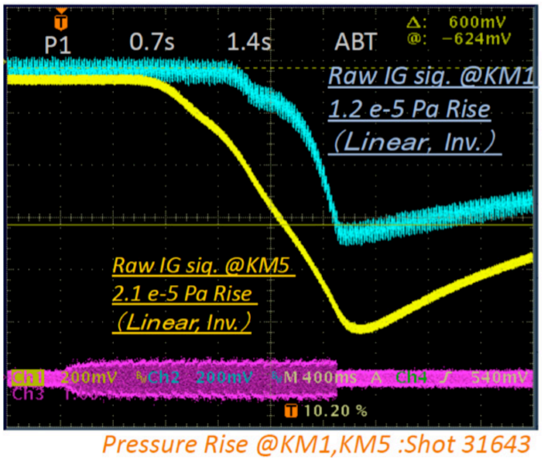

Figure 2.

Single Shot

Figure 2 shows a detailed time dependence of the pressure rise as ionization current from B-A gauge measured by current monitor. The pressure rise occurs at the latter half of 1.9s acceleration period, not at injected 3GeV nor low energy, and turn to decrease immediately after beam extraction. This suggest that the pressure rise occurred by the beam, beam induced secondary emission electrons and desorption of residual gas from vacuum surface.

Continuous Shots

Figure 3 shows an example of the baking by beam. The average pressure of each 5 kicker magnet chambers goes down one order with continuous shots during a half day. In this period, the order of pressure rise suddenly changes. This suggests that a gas source appears one after another from bulk body of ferrite or metals.

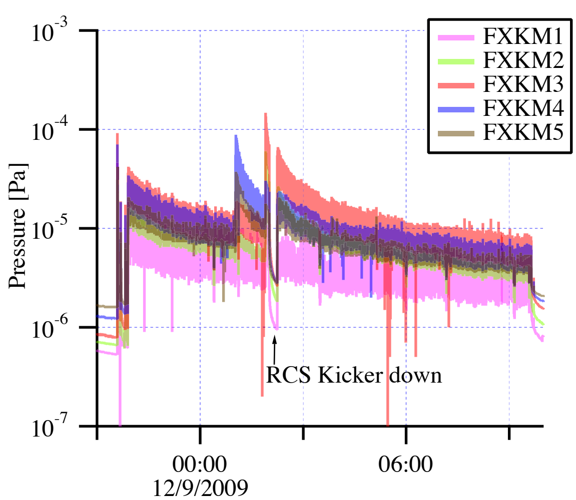

Figure 3. 6s cycle shots with intensity of 6.5 Tppp.

Residual Gas Analysis(RGA)

Figure 4 shows RGA during several 55Tppp (worth 73kW) shots measured by quadrupole mass spectroscope (QMS) attached to branch port of kicker#1 in Feb. 2010. For the single shots, generated molecules are adsorbed quickly by the pumps, therefore the measured spectrum tends to downward right. Nevertheless, the spectrum shows that the dominant desorbed molecules consist of hydrogen, carbon, hydrocarbons, not water.

In the old days Oct. 2006, we have measured RGA before installation. Figure 5 shows the spectrum variation before and after 100°C 85 hours mild baking. The main residual gas is water and there are many hydrocarbons before bake and on bake. From these spectra, the present pressure rise origin is identified as the contamination of ferrite or chamber during the production process.

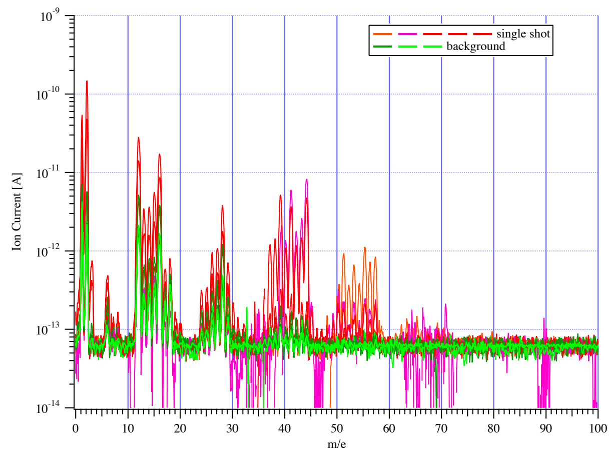

Figure 4. RGA of Kicker#1 with several single shots (2/3/2010). Each pressure rise up about 2×10^{-5}Pa.

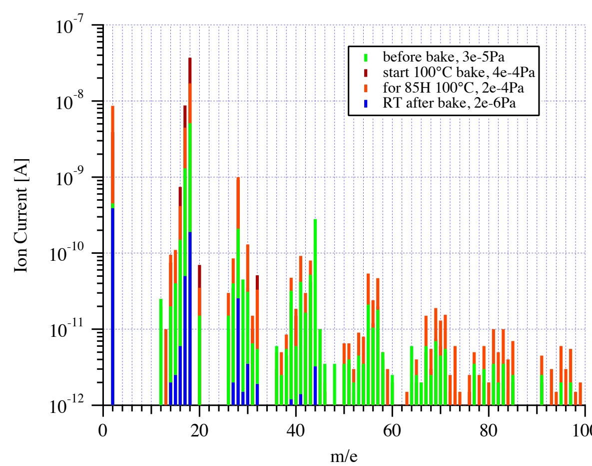

Figure 5. RGA variations before and after baking of the kicker chamber with ferrite cores, before installation to the accelerator tunnel (Oct. 2006).

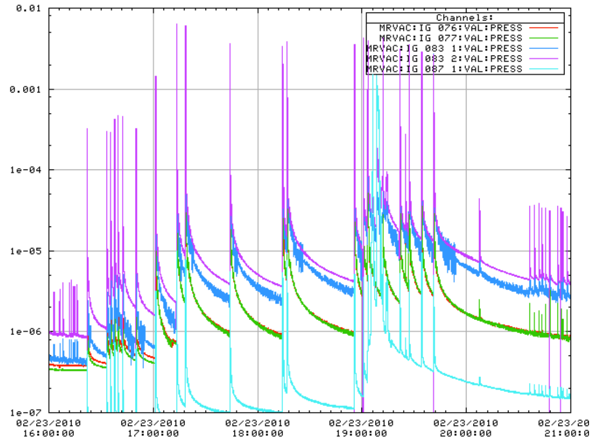

Figure 6. The pressure rise of SX chambers by many 30—70Tppp (100kW) single shots. SX MS#2 is purple line.

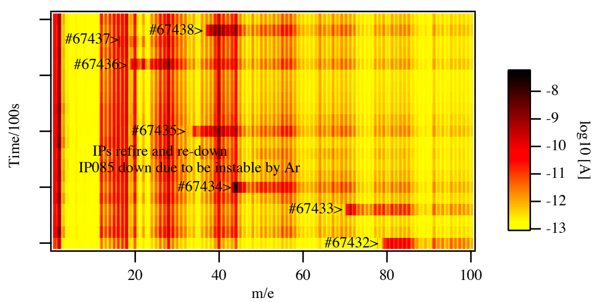

Figure 7. Surface plot of RGA ion current of SX MS#2 at 2/3/2010 19:00 in Fig.6. Scanning time is 1s/au. #xxxxx means shot number.

SX MAGNETIC SEPTUM CHAMBER

Each chamber of cylindrical stainless steel tank of 0.8m diameter and about 4m long has two 0.6 m^3/s IPs. The magnet core is iron in vacuum; therefore the proton beam looks iron and copper electrode and stainless steel of inner chamber wall. The pressure rise is same as that of kickers, shown as Fig. 6.

Residual Gas Analysis(RGA)

Figure 7 shows RGA during several 70Tppp (worth 100kW) shots by QMS attached to branch port of SX MS#2. The spectrum shows that the desorbed molecules consist of hydrogen, carbon, water, a lot of hydrocarbons, and also argon. The origin of argon is identified as leak in hadron beam line; while the origin of hydrocarbons are not well known.

NORMAL DUCT IN ARC

Recently, 40—50kW continuous beam operations successfully are achieved for the first time to the neutrino beam line in Apr. 2010, then the pressure rise are found at the ordinary pipe between magnets of the short straight section in arc section. The momentum dispersion is not zero in there, therefore the beam loss happens by scattering with residual gas in a few 10m long section of 10^{-4}Pa.

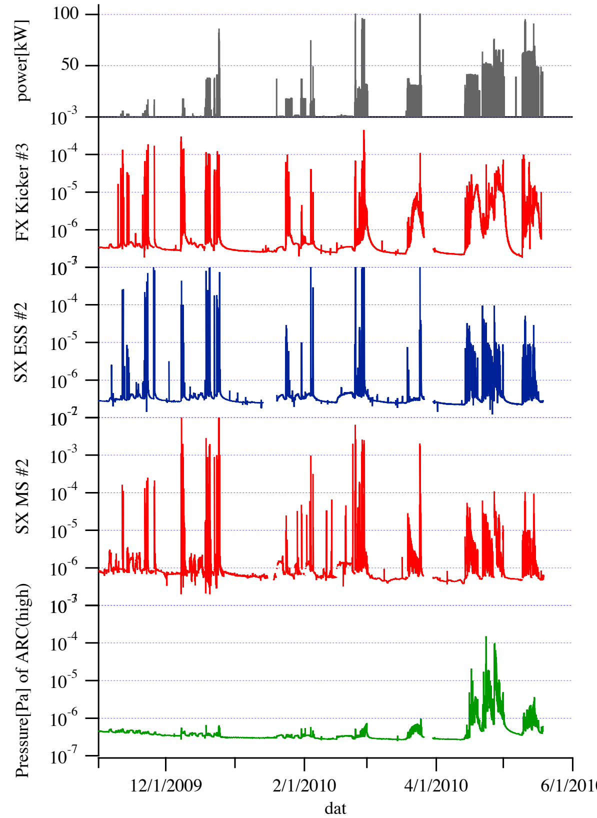

Figure 8. Pressure rise of typical area and beam intensity trend of Nov.2009—May.2010.

BEAM SCRUBBING EFFECT

Figure 8 shows a long time trend of typical pressure rise of FX Kicker#3 and SX MS#2 and the arc section. As the continuous beam operation, beam intensity rise up little by little and the pressure not rises catastrophically but is about the same or reduce.

CONCLUSION

As higher beam intensity of J-PARC MR, a large pressure rise is occurred and soon reduced by continuous beam operations as scrubbing effect; considered the "baking by beam". The components of outgases are mainly consist of hydrogen, carbon, hydrocarbons. the origin may come from the chambers production process.

REFERENCES

[1] M. Uota et al., "Vacuum System of J-PARC 50GeV Synchrotron Ring", VASSCAA-4, 2008, 29P148.

[2] M. Uota et. al., "The Present Status of Vacuum System of J-PARC Main Ring and 3-50 Beam Transport", Proceedings of Particle Accelerator Society Meeting 2009, Japan, p.974 (in Japanese).