STATUS OF VACUUM SYSTEM IN J-PARC RCS

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Abstract

Vacuum system of J-PARC Rapid Cycling Synchrotron (RCS) has been operating since 2007. There had been almost no trouble since then, so the actual system behaviour in case of unexpected trouble has not been examined. However, the J-PARC site was hit by the Great East Japan Earthquake in March 2011. Though accident analysis and recovery work, we investigated whether the system behaved correctly and how much damage the devices are sustained. We also summarize the results of the investigation about the dynamic pressure, which is caused by the high power beam and other elements.

INTRODUCTION

J-PARC is a high intensity proton accelerator facility. The 3GeV RCS is a keystone of J-PARC facility since it plays a role of both the main accelerator for the Material and Life Science Facility (MLF), which uses the world highest intensity pulsed neutron and muon beams, and the injector to the Main Ring (MR), which is a 50 GeV synchrotron for high energy particle physics. The RCS aims to achieve the proton beam power of 1 MW, which corresponds to each cycle 8.3×10^{13} protons accelerated up to 3 GeV at the repetition rate of 25 Hz.

The vacuum system of the RCS is distinguishing[1]. Vacuum chambers of RCS have large size of aperture in order to accept such a high intensity beam. The normal diameter is 200 mm, while the largest diameter is 500 mm in the injection and extraction section. Alumina ceramics chambers are used in the aperture of the bending and quadrupole magnets, whose repetition rate of the magnetic field is 25 Hz, in order to prevent the eddy current heating[2]. Other vacuum chambers and bellows are made of titanium because of its small residual radioactivity. In normal operation 24 turbo molecular pumps (TMP) are used to evacuate RCS. Advantages of using TMP for main pumping system is the following.

- TMP can evacuate large amount of outgassing steadily without expelling the gas like a spattering ion pump. This is effective for our machine because there are some components which has large outgassing like ferrite cores in kicker magnet, carbon foils for charge exchange, collimators.
- TMP can smoothly exhaust from the atmospheric pressure to below 10^{-4} Pa in only about half day. It is effective after maintenance period, during which beam lines are purged to atmospheric pressure.

Cold cathode gages (CCG) and B-A gages (BAG) are used to measure pressure. Pressure has been about 10^{-7}-10^{-6} Pa.

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This time we would report the status of the vacuum system from two different perspectives.

1) System behaviour at the instant of disaster
In 11th March 2011, J-PARC site was affected by the Great East Japan Earthquake. Did the system behave correctly at the instant of such unparalleled disaster?

2) Dynamic pressure
The high power beam has been operated up to 300 kW (~200 kW for user operation). How the beam line pressure reacts to high power beam and what is the origin?

SYSTEM BEHAVIOR IN THE INSTANT OF DISASTER

The Great East Japan Earthquake

Seismic intensity at J-PARC site was 6 lower (JMA seismic intensity scale) at the Great East Japan Earthquake, 11th March 2011. Just after the occurrence of the earthquake, the electrical failure happened. When the electric failure happens, power system of the vacuum system is designed to work as following.

- Power system for the control system (Remote controller of pumps, gauges, valves, etc, PLC, and system server PC): Even when electric power failure happens, the power system is not cut suddenly because it is connected to the uninterruptible power-supply system (UPS).
- Main power system for pumps and valves: When electrical power failure happens, the power system is connected to the emergency power after about 1 minute.

Each power system worked as above just after the earthquake, and the following situation happened.

a) System server continued to take data from PLC by virtue of the UPS. After about 4minutes, the system was shut down because the battery of the UPS is expired.
b) Gauges should have been operating owing to the UPS. However, many gauges stopped or disconnected electrically.
c) TMP were stopped by the order of PLC due to the main power system failure before connection to the emergency power.
d) Gate valves should have been closed because all turbo molecular pumps were stopped, 6 gate valves (total 8 gate valves) were left open. One possible reason is that the power of the air compressor, which supplies compressed air for gate valve movement, was lost and the PLC did not order to close the gate valves.

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Fig. 1 shows pressure in the beam line. You can understand the above behaviour of each device described above.

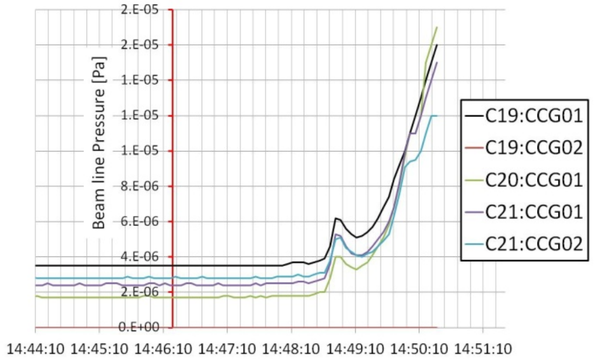

Figure 1: Beam line and fore line pressure at the occurrence of the earthquake.

For the broken devices some filaments of pirani gauges, which are disconnected. And when the system restart the continuous operation in October 2011, two device controllers are broken due to the circuit element break. One possibility is high humidity due to the electrical loss for 5 months.

Ceramics ducts were used for beam ducts, which are installed in the aperture of bending and quadrupole magnets. Damage of the ceramics ducts (and other components in the beam line) has been checked as following. Because incoming panels are broken by the earthquake, we could only use the electricity from the temporary dynamo. The power was limited to the wall socket in the accelerator tunnel. Therefore, we construct the makeshift pumping system as Fig. 2 using the beam line turbo molecular pumps. After a few hours of pumping, the pressure reached below 10^{-4} Pa, so we could conclude that there is no large leakage in the beam line.

From November 2011, the beam line has been continuously pumped down. Figure 3 shows the comparison of beam line pressure after continuous pumping. There is no noticeable difference of the pressure between before and after earthquake.

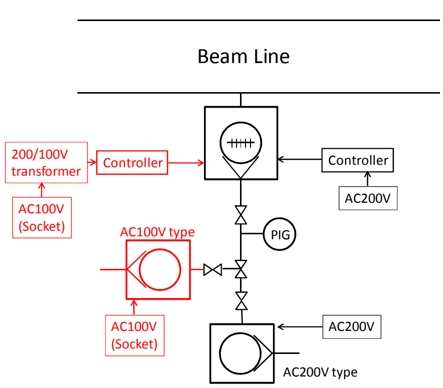

Figure 2: Makeshift pumping system (red ones means) in order to pump with limited electricity.

Other Instantaneous Power Failures

When instantaneous voltage drop, which is triggered by the ground discharge and others, occurs, the vacuum system operates as follows.

- When PLC detects voltage drop of a turbo molecular pump, it commands controller of the turbo to stop.
- If all turbo molecular pumps in a section go to decelerate, PLC commands gate valves at each side of the section to close.

In fact this year 2012, the instantaneous voltage drop, which affected the vacuum system, occurred twice (17th January and 6th May). In each voltage drop, the vacuum system acted correctly as above.

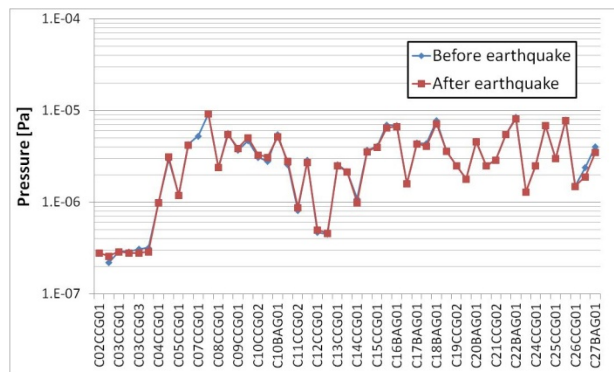

Figure 3: Comparison of beam line pressure distribution after continuous pumping before and after earthquake.

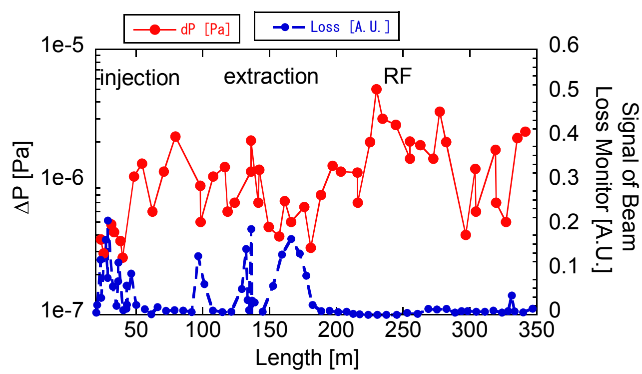

Figure 4: Distribution of beam loss intensity and pressure increase

DYNAMIC PRESSURE IN BEAM LINE

Dynamic pressure in accelerators and nuclear fusion machines is thought to be caused by the mixture of the following processes [3].

- Thermal desorption of gas adsorbed on the vacuum walls.
- Desorption due to bombardment by ions, electrons, and photons.
- Chemical reactions which release gaseous contaminants such as H_2O and CH_4.

There is many source in RCS to trigger pressure increase. In the following we investigate the dynamic pressure caused by beam and others.

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Particle Induced Desorption

For accelerators, there are a lot of reports about the particle induced desorption [4]. However I think that there is not common dominant process, which explains dynamic pressure for all accelerators because induced particles and material of walls (and its treatment) are different from each machine. It is meaningful to investigate the origin of the dynamic pressure in our machine RCS, where high power proton beam is accelerated through the beam pipes which are made of pure titanium and TiN coated alumina ceramics.

High energy proton induced desorption can be examined by the comparison of the beam loss and the pressure increase. Figure 4 shows the distribution of beam loss intensity and pressure increase. Because there is no correlation between them, it can be concluded that high energy proton induced desorption yield is small.

Chemisorption and physisorption energy on the surface is a few eV and 0.5 eV, respectively. Therefore, even if the energy of particle is below 1 keV, it is enough to desorb molecules, which are adsorbed on the wall surface. Such low energy particles are generated as the following. First, residual gases are ionized by proton beam. Next, the ions and electrons are accelerated by the potential made

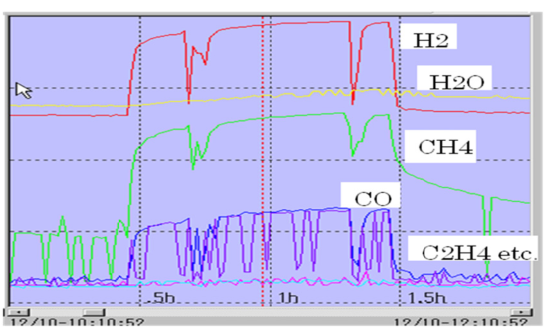

Figure 5: the gas components during the beam operation with high power beam of 300 kW.

by the beam current. These particles have energy of <1keV[5]. Fig 4 shows the gas components during the beam operation with high power beam of 300 kW. Hydrogen and carbon related molecules increases. They are gas components, which are generally adsorbed on the vacuum surface. Fig 6 shows pressure history with beam on. You can see the conditioning effect during such long period. Furthermore, after the long shutdown, where the beam line is bent by pure argon up to atmospheric pressure, the pressure increases again because some molecules are adsorbed again on the vacuum surface. We can conclude that these pressure increase is caused by ion/electron induced desorption.

Other Element for Pressure Change

There are many other elements, which change the beam line pressure. The main origin is temperature change, which is caused by the air conditioner, magnet excitation, and so on. It can be thought that molecules are desorbed when the vacuum wall temperature become higher. You can see the variety of pressure change, which are caused by some elements in Fig.7.

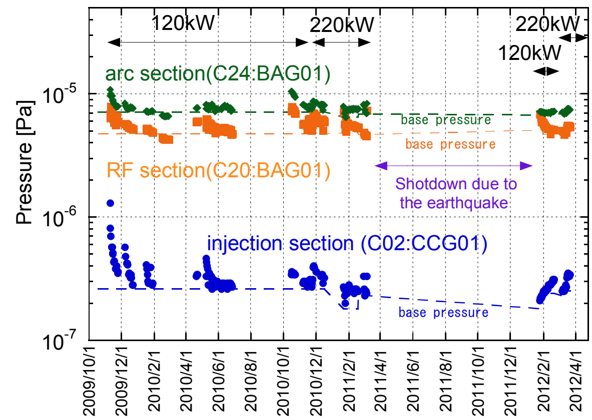

Figure 6: Pressure history (on beam).

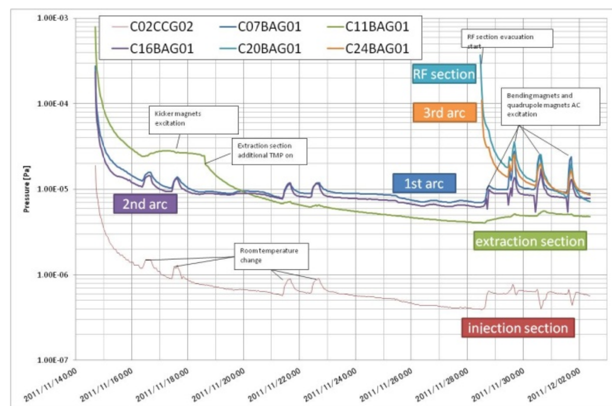

Figure 7: Pressure change caused by some elements.

SUMMARY

In this report, we mentioned about two different topics. Each topic can be summarized as the following.

1. System behaviour at the instant of disaster
   The system behaves correctly in unanticipated incident such as earthquake and instantaneous voltage drop.

2. Dynamic pressure
   Dominant process for dynamic pressure caused by beam is thought of as ion/electron induced desorption.

Other element causes temperature change following the desorption of molecules.

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