IMPROVEMENTS OF VACUUM SYSTEM IN J-PARC 3 G V SYNCHROTRON

J. Kamiya†, Y. Hikichi, Y. Namekawa, K. Takeishi, T. Yanagibashi, M. Kinsho, K. Yamamoto, JAEA/J-PARC, Shirakata 2-4, Tokai, Naka, Ibaraki, Japan
A. Sato, NAT, Muramatsu 3129-45, Tokai, Naka, Ibaraki, Japan

Abstract

The RCS vacuum system has been upgraded since the completion of its construction towards the objectives of both better vacuum quality and higher reliability of the components. For the better vacuum quality, (1) pressure of the injection beam line was improved to prevent the H^- beam from converting to H^0; (2) leakage in the beam injection area due to the thermal expansion was eliminated by applying the adequate torque amount for the clamps; (3) new in-situ degassing method of the kicker magnet was developed. For the reliability increase of the components, (1) A considerable number of fluoroelastmer seal was exchanged to metal seal with the low spring constant bellows and the light clamps; (2) TMP controller for the long cable was developed to prevent the controller failure by the severe electrical noise; (3) A number of TMP were installed instead of ion pumps in the RF cavity section as an insurance for the case of pump trouble.

INTRODUCTION

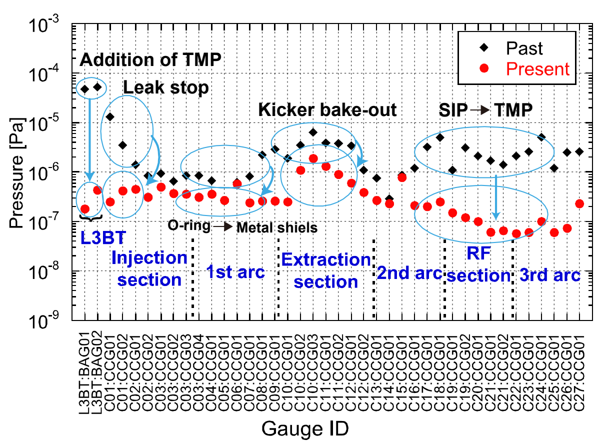

Figure 1: Comparison of the present beam line pressure distribution with the past one. Improvements in 2nd and 3rd arc also owes the replacement of O-ring to the metal seals.

The 3 GeV Rapid Cycling Synchrotron (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), and the injector to the Main Ring (MR). 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 design concept of the RCS vacuum system, the uniquely developed vacuum components, and the basic vacuum characteristics achieved were reported in the previous articles [1, 2]. Since the completion of its construction, the chief purposes of the RCS have been accomplishment of the higher beam power and more stable operation. For both purposes, improvements of the vacuum quality and increase of the vacuum components reliability have been performed in the RCS vacuum system. As an example of such efforts, Fig. 1 shows the comparison of the present beam line pressure distribution with past one. The pressure was improved in the several sections. In this article, the upgrades of the vacuum system are shown from the perspectives of the vacuum quality improvement and reliability increase of the vacuum components.

VACUUM QUALITY IMPROVEMENTS

Beam Loss Reduction by Lower Pressure at the Injection Beam Transport Line [3]

The injection line called L3BT line (Linac to 3GeV synchrotron Beam Transport line), was the section, where the high beam line pressure causes the beam loss. In this section, H^- beam from Linac was converted to H^0 by charge stripping due to the interaction between H^- beam and the residual gas molecules. Such H^0 beam was not bended by the injection septum magnets and directly hit the vacuum wall at the injection branch. Additional vacuum pumps were installed in this section to reduce the beam line pressure and beam loss in this section. By installing two turbo molecular pumps (TMP), the beam line pressure was reduced by double-digit from 10^{-5} Pa to 10^{-7} Pa. As a result, the beam loss in the injection branch area due to the charge stripping of the injection beam was successfully suppressed as shown in Fig. 2.

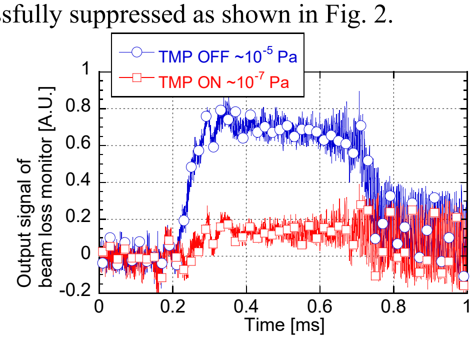

Figure 2: Beam loss suppression in the injection branch area by the vacuum improvement in L3BT line.

Elimination of Vacuum Leak in the Beam Injection Area

Vacuum leak happened in the RCS beam injection area where the normal pressure without leak is less than 10^{-6} Pa. The amount of leak shows unique property as shown in Fig. 3. The leak increased when the shift bump

#junichiro.kamiya@j-parc.jp

ISBN 978-3-95450-182-3

magnets, which generates the pulse magnetic field, are not excited, while it decreased with the bump magnets excitation. Such situation would be caused by the thermal expansion of the beam pipe of alumina ceramics and/or the flange of pure titanium, which is installed in the aperture of the shift bump. Measured temperature was about 50 °C for the beam pipes and 100 °C for the flanges, respectively, which was caused by the radiation from the magnet cores and induced current by the pulse magnetic field. Corresponding thermal expansion is 0.4 mm to the beam direction and 0.3 mm to the flange diameter direction, respectively. In the construction period, minimum amount of torque, which guarantees vacuum leak of less than 10^{-11} Pa m^3/s was applied for each flange clamps to prevent the sealing surface of the flange from denting by the metal seal. Actually, the amount of torque was 10-20 N m. However, the repeated thermal expansion would have caused the clamp laxity resulting the gap between the flanges.

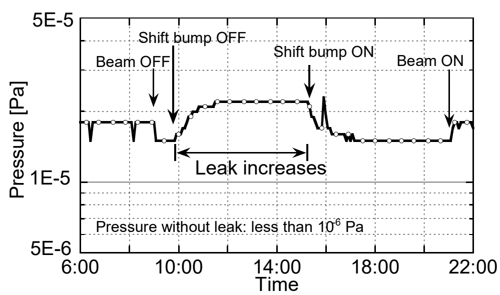

Figure 3: Leak property in the beam injection area. The leak caused by the thermal expansion increases without excitation of the pulse magnets.

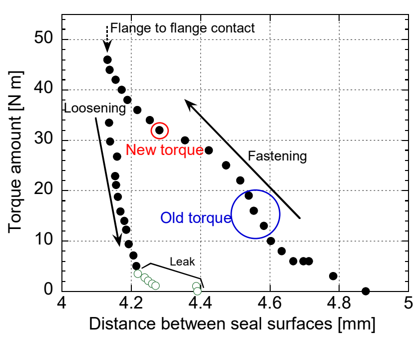

Figure 4: Measured typical compression curve of the metal seal.

To search the adequate torque amount, the compression properties of the metal was measured. Figure 4 shows the measured typical compression curve of the metal seal. The torque amount of 10-20 N m is obviously too small because such region is just the start of the compression. The torque amount of 30 N m would be enough because the seal is sufficiently compressed to near the flange and flange contact. Therefore, the torque amount of 30 N m was applied to the clamps in the injection area. As a results the leak has not occurred so far. Furthermore, we are currently measuring the compression curve with the maximum torque amount of 30 N m to demonstrate that such torque amount does not actually cause the vacuum leak if the bolts slack by the repeated thermal expansion.

In-situ Bake-out of the Kicker Magnets [4]

Degassing of the kicker magnets in vacuum is necessary to prevent the damage of the components, such as ferrite cores and aluminum electric plates, by electric discharge. The usual bake-out method, which involves heating the vacuum chamber by the heaters attached on the outer surface of the chamber, cannot be applied in the beam line due to the thermal expansion of the long chamber with the length of about 5 m. If the chamber was baked at 120 °C, where the main outgassing components of water vapour is effectively desorbed, the thermal expansion would be more than 5 mm and it would break the nearby ceramics pipes.

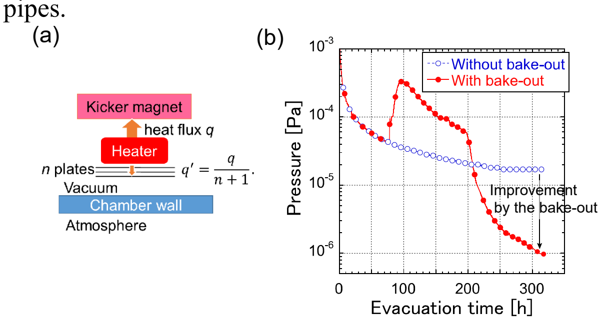

Figure 5: (a) Conceptional diagram of new baking method. (b) Beam line pressure improvement in the kicker magnet area by the in-situ baking method.

We have developed a new degassing method based on the principle of the thermal radiation shielding, by which only kicker magnets are baked out without raising the temperature of the vacuum chamber to prevent unwanted thermal expansion of the chamber. The principle of thermal radiation shielding recognizes that the thermal radiation heat flux q is reduced to one-$(n+1)^{th}$ by n shielding plates. For the kicker degassing, by simply installing the heater and thermal radiation shield plates between the kicker magnet and the chamber wall as shown in Fig. 5 (a), most of the heat flux from the heater directs towards the kicker magnet. Verification measurement with the R&D kicker demonstrated that each part of the kicker magnet was heated to above 120 °C with a small rise in the vacuum chamber temperature less than 20 °C by using the 5 shield plates. Degassing of the kicker magnets in the RCS beam line was actually performed by the new bake-out method. As a result, with keeping the thermal expansion of the chamber less than 0.2 mm, the beam line pressure was successfully improved as shown in Fig. 5 (b).

RELIABILITY INCREASE OF THE VACUUM COMPONETNS

Replacing O-ring to Metal Seals Along with Low Spring Constant Bellows and Very Light Clamps

In the construction period of the RCS vacuum system, O-ring seals of fluoroelastmer were used for about 35 flange

ISBN 978-3-95450-182-3

joints out of about 450 in total because the leak did not stop with the metal seal. Especially the connection with the beam pipes for the bending magnet tended to leak because it is difficult to parallelize the flanges and align each central axis for the bended beam pipes. However, the O-ring seals should be replaced to the metal ones for higher intensity beam operation because fluoroelastmer would deteriorate with high radiation. Thus, bellows with low spring constants were developed to connect such misaligned flanges. Hydroformed bellows with large apertures generally have high spring constants. The flexible bellows without welding were successfully developed by obtaining a narrow pitch of approximately 3 mm, which was formed by a combination of hydroforming and pressing. A spring constant of less than 25 N/mm was achieved. Universal type, which consists of two bellows and a pipe between them, was applied to connect a large displacement perpendicular to the beam axis of approximately 5 mm. The connection point with developed bellows and clamps are shown in Fig. 6. For the flanges joint, the light clamps of aluminum alloy with high mechanical strength was newly manufactured. This clamp consists of only two semi-circular parts for one flange for better handling.

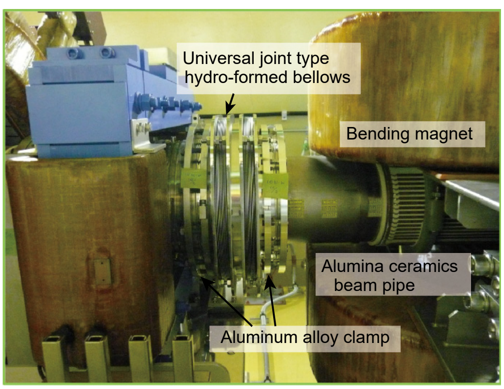

Figure 6: Low spring constant hydro-formed bellows with universal joint type and the light clamp of aluminium alloy.

TMP Controller for Long Cable

According to the upgrade of the injection beam energy from 181 MeV to 400 MeV, the excitation current for the injection shift bump magnet was increased. After that, the controllers of the TMP often froze due to the electrical noise and rotor touched down with rated rotating speed. This was very big problem because the TMP rotor and stator blades contact with each other, causing the deformation of such blades. Figure 7 shows the solution of this problem. Controllers were placed in the utility tunnel, which was just under the accelerator tunnel, because of the limitation of the cable length between the TMP and its controller. We decided to relocate the controllers to noise-free environment by developing the control method with long cables. By combining the amplifier with the controller, the cable length was successfully lengthened to more than 150 m. The failure of the TMP controller have been eliminated by such countermeasure.

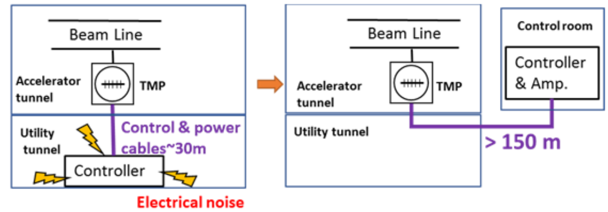

Figure 7: Counter measure against the TMP controller freeze by the electrical noise. The controller with amplifier was newly developed for using the long cables.

System Reliability Improvement of RF Cavity Section

The TMP and spattering ion pumps (SIP) were concurrently used at the first stage of the vacuum system operation. However, the absorbed ions, which might be the residual molecules ionized by the electrical field of the RF cavity, were suddenly re-desorbed as a large amount of outgassing during the beam operation. The SIP had not been used since then. As a result, pumping of the RF cavity section depends on only one TMP. In such situation, failure of the TMP directly leads to the long term stop of the beam operation. Two SIP were replaced by the TMP as shown in Fig. 8. The stable operation become insured even if one or two TMP failure in this area with achieving lower beam line pressure as a matter of course.

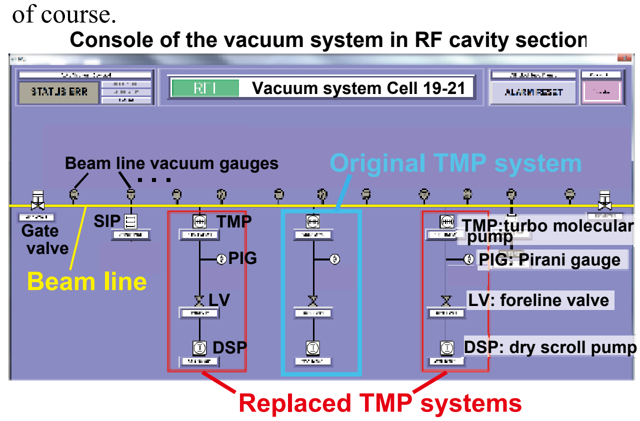

Figure 8: TMP replaced from SIP in the RF cavity section.

CONCLUSION

Continuous upgrades of the RCS vacuum system have been performed for obtaining the better vacuum quality and higher reliability. In consequence, the lower pressure along the entire RCS beam line and the more stable vacuum system operation are achieved.

REFERENCES

[1] N. Ogiwara *et al.*, ”Vacuum system for the 3-GeV RCS in J-PARC”, Vacuum, 84, pp.723-728, 2009.
[2] M. Kinsho *et al.*, “Titanium flanged alumina ceramics vacuum duct with low impedance”, Vacuum, 81, pp.808–811, 2007.

[3] J. Kamiya *et al*., in *Proc. IPAC'14*, 2014, pp. 2338-2340.
[4] J. Kamiya *et al*., "In-situ baking method for degassing of a kicker magnet in accelerator beam line", J. Vac. Sci. Technol. A, 34, p.021604, 2016.

ISBN 978-3-95450-182-3