ANNULAR-RING COUPLED STRUCTURE LINAC FOR THE J-PARC LINAC ENERGY UPGRADE

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Abstract

The Japan Proton Accelerator Research Complex (J-PARC) linac is the injector to the 3-GeV rapid cycle synchrotron. To increase the beam power of the synchrotron, the task of upgrading the energy of the linac to 400 MeV started in March 2009. At the downstream of the 191-MeV separated-type drift tube linac, 25 modules of the annular-ring coupled structure (ACS) linac will be added in August 2013. Cavity fabrication of the ACS is nearly complete, and the completed modules are kept at the J-PARC site. Currently, pumps and vacuum components are being installed on the cavities for testing of vacuum conditions. For the J-PARC pulsed beam, vacuum pressures need to be less than 10^{-5} Pa along the beam line in order not to exceed 0.1 W/m beam loss. In this paper, we present the measurement results for reducing the vacuum pressure using the stored ACS cavity to enable the high-intensity operation.

INTRODUCTION

The annular-ring coupled structure (ACS) linac will be added to the Japan Proton Accelerator Research Complex (J-PARC) in August to increase the linac beam energy from 181 to 400 MeV. A total of 25 ACS modules have been fabricated, and two buncher modules and two accelerating modules have already been conditioned up to the design input power [1].

Keeping vacuum pressures as low as possible (typically, less than 10^{-6} Pa) is important for reducing the beam loss from residual gas in high-intensity proton accelerators. During user operation, research and development on vacuum improvement can be difficult because it would require the frequent changing of vacuum pumps and vacuum gauges. The vacuum pressure distribution in the ACS module was, therefore, measured and attempts were made to improve it using the stored module before installation. This report describes the evacuation test and the possible vacuum improvement options that will enable high-intensity operation.

EVACUATION TEST

As additional vacuum pumps, nonevaporable getter (NEG) pumps (CapaciTorr D400 manufactured by SAES Getters [2]) were used in this experiment to improve the vacuum pressure. NEG pumps have several advantages; they are its lightweight, can be easily attached to the cavity, and do not need an additional high-voltage cable. Meanwhile, the lifetime (interval of activation) should be confirmed separately because its pumping process sorbs active gas molecules by chemical reaction.

Figure 1 shows the configuration of the NEG pumps and the vacuum gauges (Bayard-Alpert). One ACS accelerating module is evacuated by two 500 L/s ion pumps (IPs), one at each end, and one 150 L/s IP at the center. When the achieved vacuum pressure was around 10^{-6} Pa after the 60 h of evacuation, the change in vacuum pressure caused by additional NEG pumps (resulting from the opening or closing of the angle valve attached to the NEG pump) was measured.

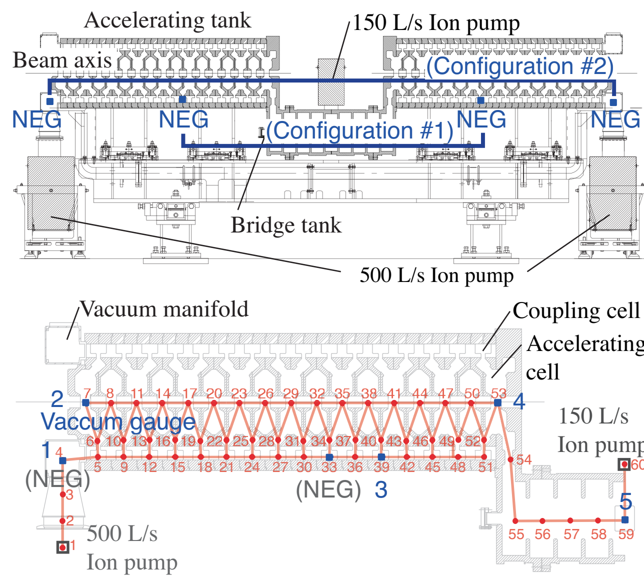

Figure 1: Configuration of NEG pumps (#1 and #2) and vacuum gauges (1-5) and diagram of the vacuum network in the ACS accelerating tank (nodes 1-60).

The following two NEG pump configurations were compared:

- (#1) NEG pumps were attached to the center of the accelerating tank (node 33). This point is far from the IPs and is expected to have the highest pressure.
- (#2) NEG pumps were attached to the vacuum manifolds at both ends of the module.

Here, it should be mentioned that the rotating tuner attached to the coupling cell needs to be removed when the additional NEG pump is added at the center of the accelerating tank.

The measured pressures for the configuration #1 are shown in Fig. 2 and listed in Table 1. It can be seen from

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the decreasing pressure of gauges 2, 3, and 4 that the vacuum pressure at the minimum change point (gauge 2) decreased by at least 6%.

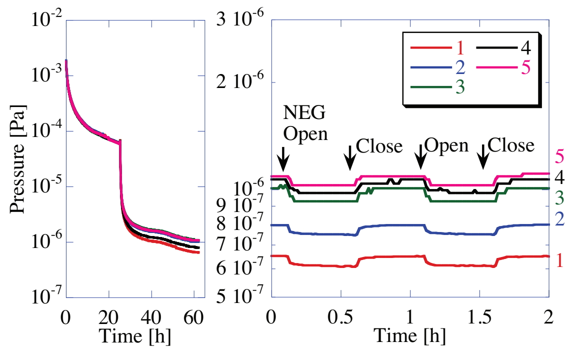

Figure 2: Evacuation curve and change in vacuum pressures caused by NEG pumps (configuration #1).

Table 1: Averaged Pressure (in Units of 10^{-6} Pa) from Two Measurements Made in Configuration #1

Gauge No.	IP only	IP+NEG	Ratio
1	0.65	0.61	93.7%
2	0.80	0.75	94.0%
3	1.01	0.93	91.7%
4	1.07	0.98	91.5%
5	1.09	1.03	95.3%

The measured pressures for configuration #2 are shown in Fig. 3 and listed in Table 2. As can be seen from the pressure changes of gauges 2, 3, and 4, the vacuum pressure at the minimum change point (gauges 3 and 4) decreased by at least 5%.

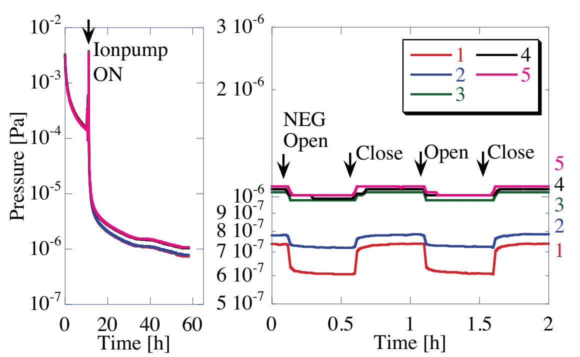

Figure 3: Evacuation curve and change of vacuum pressures caused by the NEG pumps (configuration #2).

A comparison of the results for the two configurations indicates a relatively small vacuum pressure difference of 1% at the minimum change point. Consequently, it is sufficient to attach additional NEG pumps to the vacuum manifolds to improve the vacuum pressure in the accelerating tank, without the need to remove the rotating tuners.

Table 2: Averaged Pressure (in Units of 10^{-6} Pa) from Two Measurements Made in Configuration #2

Gauge No.	IP only	IP+NEG	Ratio
1	0.74	0.61	82.4%
2	0.78	0.72	92.3%
3	1.03	0.98	95.0%
4	1.05	1.00	95.0%
5	1.07	1.02	95.6%

EVALUATION OF PRESSURE DISTRIBUTION

The characteristic matrix calculation [3] and the measured pressures were compared to evaluate the vacuum pressure distribution along the beam line. The diagram of the vacuum network for the matrix calculation is shown in Fig. 1. The following three combination of the IP operation were examined to select a proper value for the outgassing rate per unit surface area in the calculation: (i) operating all IPs (two 500 L/s and one 150L/s), (ii) operating only two 500 L/s pumps, and (iii) operating only one 150 L/s pump. Figure 4 shows a comparison of the calculated and measured pressures.

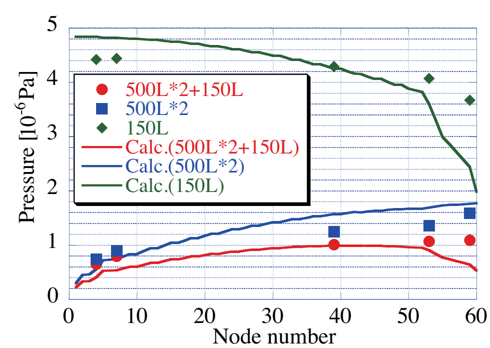

Figure 4: Comparison of pressures obtained by characteristic matrix calculation and measured pressures.

The total pressures were proportional to the outgassing rate in this calculation. Here, the outgassing rate was supposed to be constant because most of the inner surface consisted of oxygen free copper. Its value was adjusted to 2.2×10^{-8} Pa m^3/m^2 s to fit the measured total pressures.

As can be seen in Fig. 4, there is a large difference between the calculated and measured pressure at vacuum gauge 5 (node 59). This difference suggests a high outgassing rate around vacuum gauge 5, because the 150 L/s IP (at node 60) was ineffective in reducing the pressure around here in the case when all IPs were operating compared with that of two 500 L/s only, and because the calculated pressure at vacuum gauge 5 (node 59) was much higher than the measured one in the case of only one 150 L/s IP. It is suspected that this large outgassing rate is due to the ceramic surface of the RF window, which is positioned at the connecting part between the cavity and the waveguide (node 60). The outgassing rate of only the RF window needs to be measured for further investigation. The large outgassing rate of the RF window is expected to be reduced by high-power conditioning. It is, therefore, important to notice the vacuum pressure decreasing around the RF window to evaluate the conditioning effect from the viewpoint of vacuum improvement.

Outgassing rates from the inner surface of the ACS module were evaluated by using the pressure rise method. The pressure rise $\Delta P/\Delta t$ (where P is pressure and t is time) was measured by the vacuum gauge at the center of the ACS module (gauge 5). In this measurement, all the other gauges were turned off. The measured pressure rise is shown in Fig. 5.

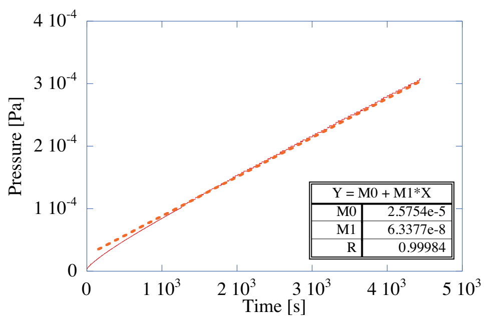

Figure 5: Pressure rise. The dotted line is a linear approximation using data for $t > 1.5 \times 10^3$ s.

The outgassing rate Q was calculated to be 1.03×10^{-8} Pa m^3/m^2 s by using $Q = V(\Delta P/\Delta t)/A$, where the volume V and the inner surface A are estimated by using three-dimensional computer-aided design to be 0.28 m^3 and 17.2 m^2, respectively. The measured value has the same order of magnitude as the value 2.2×10^{-8} Pa m^3/m^2 s determined from the characteristic matrix calculation. It should be mentioned that the outgassing rate measured by using the pressure rise method tends to be smaller than that measured by using the throughput method [4]. Here, these outgassing rates are less than half of that of an oxygen-free copper [(5-9)$\times 10^{-8}$ Pa m^3/m^2 s]. Outgassing rates should be measured by using the throughput method to obtain the more accurate values.

IMPROVEMENT OF VACUUM PRESSURE

In configuration #2, the effective pumping speed of the NEG pump was evaluated by using the characteristic matrix calculation to examine the possibility of using larger pumps. The pumping speed was varied in the calculation to agree with the measured pressure change between configurations with and without NEG pumps. Figure 6 shows the calculated pressure distribution and the measured pressures. The pumping speed of the NEG pumps herein is set to be 35 L/s.

As shown in Fig. 6, although the measured pressure at gauge 3 (node 39) is slightly smaller than the calculated one, the calculated values are in fairly good agreement with

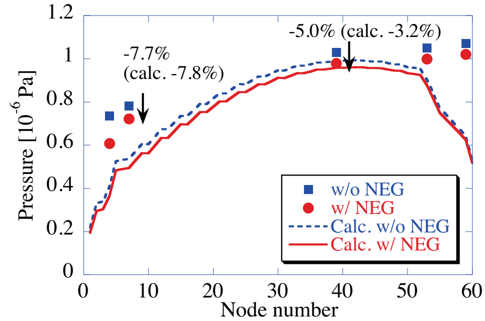

Figure 6: Pressure change between configurations with and without NEG pumps. (35-L/s NEG pumps are supposed.)

the measured ones. One possible reason for this difference is that the vacuum conductance used in the calculation was smaller than the actual ones.

The vacuum conductance of the inlet of the vacuum manifold (ICF114, 50 mm length, which corresponds to 209 L/s) is much larger than the effective pumping speed of 35 L/s. Thus, if large NEG pumps are adopted, for example, CapaciTorr D1000 (which has 2.5 times the pumping speed of the D400), 10% lower pressure can be achieved.

SUMMARY

It is possible to realize 10% lower pressure than 1×10^{-6} Pa for the ACS accelerating module using large NEG pumps (for example CapaciTorr D1000). The lifetime (interval of activation) of the NEG pumps should be considered carefully because its pumping process sorbs active gas molecules by chemical reaction. To better understand this issue, long-term evacuation tests using an ACS module and NEG pumps should be considered for future work to confirm the practical lifetime.

ACKNOWLEDGMENT

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