

HIGH POWER CONDITIONING OF ANNULAR-RING COUPLED STRUCTURES FOR THE J-PARC LINAC

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Abstract

For the energy upgrade of the J-PARC linac, 25 annular-ring coupled structure modules were fabricated and installed to a beam line. In the high-power conditioning process of these modules, we faced the issue of the unstable operation of a module No. 4. Eventually this issue was naturally resolved, however the cause of this issue was uncertain. To address the cause, we investigated the records of its vacuum pressure with attention to the fluctuations of the vacuum pressure. This result indicates that the pressure fluctuation correlates with operation stability.

INTRODUCTION

Annular-ring coupled structure (ACS) has been developed for the energy upgrade of the J-PARC linac from 181 to 400 MeV [1, 2]. The ACS is a kind of coupled-cavity linac operated in $\pi/2$ mode, for example, a side-coupled structure (SCS). Comparing the SCS, the ACS has the advantage of an axial symmetry around the beam axis, which realizes a negligible small dipole component of an accelerating field and smooth surface finishing with a ultra-precision lathe. Figure 1 shows the mechanical structure and the electric field pattern of the ACS.

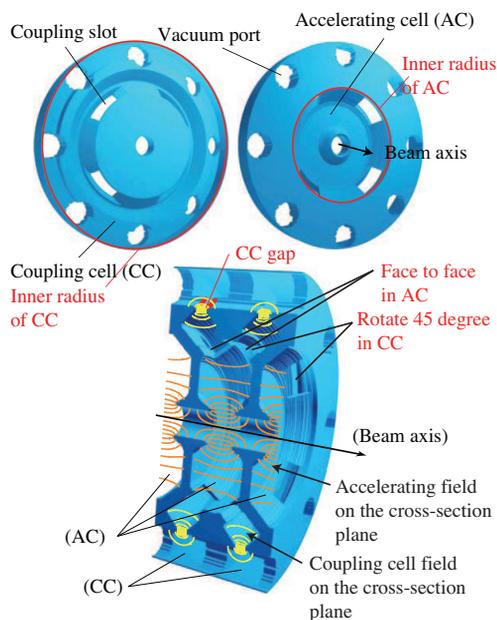


Figure 1: Structure and electric field of the J-PARC ACS [2].

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For the energy upgrade, 25 ACS modules have been fabricated in total. The configurations of the J-PARC linac before and after the energy upgrade are shown in Fig. 2. From a

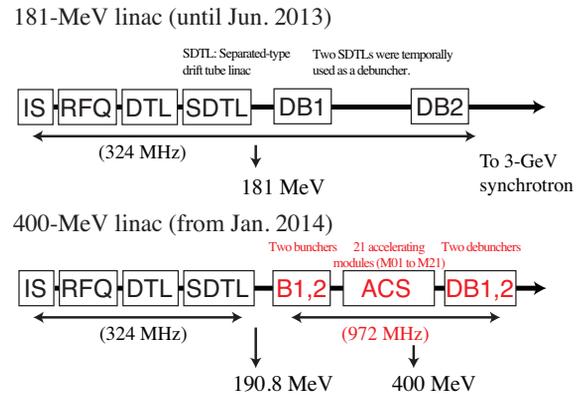


Figure 2: Configuration of the J-PARC linac.

summer maintenance period in 2013, these ACS modules were sequentially installed to a beam line. After that we started the high-power conditioning of the ACS modules. Most of ACS modules have not been powered before an installation, thus there were some troubles and issues in a conditioning process. This report focuses on a one of the most serious issues of this conditioning process: the instability of a module No. 4 (M04).

CONDITIONING HISTORY OF M04

The conditioning history of M04 is shown in Fig. 3. It should be noted that this module had been already conditioned up to 1.6 MW before the installation. This module could be, therefore, quickly and successfully conditioned more than 2 MW with a short pulse length of 50 μ s at first, and then it was reconditioned from 0 aiming at 2 MW with a long pulse length of 600 μ s, which is the design pulse length of the ACS [3]. The pulse repetition frequency was 25 Hz, which was constant through this conditioning.

After 27 hours later from starting the conditioning, input power was suddenly limited by the interlock due to RF power reflection. Figure 4 shows the detail around the interlock at $t = 28$ hours 35 minutes. As shown in Fig. 4, an RF interlock by power reflection occurred just before 28 hours 35 minutes. Just after this incident, the input power was successfully recovered to a previous power level of 1600 kW. However, in the following interlock incidents, the input power could not be recovered to the same level. Consequently, the input power gradually decreased to approximately 500 kW, which is less than 1/3 of an achieved power level of 1600 kW.

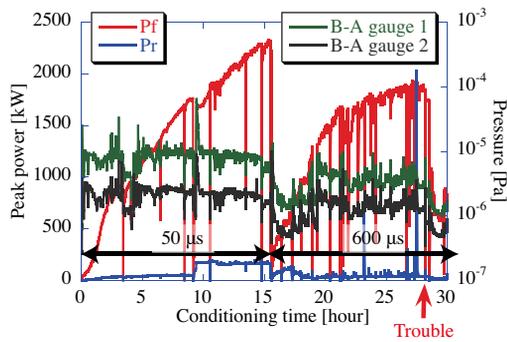


Figure 3: Conditioning history from $t = 0$ to 30 hours.

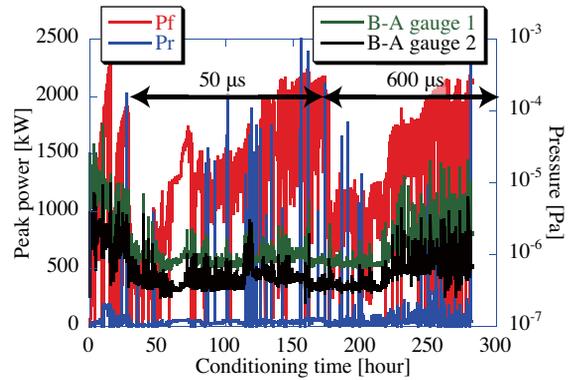


Figure 5: Whole conditioning history.

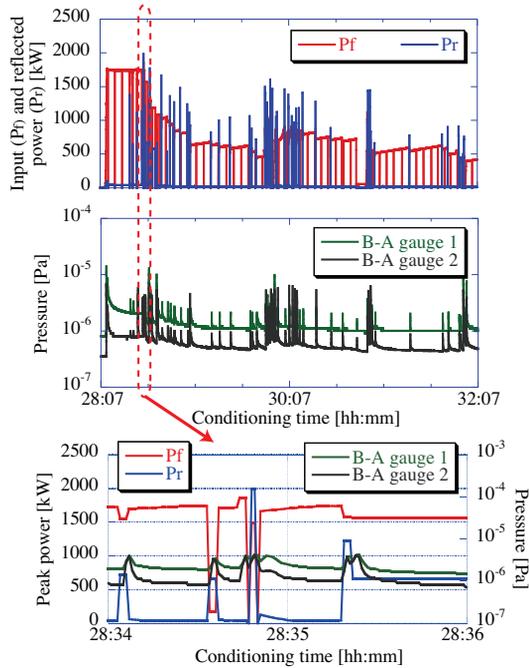


Figure 4: Detailed conditioning history around the time of the input power degradation due to an RF interlock.

period shown in Fig. 6. The interval (vertical axis) is defined as elapsed time from an interlock to the next one. The horizontal axis shows the date and time of the occurrence of each interlock.

Comparisons between a period from Jan. 17 to 21 and a period from Jan. 22 to 28 show a small extension of the stable operation time. After that, the beam commissioning continued including a 3-GeV synchrotron. Eventually, this instability was improved after starting user operation on Feb. 17 without any discoverable cause.

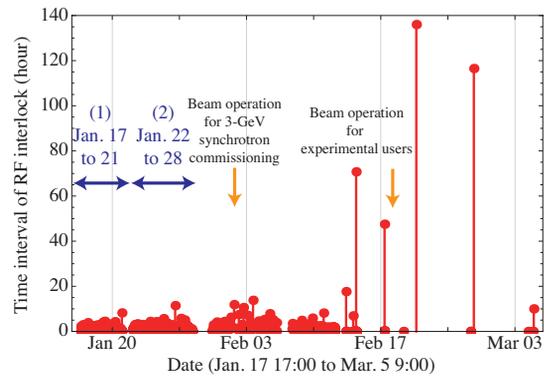


Figure 6: Long-term operation stability of M04.

Hence, from the above reasons, the pulse length was shortened to $50 \mu\text{s}$ again, and then M04 was carefully reconditioned up to 2000 kW. After this short pulse conditioning, the long pulse conditioning, a pulse length of $600 \mu\text{s}$, was restarted from 0 to 2000 kW. In this recovery conditioning from $t = 30$ to 220 hours shown in Fig. 5, the vacuum pressure was kept less than 1×10^{-6} Pa to avoid and to reduce the damage of discharging. The upper limit value of the vacuum pressure was slightly raised after $t = 220$ hours because the conditioning time run out to start beam commissioning.

RF TRIP RATE

After recovering the achieved input power of M04 as described in above section, the operation stability was still an issue for 400-MeV beam commissioning. Figure 6 shows the operation stability of M04 from a view point of the time interval of the RF interlock. M04 had been operated at an approximate input power of 1.1 MW for the most of the

STABILITY VS. VACUUM PRESSURE

As described in the previous section, the RF trip rate was sharply improved after the middle of February. In this section, we would like to consider a correlation between the operation stability and the vacuum pressure of the cavity.

Little information is available about the inside of the operating cavity: RF signals, arc sensors, and vacuum pressures. Although an arc censor was attached to M04 to monitor arcing around an RF window, no arcing was observed in the conditioning process. Thus, we investigated the RF signals, especially for reflected power, and the vacuum pressures. This data treatment process from raw data is shown in Fig. 7. The reflected power and the vacuum pressure were recorded every one second.

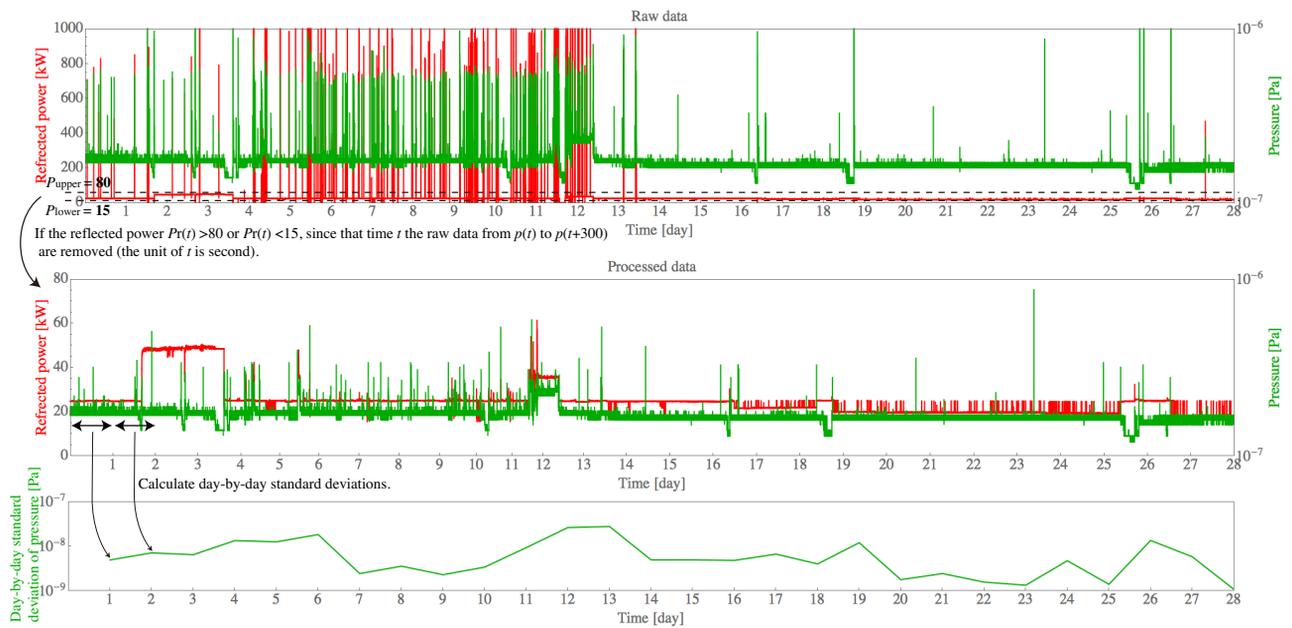


Figure 7: Reflected power and vacuum pressure of M04 in Feb. 2014. (Upper) Raw data. (Middle) After removing pressure fluctuations by an RF trip. (Bottom) Day-by-day standard deviations of the vacuum pressure.

In this data, we focused on a small fluctuation of the vacuum pressure under stable operation. To clarify this point, the pressure fluctuation due to an external source such as an RF interlock was excluded from the raw data (see the top of Fig. 7). An RF interlock was distinguished by a reflected power level: $P_r < P_{lower}$ or $P_r > P_{upper}$, where $P_{lower} = 15$ and $P_{upper} = 80$ kW were used as the lower and upper limits of a reflected power P_r . When an RF interlock occurs, simultaneously the vacuum pressure sharply increases. After that the pressure gradually decreases, and finally the pressure returns the previous value, which was typically within five minutes. We, therefore, excluded the five minutes data after an RF interlock from the raw data (see the middle of Fig. 7). Day-by-day standard deviations of the pressure were also calculated to quantitatively evaluate the pressure fluctuation (see the bottom of Fig. 7).

As can be seen from the middle of Fig. 7, there are many pressure fluctuations before Feb. 13. The standard deviations of the pressure before Feb. 13 also are larger than those after Feb. 13. These analysis results indicate that the small pressure fluctuation correlates with the operation stability and the cavity properties.

SUMMARY

We faced the issue of the unstable operation of M04 in the cavity conditioning process for the energy upgrade. Eventually this issue was naturally resolved, however the cause of this issue was uncertain. To address the cause, we investigated the records of the vacuum pressure with attention to the fluctuations of the vacuum pressure.

Even though the original source of the pressure fluctuation was not found at this time, the pressure fluctuation correlates with the operation stability. The detailed records of the RF power and the vacuum pressure (a sample rate of 1 Hz) are, therefore, useful to monitor the status of the cavity inside and its operation stability. We are planning to utilize these data processing procedures to keep a stable operation.

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