Status and Future Prospect of Muon Target at J-PARC MLF

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on behalf of Muon Science Section

A pulsed muon beam with unprecedented intensity will be generated by a 3 GeV 333 μA proton beam on a muon target made of 20 mm thick isotropic graphite at J-PARC MLF MUSE (Muon Science Establishment). The first muon beam was successfully produced on September 26th, 2008. To extend the lifetime of the muon target, a muon rotating target, in which the radiation damage is distributed to a wider area, was installed in September of 2014. The rotating target has been successfully used for five years without replacement. Meanwhile, the failure on the rotation system that leads the possibility of the loss of the transmission was found during the long-shutdown in September of 2018. The rotating target had been operated with the careful monitoring and the measures in preparation for the loss of the transmission from September 2018 to July 2019. In this report, the trouble of the rotation system and the measures at J-PARC MLF MUSE will be introduced.

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1.   Introduction

A pulsed muon beam with unprecedented intensity will be generated by a 3 GeV 333 µA proton beam on a muon target made of 20 mm thick isotropic graphite at J-PARC MLF MUSE (Muon Science Establishment). The energy deposited by a 1 MW proton beam is estimated to be 3.9 kW in the muon target. The first muon beam was successfully produced on September 26th, 2008. Gradually upgrading the beam intensity, continuous 300 kW proton beam operation has been conducted by a fixed target method without replacements till June of 2014 [1]. However, the lifetime of the fixed target will be less than 1 year by the proton-irradiation damage of graphite through 1 MW proton beam operation. To extend the lifetime, a muon rotating target, in which the radiation damage is distributed to a wider area, had been developed [2]. The muon rotating target was installed in September of 2014. The rotating target has been successfully used for five years without replacement. Since 2018, continuous and stable 500 kW proton beam operation has been successfully conducted. Accumulated operational period and the number of revolutions reaches 17000 hours and 16 million in July, 2019. Furthermore, on 3rd, July of 2019, 1 MW beam operation for 11 hours (Beam power, 935 kW: 1 MW equivalent for one pulse) was successfully achieved. Meanwhile, the damage on the flexible coupling in the rotation system was found during the long-shutdown in September of 2018. The rotating target had been operated with the careful monitoring and the measures in preparation for the loss of the transmission from September 2018 to July 2019. In this report, the trouble of the rotation system and the measures at J-PARC MLF MUSE will be introduced.

2.   Failure on the rotation system

When the rotation feedthrough between a vacuum and air was replaced as a regular maintenance in September, 2018, the damage on the flexible coupling that connects the feedthrough and the rotation shaft was found. Though the coupling had survived in spite of the damage, it completely broke to pieces through the replacement process. We recognized that the damage originates from the drawing instructions for the machining of the coupling. The inappropriate couplings were employed on the two positions of the rotation system. Figure 1 shows pictures of the rotating target assembly (right), the replacement of the vacuum feed-through with the glove box (left-up), and the broken flexible coupling (left-down). While the broken coupling was replaced with the appropriate one immediately, it was difficult for another one to replace before the restart of the beam operation because of its uneasy
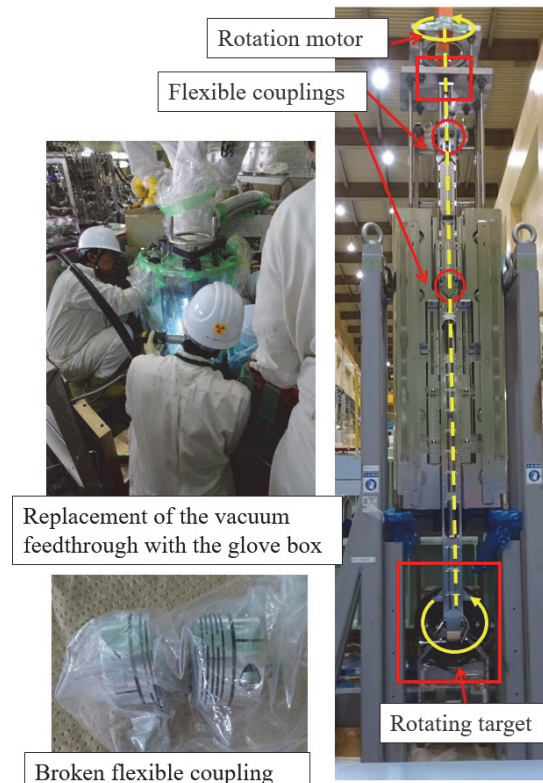

Figure 1: Pictures of the rotating target assembly (Right), the replacement of the vacuum feed-through with the glove box (left-up), and the broken flexible coupling (left-down)

accessibility, the high residual radiation dose, and the high contamination of tritium. Consequently, we decided to keep on utilizing the inappropriate coupling with the careful monitoring and the measures in preparation for the loss of the transmission.

3. Analysis of rotation stop

The rotation stops during the proton beam operation had to be detected the most reliably by the increment of the torque of the rotation motor. When the coupling breaks down, the detection might not work as expected. Therefore, the variation of the temperature and the subsequent thermal stress were carefully evaluated through a finite element method, ANSYS [3].

The graphite itself is divided to three pieces to release thermal stress originating the temperature difference on the graphite. The divided three pieces are unified as the target wheel by the centrifugal-force ring made of Nickel-based alloy. The weight of the target wheel is 3 kg, and the temperature of the target wheel reaches 930 K. The target wheel is supported by the rigid wheel support with the nine flat bars made of nickel-based alloy. The cutting section of the flat bar is rectangular of 1 mm by 10 mm, and the length of the bar is 35 mm. The rectangle is located in parallel with circumferential direction of the target wheel to release the thermal stress originating the large temperature difference between the target wheel and the wheel support as well as to support the weight of the target wheel. Figure 2 shows a picture of the rotating target. To validate the effect of the unexpected rotation stop, the maximum temperature of the graphite, the thermal stress on the graphite, the thermal stress on the flat bar are evaluated. To save time for the simulation, the simplified 3-dimensional model of the graphite wheel is used for FEM code since the results are almost similar to the full model. The thermal stress on the flat bar is evaluated by a theoretical calculation with a double supported beam model under the condition of the rotation is restricted on the both ends. The criteria of the maximum temperature of the graphite, the thermal stress on the graphite, the thermal stress on the flat bar are 2300 K, 25 MPa, 200 MPa, respectively.

Figure 2: A picture of the rotating target

Table 1 shows the results of the analyses under the conditions of 500 kW and 1000 kW with rotation (W/R) and the conditions of 500 kW, 700 kW, and 1000 kW without rotation (W/O/R). As the results of simulations, the allowable beam intensity without rotation is proved to be 500 kW. When the beam intensity is beyond 500 kW without rotation, the graphite is probably cracked and the flat bar is plasticly deformed. However, even if the temperature of the graphite reaches to 2300 K, the evaporation rate of the graphite is still low enough (1.4 μm/hour). Furthermore, the used rotating target can be replaced with a new one, because the aperture of the target chamber is large enough to extract the rotating target, even composed of the plasticly-deformed flat bars. On the other hand, the radioactive gases including tritium are produced and stored in the graphite
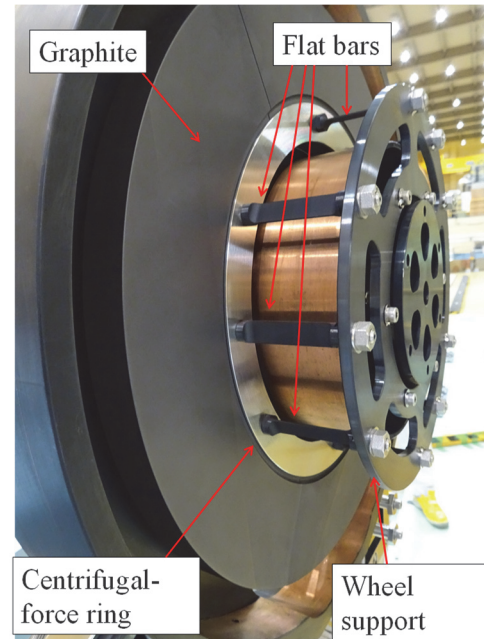
during the beam operation. The radioactive gases from the graphite at high temperature should be taken into account.

Table 1: Results of the analyses under the conditions of 500 kW and 1000 kW with rotation (W/R) and the conditions of 500 kW, 700 kW, and 1000 kW without rotation (W/O/R).

	Criteria	500 kW W/R	1000 kW W/R	500 kW W/O/R	700 kW W/O/R	1000 kW W/O/R
Max. temperature of Graphite (G.) (K)	2300	740	880	1690	1990	2390
Temperature difference on Graphite (K)	-	30	50	950	1220	1600
Equivalent stress on Graphite (MPa)	25	0.7	1.1	22	29	38
Temperature of CF ring	-	-	450	910	1000	-
Equivalent stress on flat bar	200	-	80	180	240	-

4.   Restart of beam operation

Because the results showed the 500 kW of the beam operation is acceptable, we decided to keep on utilizing the current rotating target with the inappropriate couplings. To detect the rotation stop immediately, the sensitivity of the machine protection system, such as the quadrupole mass spectrometer, the torque monitor of the rotation system, and the temperature measurement has been improved. To avoid the release of the emitted radioactive gases to the outside of the facility via the vacuum pumping system, the buffer tank was implemented to keep the pumped gas tentatively until their activities are measured and are confirmed to be low enough. Figure 3 demonstrates a schematic view of the buffer tank system. The rotating target had retreated to the escape position from 20th October to 6th November to validate the new vacuum pumping system and the buffer tank. After resume of the rotating target, the 500 kW proton beam operation had been stably conducted. In the long-shutdown of 2019, the replacement of the entire rotating target assembly was successfully completed.
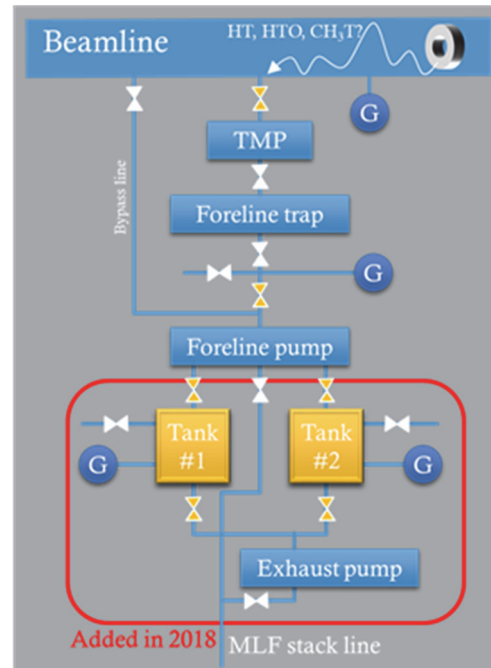

Fig. 3: A schematic view of the buffer tank system.

5.   Future Prospect of Muon Target at J-PARC MLF

The temperature of the muon rotating target cannot be measured by direct contact because it is not possible for a thermometer thermocouples to be attached to the rotating body. Thermo-couples are attached to the cooling jacket to measure the temperature rise due to thermal radiation from the muon target. However, in the case of a significant temperature rise, due to the delay in the thermocouple detection, this monitoring system cannot stop the proton beam quickly. To realize the quick measurements we are developing a real-time two-dimensional radiation

thermometer which can monitor the temperature of muon rotating target indirectly. The thermometer will be installed in September of 2019, and a validation run will initiate.

6.   Acknowledgement

References

[1] S. Makimura et al., JPS Conf. Proc. , 051002 (2015), http://dx.doi.org/10.7566/JPSCP.8.051002.

[2] S. Makimura et al., Journal of Radioanalytical and Nuclear Chemistry 305 (2015) 811-815.

[3] https://www.ansys.com/, accessed in November 2019.

[4] https://nat-web.com/, written in only Japanese, and accessed in November 2019.