Technical Evaluation of Cutting Device for Volume Reduction of High Radio-Activated Instruments

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Abstract: The cutting techniques and the basic design of cutting device for volume reduction of a mercury target vessel, with high radio-activation after operation and the cooling time about 30 years for decay heat, which is made of SUS316L steel used in J-PARC center was evaluated. Rotation blade cutting system is very useful to apply the cutting method of the irradiated vessel and the dry cutting device was conceptually designed. In this design the main specification was set to be dry cutting method and the suppression of elevating temperature during cutting. Thus, the rotation speed of the cutting device is to be 30 RPM and the transfer speed is set to be 1 mm/min. The material for the saw blade is selected to be Cr-Mo steel which has a higher strength because the irradiated 316L steel of the vessel has a high ultimate tensile strength. The circle saw blade is 420 mm in diameter and 2.7 mm in the thickness. Based on this design, a mock-up cutting test machine for dry condition with no water was fabricated, and the cutting tests was performed. The temperature during cutting in the mock-up vessel was lower than 50°C. The cutting fragments after the cutting of mock-up vessel were found to be relatively large, roughly 1 mm size. It is expected that these fragment chips would be easy to collect even in remote handling in hot cell.

KEYWORDS: Cutting device, Mercury target vessel, Volume reduction, Dry cutting, Design of cutting device

1. Introduction

The mercury target vessel [1,2] for the spallation neutron source at the Materials and Life Science Experimental Facility (MLF) [3] in the Japan Proton Accelerator Research Complex (J-PARC) was fabricated using mainly 316L austenitic stainless steel. The target vessel is replaceable type and consists of multi-walled vessels with mercury area, helium gas one and water cooling one, support frames between the vessels and a target flange, and a connection large target flange (about 1.3 m in diameter) as shown in Figure 1. The length from the flange to the front of the vessel is about 2.0 m. The target vessel is irradiated by 3 GeV protons, and the target vessel and the mercury are highly radio-activated by the irradiation [4,5]. After the operation, the mercury target vessel will be replaced by a new one, and the used vessel will be stored temporary in the storage hot cell and it needs to wait for reduction of radio-activity level. The used target vessels have to be treated by the radioactive waste processing after radio-activity cooling in near future.
The size of the vessel is relatively large, and the volume has to be reduced by cutting devices. The vessel will be irradiated and irradiation hardening will occur. Many studies of irradiation hardening are performed [6-8]. In this study the cutting techniques and the design of cutting device for volume reduction of a mercury target vessel which is made of SUS316L steel used in J-PARC center was evaluated.

Fig. 1. (a) Top view and (b) side view images of mercury target vessel. The cutting size of between A and B: 0.290 m in width and 0.122 m in height, between B and C: 0.485 m in width and 0.122 m in height, between C and D: 0.485 m in width and 0.122 m in height, and between D and E: 0.480 m in width and 0.300 m in height.

2. Basic Design of the Cutting Device

Figures 1(a) and (b) are top view image and side view one of mercury target vessel, respectively, and a plan of fifth divided regions are shown for cutting. Radioactivity ratio in the region for mercury target vessel after operation is given in TABLE I (operation condition: 1 MW, 5000 hr, decay time: 30 yr), and the total radioactivity is $1.3 \times 10^{12}$ Bq which is including $^{60}$Co with $1.5 \times 10^{10}$ Bq and $^3$H with $9.75 \times 10^{11}$ Bq. The regions of A and B have very high radioactivity and the value is corresponds to about 60%. The radioactivity percentage from region A to region D is about.

| Region | Ratio of Radioactivity |
|--------|------------------------|
| A      | 13.3%                  |
| B      | 46.8%                  |
| C+D    | 28.7%                  |
| E      | 11.3%                  |
In kinds of mechanical cutter device in nuclear facility, hacksaw, circular saw, and band saw type are often used for cutting of relatively larger size instruments and materials. As the other methods, plasma arc cutting under water, arc saw cutting, and laser cutting methods are also useful for decommissioning of nuclear facilities and instruments [9]. Handling of highly radio-activated mercury target vessels have to be treated for the cutting in hot cell by remote handling, and the system design of cutting device is basically considered that the parts of the device have to be exchanged easily by remote handling tools and it needs to reduce contamination and fragments scattered during the cutting and to decrease also the cutting temperature owing to suppress of tritium release from the materials. While, the mercury target vessel will be irradiated by 3 GeV proton beam at temperatures from about 50°C to about 150°C, and the irradiation hardening occurs. The data of austenitic stainless steels irradiated by proton beams in ORNL SNS, LANL LANSCE, and PSI SINQ were obtained and shown that the ultimate tensile strength had about 700 – 950 MPa at 10 dpa level [10,11]. From these points, it is very important to select the type of cutting device. In the specification of the design, the cutting coolant should be reduced, and no water condition is more desirable for the selection.

From these requirements, the cutting device was selected as twin circle saw type with low rotation rate. A schematic image of cutting device and the target vessel set in the cutting device is shown in Figure 2, and the specification of cutting device is given in TABLE II. The material for the saw blade is selected to be Cr-Mo steel which has a high strength because the irradiated 316L steel of the vessel has a high strength. The circle saw blade is 405 mm in diameter and 2.7 mm in the thickness.

![Schematic image of designed cutting device with twin circle saw blades and the setting Mercury target vessel for volume reduction. The diameter of blade is 405 mm.](image)

**Fig. 2.** Schematic images of designed cutting device with twin circle saw blades and the setting Mercury target vessel for volume reduction. The diameter of blade is 405 mm.
3. Fabrication of mockup cutting device and the cutting test

Figure 3 shows a circle saw type of a mockup cutting fabricated from the basic design evaluated in section 2, and the mockup specimen which has a similar curvature and thickness (t=8 mm) with the mercury vessel was prepared and set in it. In Figure 4, in situ of cutting test for mock-up vessel and circle saw blade are shown under a slow rotation speed of 30 RPM and a transfer speed of 1 mm/min. Appearance of temperature measurement under cutting by radiation thermometer is seen in Figure 5, and the temperature during cutting was 38°C. The result was judged to be very good. In Figure 6, many cut fragments after the cutting test of the mock-up vessel are shown, and the size of the fragments are found to be relatively large. These fragments can be expected to be easily collected even in hot cell by remote handing tools.

![Figure 3](image1)
![Figure 4](image2)

**Table II.** Specification of Cutting Device.

| Items                  | Test Condition |
|------------------------|----------------|
| Rotation Speed         | 30 RPM         |
| Transfer Speed         | 1 mm/min       |
| Cutting method         | Dry Cutting    |
| Blade size             | Φ405mm, t= 2.7 mm |
| Number of blades       | 60             |
| Material of blades     | Cr-Mo steel    |
| KS5 (JIS G 4404)       |
| Hardness (HRC)         | 45             |
4. Conclusion

The cutting techniques and the basic design of cutting device for volume reduction of a mercury target vessel, with high radio-activation after operation and the cooling time about 30 years for decay heat, which is made of SUS316L steel used in J-PARC center was evaluated. Rotation blade cutting system is very useful to apply the cutting method of the vessel and the dry cutting device was designed. In this design the main specification was set to be dry cutting method and the suppression of elevating temperature during cutting. Based on the basic design, a mock-up cutting test device for dry condition with no water was fabricated, and the cutting tests was performed. The temperature during cutting in the mock-up vessel was lower than 50°C. The size of cutting fragments after the cutting of mock-up vessel were found to be relatively large, roughly 1 mm size. It is expected that these fragments would be easy to collect even in remote handling in hot cell.

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