Thermo-mechanical simulation of high-power rotating target for BigRIPS separator

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Thermo-mechanical simulations have been performed for the high-power rotating target system[1,2] of the BigRIPS separator in order to evaluate the stability of the rotating target against high-power beam irradiation. A 2-mm-thick Be target rotating at 300 rpm is expected to heat up to 1230°C[3] with a ^{238}U beam at an energy of 345 MeV/nucleon and intensity of 1 particle μA, which meets the target beam intensity of RIBF. The Be target does not melt in the heat of the beam, because the melting point of Be is 1287°C. However, it is not clear whether the target is stable under thermal deformation or the destruction of the target at such a high temperature. Thus, the thermo-mechanical simulation of the rotating target was performed to check its stability.

Coupled transient thermal-structural finite-element analysis using the simulation code ANSYS[4] was utilized for the thermo-mechanical simulation. In the first step, the temperature distribution of the rotating target was obtained through a transient thermal calculation with the moving heat-source model described Ref. 3). The simulation model consisted of the Be target with a diameter of 300 mm and thicknesses of 2, 3, 4 mm and a cooling disk with a diameter of 240 mm and a thickness of 25 mm in which a cooling water channel was formed. The temperature dependence of thermal conductivity and heat capacity were taken into account in the calculation. Heat transfer coefficients of 10.5 and 3 kW/m^2 K were used for thermal contacts between the cooling water and cooling disk and between the cooling disk and Be target, respectively. The obtained time-dependent temperature distribution was then transferred to the transient structural calculation with ANSYS under elastic and plastic deformation. The deformation and stress caused by the thermal expansion of the target at the given temperature distribution were calculated in a time-dependent manner. The temperature dependence of the Young's modulus, strain-stress curve (bilinear hardening is assumed), and thermal expansion coefficient of the Be target were taken into account in the calculation.

Figure 1 shows the calculated results for a ^{238}U beam at 345 MeV/nucleon and 1 particle μA with a size of 1 mm^2 impinging on a 2-mm-thick Be target rotating at 300 rpm. In the figure, only half of the model is displayed in order to show the cross section of the target. In Fig. 1(a), the temperature distribution is mapped in color on the original model shape. The highest temperature is observed at the beam spot, and the high-temperature region is spread along the beam trajectory. The Von Mises stress due to the thermal expansion is mapped on the deformed model shape in Fig. 1(b). The deformation is magnified by a factor 50 and shown in Fig. 1(b). The Be target is enlarged by 0.6 mm in the radial direction and bent toward the cooling disk by 0.3 mm at the circumference. Thus, the deformation is very small compared with the 300-mm diameter of the rotating target. A small but finite plastic deformation is observed along the beam trajectory. This is why the von Mises stress at the beam trajectory decreases after the beam passes. A plastic expansion occurs at the beam spot, and the expanded shape is retained even when the temperature drops after the beam passes through.

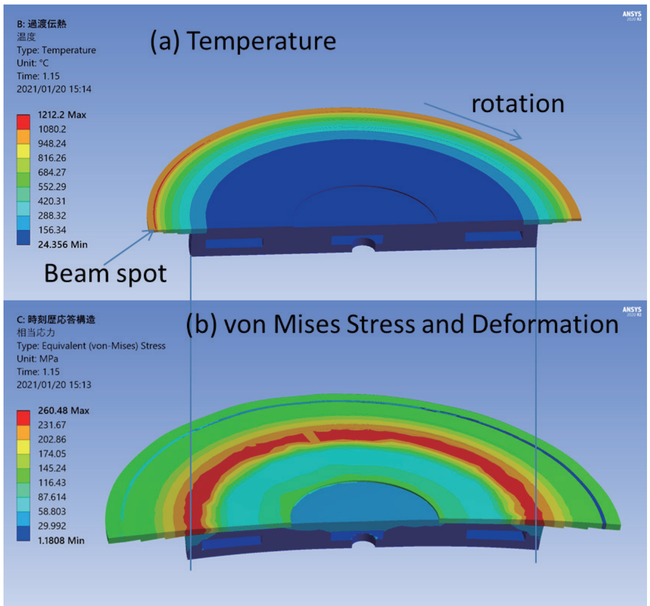

Fig. 1. Results of thermo-mechanical calculation of the rotating target. Only half of the simulation model is displayed in the figure to show the cross section of the target. (a) Temperature distribution of the target displayed in color on the original model shape (not deformed). (b) von Mises stress distribution displayed in color on the deformed shape. Deformation was magnified by a factor 50 so that the deformation can be viewed easily.

The maximum von Mises stress of 260 MPa appeared at the contact region between the target and cooling disk. The value is well below the ultimate tensile strength of 440 MPa. The calculation results show that the rotating target is stable under thermal deformation and destruction.

References
1) A. Yoshida *et al.*, Nucl. Instrum. Methods Phys. Res. A **521**, 65 (2004).
2) A. Yoshida *et al.*, Nucl. Instrum. Methods Phys. Res. A **590**, 204 (2008).
3) K. Yoshida *et al.*, RIKEN Accel. Prog. Rep. **53**, 103 (2020).
4) ANSYS. Inc Product Release 20.

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