Thermo-mechanical calculations of the high power beam dump of the BigRIPS separator

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The beam dump is a critical component for the in-flight fragment separator that uses high-power primary beams at the RI Beam Factory (RIBF). The exit beam dump and side dump of the BigRIPS fragment separator were designed and constructed in 2007. The maximum beam power is planned to be 82 kW for ^{238}U at 345 MeV/nucleon, and most of the beam power is dissipated to a target and a beam dump. The beam dump system has been successfully operated so far, although the available beam power is still less than the goal power value. The temperature of the beam dump was measured and the observed temperature was compared with the value calculated by the finite element analysis (FEA).[1)] An important aspect in high-power beam dump design is to limit the maximal temperature due to beam energy loss in the material. Controlling this absorbed power is a key challenge. The technical challenges include overheating and excessive thermo-mechanical stress load variations caused by the high beam intensity. Since the available beam intensity is lower than the goal value, the finite element thermal analysis code, ANSYS,[2)] was used to study these technical issues for 1 particle μA which corresponds to a beam power of 82 kW in the case of ^{238}U. Steady state structural FEA was performed to estimate the static stress around the exit beam dump.

To perform the thermo-mechanical simulation a 3D solid model of the exit beam dump was considered and meshed with high-order tetrahedral elements, which is shown in Fig. 1. The exit dump is a V-shaped CuCrZr plate equipped with screw tubes (M8 1.25-pitch screw formed every 14 mm) as cooling channels.[3)] Cooled water with a temperature of 13°C, a pressure of 1.0 MPa, and a flow speed of 10 m/s was supplied to the dump as the coolant. The heat transfer coefficient of the screw tube was calculated (using JAERI formula[4)]) and used in the simulation. The mechanical temperature-dependent properties of the CuCrZr for the FEA are taken from similar work.[5)] The literature results show that the CuCrZr alloy exhibits good strength and plasticity simultaneously between room temperature and 350°C. The value of the ultimate tensile strength is 308±15 MPa at 350°C. This ensures that the CuCrZr alloy has enough strength to be applied under the high temperature condition.

Figure 1 shows the solid model of the exit beam dump and the result of the equivalent stress on the exit beam dump by the static structural analysis. The beam size at the stopping location was estimated from the first-order optics calculation of the BigRIPS separator with respect to the primary beam trajectory. In the calculation, the input power was given as the heat generation, which is approximately 49 W/mm^3. The maximum temperature of the beam center is approximately 355°C and the maximum von-Misses stress is 291 MPa under the above mentioned conditions.

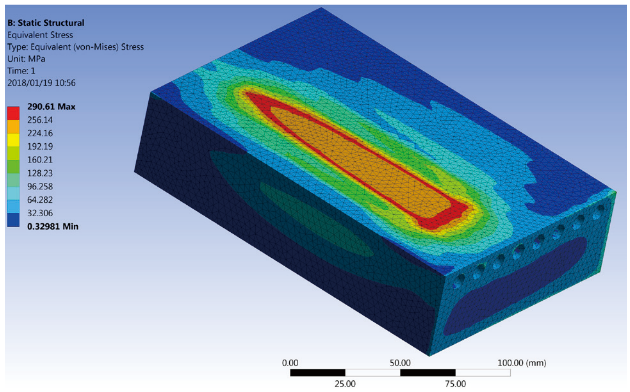

Fig. 1. Calculated equvialent (von-Misses) stress on the exit beam dump.

The simulation results showed that the maximum temperature exceeds the critical limit (350°C) to avoid creep and softening under irradiation for the CuCrZr alloy while the maximum stress is found at the limit of the ultimate tensile strength. The thermal creep effect needs to be considered at a temperature more than 350°C. When the thermal and thermo-mechanical data can be measured, the beam dump should be tested with a high intensity beam in order to understand and characterize the thermo-mechanical challenges and validate simulation results.

References
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