MECHANICAL DESIGN OF A HEAVY ION BEAM DUMP FOR THE RIA FRAGMENTATION LINE *

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Abstract

The RIA fragmentation line requires a beam stop for the primary beam downstream of the first dipole magnet. The beam may consist of U, Ca, Sn, Kr, or O ions. with a variety of power densities. The configuration with highest power density is for the U beam, with a spot size of 3 cm x 3 cm and a total power of up to 300 kW. The mechanical design of the dump that meets these criteria consists of a 70 cm diameter aluminum wheel with water coolant channels. A hollow drive shaft supplies the coolant water and connects the wheel to an electrical motor located in an adjacent air space. The beam strikes the wheel along the outer perimeter and passes through a thin window of aluminum where 15% of its power is absorbed and the remainder of the beam is absorbed in flowing water behind the window. Rotation of the wheel at 400 RPM results in maximum aluminum temperatures below 100 °C and acceptably low thermal stresses of 3 ksi. Rotating the wheel also results in low radiation damage levels by spreading the damage out over the whole perimeter of the wheel. For some of the other beams, a stationary dump consisting of a thin aluminum window with water acting as a coolant and absorber appears to be feasible.

Introduction

The Rare Isotope Accelerator (RIA) generates heavy ion beams with a power of 400 kW. After passing through a target and the first dipole magnet, approximately 295 kW of the heavy ion U beam is absorbed in a beam dump. The beam dump design consists of a rotating barrel shape with the beam partially absorbed in 2 mm of aluminum material and the rest of the beam absorbed in 2 cm of depth of flowing water behind the aluminum.

Analyses of the energy deposition of the beam in the dump material were made. The thermal and structural response of the dump due to the energy deposition was also analyzed. Rotation of the dump is necessary to reduce the volumetric energy deposition to result in lower temperatures, thermal stresses and radiation damage in the material.

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U Beam parameters

The U beam impacting the beam dump has a power of 295 kW and has a profile as shown in figure 1. The beam ions have an energy of 400 Mev per nucleon.

Other profiles for the essentially fully ionized U beam are as shown in figure 2. The U^{+90} charge state here is the part of the beam of most concern because its width is less than 1 cm and its power is high at 184 kW.

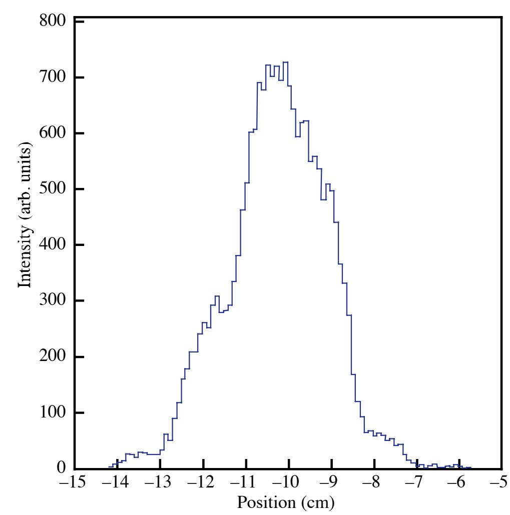

Figure 1: U beam horizontal profile [1].

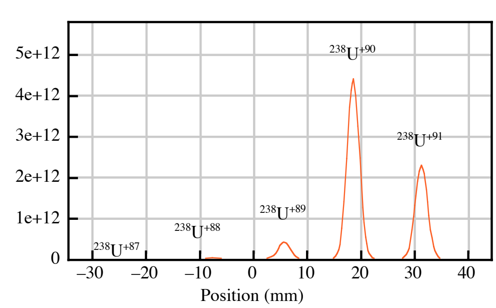

Figure 2. Narrow width U^{+90} charge state beam, 184 kW [2].

Design layout of the beam dumps

The beam dumps are barrel shaped and rotate about a horizontal axis. The dumps are located between the first dipole magnet and multipole magnet. Figure 3 shows the two dumps in place and figure 4 shows the individual dump module.

The dumps are located in a vacuum space surrounding the dipole magnet. The dumps have a diameter of 70 cm

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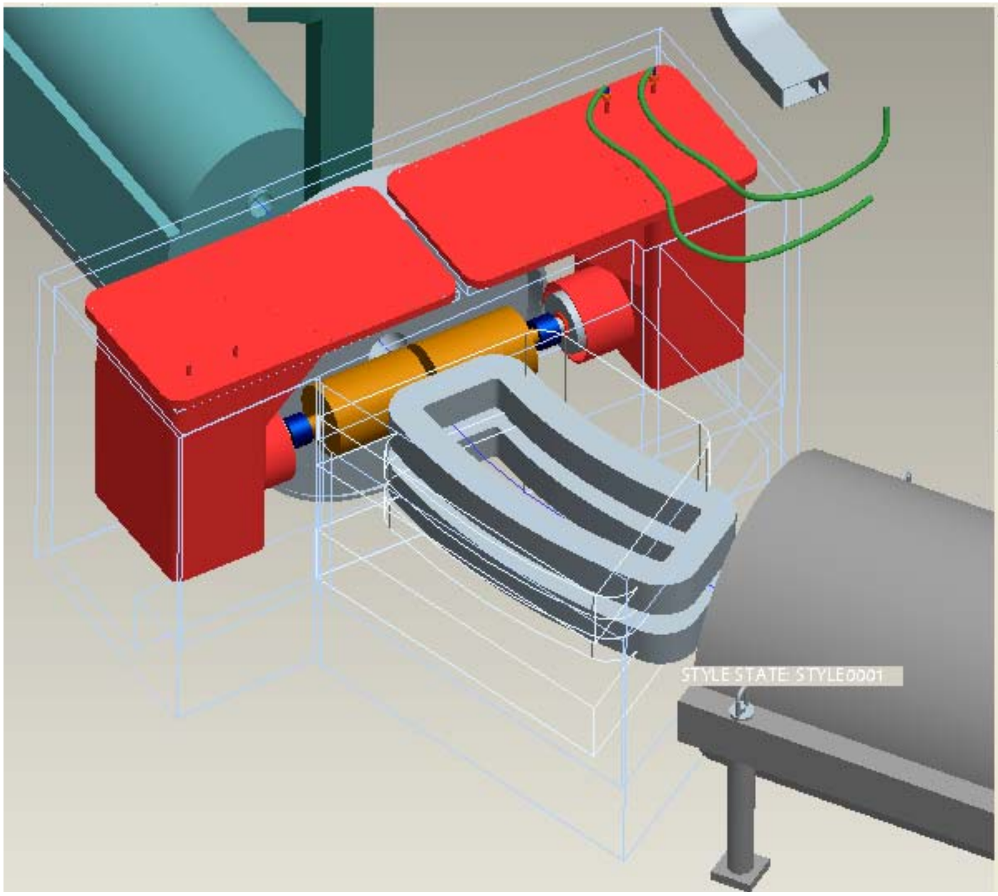

Figure 3: Two barrel shaped beam dumps located in the vacuum space between the first dipole and multipole magnets.

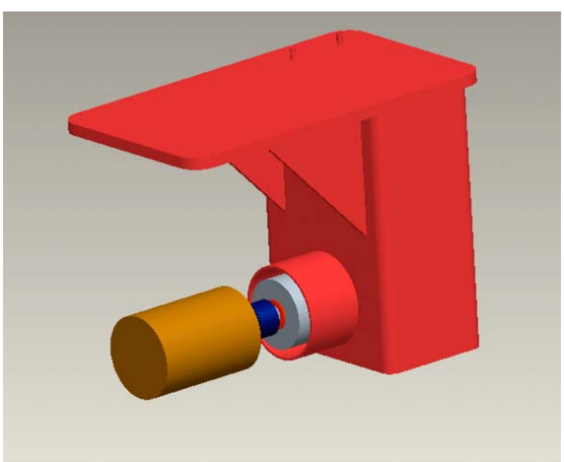

Figure 4: Individual beam dump module.

and are 70 cm long axially. Water cooling flows along the dump shaft and out to the perimeter of the barrel as shown in figure 5. The dump rotates at a speed of 400 RPM resulting in a 10 m/s velocity at the dump surface. The water velocity is 10 m/s in the axial direction in the annulus near the dump surface.

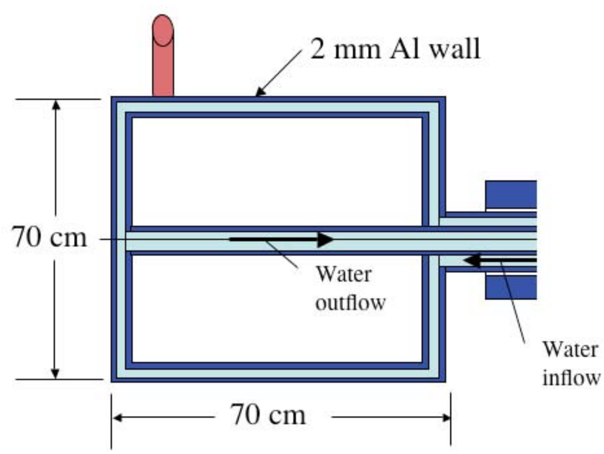

Figure 5: Cross-section of dump barrel.

Thermal stress calculations

The beam impacts the rotating aluminum material of the dump and causes a rapid temperature jump or rise over the spot dimension of the beam along the direction of rotation of the dump. The power deposited by the beam results in an increase in the aluminum temperature and the energy deposition in 2 mm of aluminum is estimated at 15% of the beam total power. This rise in temperature is however dissipated by conduction heat transfer in the aluminum and by convection heat transfer to the water behind the aluminum barrel wall. As the barrel rotates, after each revolution, a region of the dump is impacted again by the beam and heats up a further amount. The temperature of the dump material over time achieves a steady cyclical oscillation that is a balance between conduction and convection heat transfer and the beam heating every rotation.

Figure 6 shows the results of a thermal calculation (using Topaz-3d [3]) showing a temperature rise of 19 °C as the beam of figure 1 impacts the 10 m/s velocity dump material.

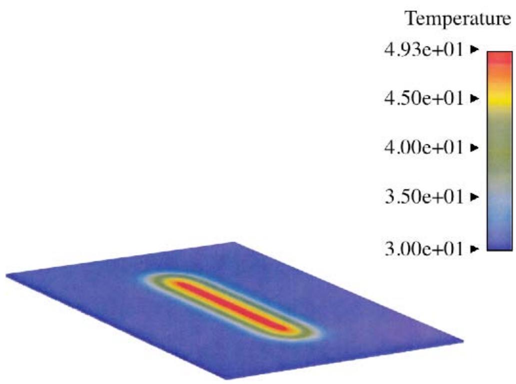

Figure 6. Temperature, °C, jump as beam penetrates the aluminum material of the dump barrel.

The resultant stress from this energy deposition is calculated (using Dyna3d [4]) at 3 ksi ($2.14x10^7$ Pa) and is shown in figure 7. The allowable fatigue stress for the aluminum alloy may be as high as 20 ksi ($1.4x10^8$ Pa) and thus the calculated stress is below allowable limits.

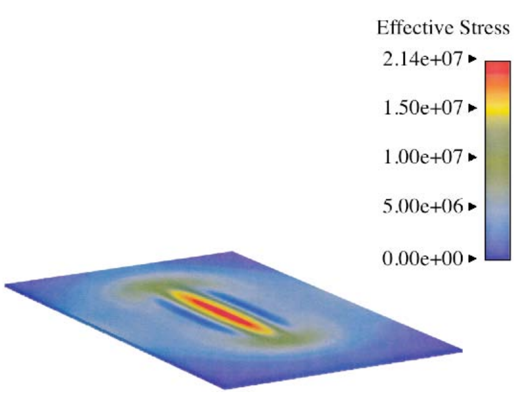

Figure 7. Thermal stress, Pa, in aluminum window of the barrel dump due to beam penetration.

Cooling Calculations

Water is used to cool the beam dump aluminum material and is used to absorb the portion of the beam that passes through the aluminum outer surface of the barrel. The water velocity along the barrel surface is 10 m/s and results in a convective heat transfer coefficient of 40,000 $W/m^2/°C$ based on Nusselt correlations. With this heat transfer coefficient, the aluminum metal temperature in the heated ring region around the barrel will be an average of 30 °C or less below the water temperature.

As the water flows by the beam penetration region on the barrel surface, the approximately 85% of remaining beam power is absorbed in the 2 cm depth of the water. A heat balance between the volume flow rate of water and the energy deposition rate of the beam results in an estimated maximum water temperature jump of 15 °C.

Radiation damage

The U beam impact on the aluminum material results in dislocations of the aluminum atoms. The number of dislocations per atom (DPA) is a measure to quantify radiation damage. For our case, an estimate for DPA's is that 0.5 DPA is reached after 10 years of operation. Material damage also occurs due to gas generation and has not yet been quantified. Experimental radiation tests of the material are planned to verify the material integrity for expected lifetime radiation doses.

Summary

The RIA fragmentation line beam dumps are designed to absorb heavy ion beams up to 300 kW. Due to the high energy deposition of the beam, the beam is allowed to deposit a fraction of its energy in a thin window layer of aluminum alloy before depositing the bulk of its energy in a layer of water. To further reduce the energy deposition rate in the dump, the dump is designed as a rotating barrel which results in spreading the energy deposition around the perimeter of the barrel. Material and water temperatures are below 100 °C and thermal stresses are below 10 ksi.

Mechanical design of the dump includes an electric motor to rotate the barrel, a rotating vacuum/air shaft seal, and a bellows arrangement that allows remote horizontal movement. Continuous operation of the dump for more than 10 weeks at a time is expected.

REFERENCES

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