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W. Stein

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RIA FRAGMENTATION LINE BEAM DUMPS

W. Stein, Lawrence Livermore National Laboratory, Livermore, CA 94551, USA

Abstract
The Rare Isotope Accelerator project involves generating heavy-element ion beams for use in a fragmentation target line to produce beams for physics research. The main beam, after passing through the fragmentation target, may be dumped into a beam dump located in the vacuum cavity of the first dipole magnet. For a dump beam power of 100 kW, cooling is required to avoid excessive high temperatures. The proposed dump design involves rotating cylinders to spread out the energy deposition and turbulent subcooled water flow through internal water cooling passages to obtain high, nonboiling, cooling rates.

Introduction

The RIA accelerator beams consist of particles in a range from protons to uranium ions, which are impacted on either ISOL or fragmentation line targets. Downstream of the fragmentation target, the beam is separated from the fission fragments and other ions by the fragmentation line dipole magnets. The separation of the main beam from the fission fragments and other ions results in the main beam impacting on one side or the other of the first dipole magnet vacuum cavity or passing through the magnet and being absorbed in a downstream beam dump.

To absorb the high-power beam requires a beam dump located in the first dipole magnet cavity and a dump located downstream of the first dipole magnet. The dumps need to be designed to absorb up to 100 kW of power and thus they require a good cooling system to avoid structural and melting problems.

In this report, a dump design is investigated that consists of rotating cylinders placed along the sides of the first dipole magnet vacuum chamber. The beam is assumed to impact the rotating cylinders at a shallow angle and the beam power deposited in the dump is removed by coolant water flowing in the coolant channels.

The analysis results show that when the cylinders are rotated, the beam heat flux values on the dump are lower than the stationary case by a factor of 19, and temperatures reached in the dump are maintained well below boiling temperature values.

Background

Beam dumps for low-power beams have been used in accelerators. When the power is low, the use of bars, bricks, or other barriers is possible because of the relatively low changes in dump temperature as the beam is absorbed.

For other, higher-power beams, dumps have been designed for the proton beams at the ISAC facility at TRIUMF in Vancouver, Canada that consist of water and copper plates. For RIA-like beams, the designs[1] of dumps in the RIKEN accelerator fragmentation line dipole magnets use copper tubes with enhanced swirling of the water. The design relies on high heat-transfer coefficients and relatively high boiling in the water.

The approach taken to design beam dumps for RIA in this paper is to rely on convection from water flow to cool the copper dumps. The water-flow cooling will rely on turbulent, subcooled (nonboiling) water to cool the dump and avoid any possible problems from the flow instabilities of boiling water.

Beam Dump Design

Beam energy deposition

The beam for the fragmentation line impacting the fragmentation target has a nominal diameter[2] of 1 mm and a power of 100 kW, with an energy of 400 MeV per nucleon. After passing through the fragmentation target, the beam emerges with a slight angle spread and passes into the first dipole magnet. The beam is estimated to be at a diameter of 2 cm as it impacts the beam dump. Selection of desired fission fragments by adjustments in the magnet results in the beam striking either side of the magnet vacuum chamber.

When the beam strikes the metal of the beam dump, the energy of the particles penetrates and deposits energy, Fig. 1, at an increasing rate with penetration depth; this is shown qualitatively as in a Bragg curve:

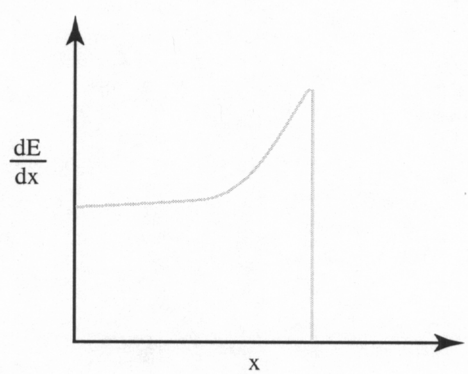

Fig. 1. Energy deposition rate of uranium ions in copper.

dE/dx equals the energy deposition as a function of depth, and x equals depth into the material. For 400 MeV per nucleon uranium ions into copper, a TRIM[3] calculation of energy deposition was made[4]. The uranium beam penetrates to a depth of 4 mm into the copper.

Beam Dump Geometry
The arrangement of the fragmentation target and the fragment separator first dipole magnet is shown in Fig. 2. The beam dump is located in the first dipole magnet of the separator and consists of two rotating cylinders on each side of the dipole magnet vacuum cavity. This is shown schematically in Fig. 3.

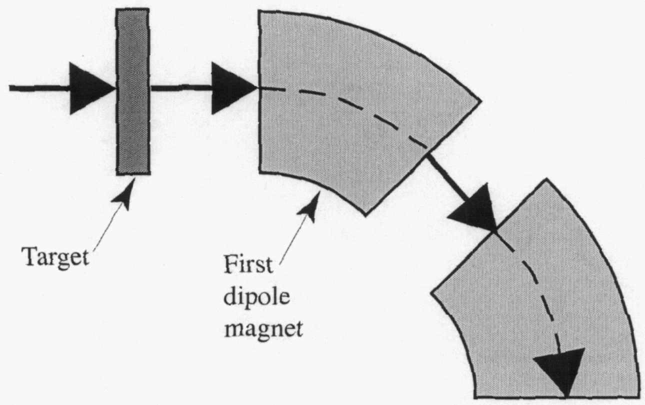

Fig.2. Fragment separator and target schematic.

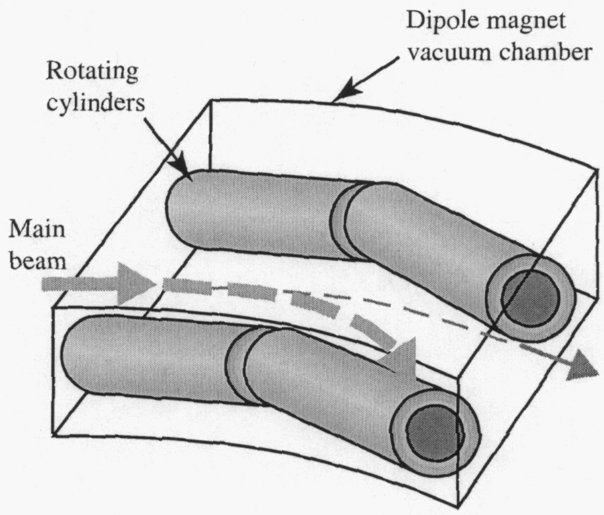

Fig. 3. Beam dumps located in the first dipole magnet cavity.

The dump material chosen is copper because of its high thermal conductivity. Fig. 3 shows schematically the beam striking the side of the rotating cylinder at an angle estimated to be 15 deg. The beam dump consists of a cylinder with many small water-coolant channels as shown in Fig. 4. Water is used as the heat transfer liquid because of the high heat-transfer rates achievable versus using air. The cylinder outside diameter is 12 cm and the inner diameter is 10.2 cm. The longitudinal channels are 1 mm wide, 2 mm high, and spaced 1 mm apart. The cylinder is assumed to be rotating in order to spread out the beam energy over the greatest possible dump surface area. Rotation of the cylinder is necessary because it results in surface heat fluxes that are approximately

19 times lower than if the cylinders were not rotating. The resultant heat fluxes from the beam will then also result in dump temperatures low enough to avoid boiling.

An infinitely high rotation speed would spread out the beam energy deposition perfectly over the rotating cylinder, but a rotation speed of 600 rpm will also effectively accomplish this. The rotation speed is calculated by having the cylinders complete one revolution in the time for which the thermal penetration depth is small (1 to 2 mm).

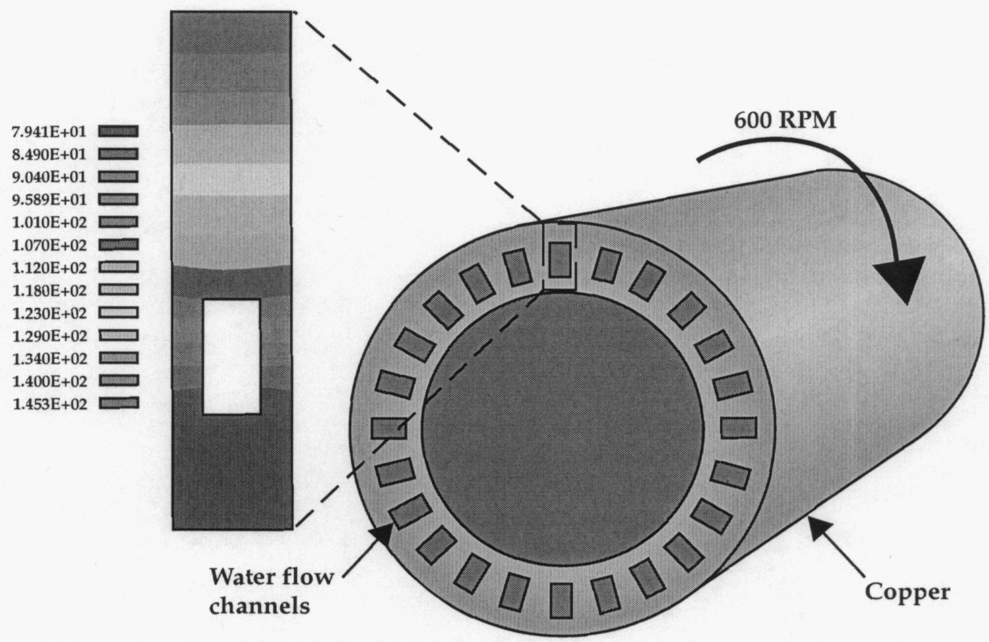

Fig. 4. Schematic cross-section of beam dump cylinder design. Calculated temperature profile in a dump cross-section (20 °C water).

Heat-transfer analyses

The impact of the 2-cm-diam beam with a 15 deg angle on the rotating surface will result in the 100-kW beam being spread out over a cylindrical surface that has a diameter of 12 cm and a length of 7.5 cm. At 15 deg, the ions penetrate to a depth of approximately 1 mm from the surface, and thus the problem is modeled with a surface flux of 3.6 MW/m^2. The cooling water is assumed to have a velocity of 10 m/s and a conservatively low turbulent convection heat-transfer coefficient of 20 $kW/m^2{}^\circ C$. The heat-transfer coefficient is calculated from Nusselt number, Nu, correlations[5] for turbulent water flow with applicable Reynolds, Re, and Prandtl, Pr, numbers:

$$Nu = 0.023(\mathrm{Re})^{0.8}\,\mathrm{Pr}^{1/3} \qquad (1)$$

Inlet water pressure is assumed to be 3 atmospheres and the inlet water temperature is 20 °C. For 100 kW of power, the water heats up less than 6 °C over its flow length.

A two-dimensional heat-transfer analysis was made to determine copper surface peak temperatures and also annulus water–copper surface temperatures. The LLNL two-dimensional finite element heat-transfer code, TOPAZ2D[6], was used to make the calculations. The code modeled the energy deposition rate per unit volume on the outside region of the copper dump, the thermal conduction heat transfer in the copper, and the convection heat transfer to the 20 °C water with a convection heat-transfer coefficient.

Fig. 4 shows a fringe plot of the temperature profile in a cross-section of the beam dump. The plot shows that the peak surface temperature of the copper on the outside diameter of the cylinder is 145 °C and the peak temperature of the channel wall is 110 °C with a water bulk temperature of 20 °C. The boiling temperature of water at 3 atmospheres is 133 °C; the channel wall temperature of 110 °C is well below that.

Future Work

Additional work on developing the beam dump designs is required to address the following concerns:

1. A design for a beam stop is required for instances where the beam passes through the dipole magnet vacuum cavity without impacting the cavity sides.

2. Analyses are required to determine the effects of radiation damage on the copper structural properties and the effects on the thermal properties. The goal of these analyses is to obtain lifetimes of several years.

3. The mechanical aspects of the design must be developed, including the design of the water cooling manifolds, the rotation of the dumps, and the use of vacuum-seal technology to develop the vacuum-seal design for rotating water coolant pipes penetrating the vacuum walls of the dipole magnet.

4. The effects of eddy currents set up by the rotating cylinders in the magnet fields must be mitigated.

References

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