Design of a beam dump for the 100 MeV proton accelerator of PEFP

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ABSTRACT

The proton energy and average current of the Korean Multipurpose Accelerator are 100 MeV and 1.6 mA, respectively, and they create a beam power of 160 kW. To absorb such a high energy a beam dump should be designed such that a beam is spreaded as widely as possible on a given dump area and an efficient cooling system needs to be installed. In this paper, the design concept of a 100 MeV PEFP beam dump to safely absorb a proton beam energy is presented. For a selection of the beam dump material, a 100 MeV proton power density distribution analysis, a stopping range calculation, a neutron and photon yield analysis, and a residual activity analysis were carried out for 6 different materials such as water, graphite, copper, nickel iron, and aluminum. For the structural integrity assessment an erosion test for the nickel coated surface, a preliminary heat transfer analysis, and a thermal stress analysis were also carried out. The results show that copper is the relatively better material for the 100 MeV beam dump in view of its residual activity, and the temperature and stress requirements for the structural integrity are also satisfied.

INTRODUCTION

The beam dump for the 100 MeV proton accelerator of PEFP is located downstream of the proton production arc for a continuous absorption of the generated beam energy. The proton energy and the average current of the PEFP accelerator are 100 MeV and 1.6 mA, respectively. These create a beam power of 160 kW, which generates a maximum heat flux of about 500 MW/m^2. This heat flux is 500 times higher than the PWR fuel rod and 50 times higher than the nuclear fusion diverter. To absorb such an extremely high energy the proton beam is expanded to decrease the peak heat flux by a special mechanism. In this regard the basic design requirement for the 100 MeV PEFP beam dump is to efficiently absorb the beam energy while maintaining the structural integrity of the beam dump under a high thermal stress. Another important design requirement is related to the residual activity by the proton.

Kim[1] designed a beam dump for the 20 MeV proton accelerator of PEFP as shown in Figure 1.

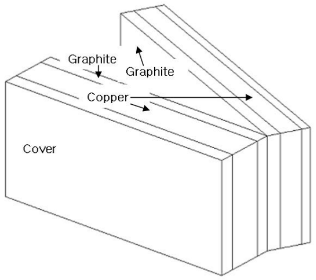


Fig.1 Design Concept of 20 MeV Proton Beam Dump of PEFP

The V-shaped plate type beam dump adapted in the 20 MeV proton beam dump makes it possible to decrease the high beam density by spreading it widely over the dump surfaces. The beam is stopped in the graphite of IG-430 and the generated heat is cooled by a cooling jacket on the rear of the OFHC plate. Gil[2] studied an activation of the 20 MeV PEFP beam dump and concluded that the beam dump with graphite-copper can reduce an activation by about 100 times more than that with only copper.

SELECTION OF THE 100 MeV BEAM DUMP MATERIAL

A proper material of the beam dump should be selected by considering its power density distribution, the residual activity, heat conductivity, and its structural strength. In this paper, six materials such as water, graphite, aluminum, copper, iron, and nickel were compared. Figure 2 is the proton peak energy deposition and Table 1 is the stopping range calculation results for the 6 different materials. The stopping range is about 77mm in water and 35~38mm in graphite and aluminum, and 12~14mm in copper, iron, and nickel.

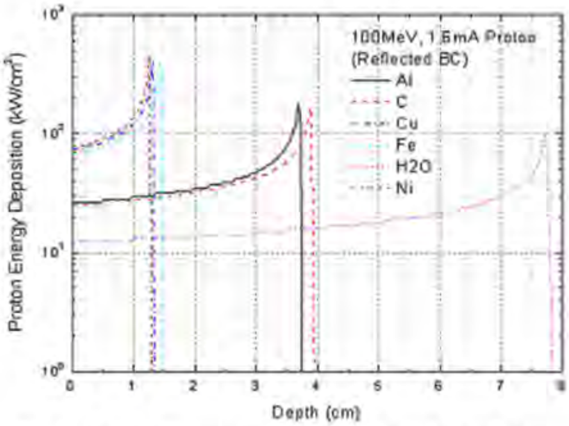


Fig.2 100 MeV Proton Power Density Distribution

Table 1. Stopping Range of the Various Materials

Materials	100 MeV	20 MeV
water(H2O)	77 mm	4.2 mm
graphite(C)	38.6 mm	2.1 mm
aluminum(Al)	36.9 mm	2.1 mm
copper(Cu)	13.1 mm	0.79 mm
iron(Fe)	14.3 mm	0.8 mm
nickel(Ni)	12.5 mm	0.75 mm

Table 2 is the neutron and photon yield for the 6 different materials and Figure 3 is the MCNPX Model for this calculation. The table shows the graphite yields less neutron than the other materials and copper yields relatively more neutron. Figure 4 shows the residual activity analysis results after an irradiation by 100 MeV, 1.6 mA proton for 3 hours for the 6 materials.

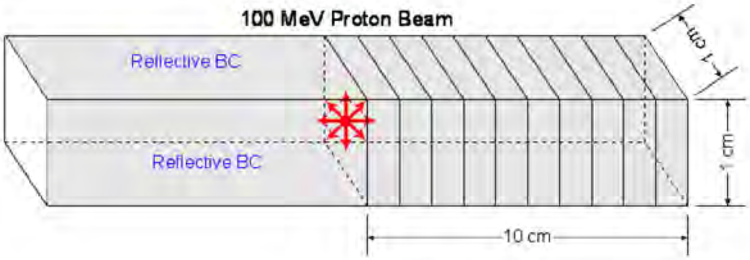


Fig.3 MCNPX Model

Table 2. Neutron and Photon Yields for the Various Materials

Materials	Neutron	Photon
water(H2O)	0.0393(4.86E-8)*	0.1066(3.36E-9)
graphite(C)	0.0365(1.03E-7)	0.0998(1.96E-9)
aluminum(Al)	0.0884(1.81E-7)	0.3944(4.38E-9)
copper(Cu)	0.2515(5.23E-7)	1.5202(3.74E-9)
iron(Fe)	0.1617(3.23E-7)	1.0075(2.81E-9)
nickel(Ni)	0.0986(2.03E-7)	0.8049(2.08E-9)

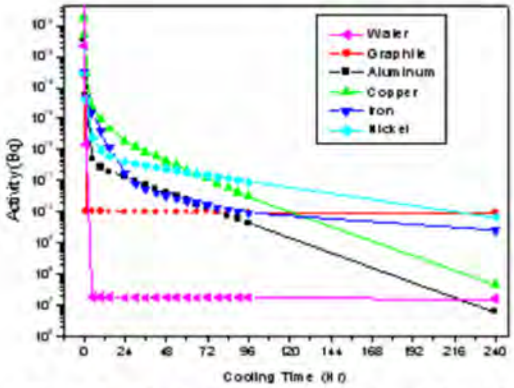


Fig.4. Residual Activities in Various Materials
(Irradiated by 100MeV, 1.6mA Proton for 3 hours)

Based on the above analyses, copper was determined as the 100 MeV beam dump material. The activation analysis for the 20 MeV beam dump performed by Gil[2] shows that graphite is a very useful material to minimize an activation. However, graphite no longer has an advantage for the 100 MeV beam dump because of its residual activity as shown in Figure 4[3].

Copper is not good for a corrosion resistance in a high temperature. So the cooling surface is coated with nickel as shown in Figure 5. To confirm the stability of the coated surface from an erosion by the cooling water an erosion test was carried out as shown in Figure 6. The surface was examined after a cooling water flow for 720 hours and no flaw was found. Since the beam dump is bent during an operation due to a temperature difference between the front and the rear surface, a bending test for the coated surface was also carried out and no flaw was found both for the obtuse and the acute angle test.

Fig.5 Copper Beam Dump Coated with Nickel


(a) Test Facility (b) Coated Surface after Erosion Test for 720 hours

Fig.6 Erosion Test

DETERMINATION OF THE BEAM DUMP PLATE ANGLE

The design concept of the 100 MeV proton beam dump is similar to that of the 20 MeV dump as shown in Figure 1 and 7. The angle between the two plates should be determined so as to minimize the peak heat flux. The spreading effect of the beam energy is influenced by the distance (d) and the height (h) of Figure 7. The optimum beam spreading effect is calculated by using the Monte Carlo code PAMILA and the result is shown in Figure 8, where the minimum peak heat flux is 330 W/m^2 in the case of an angle of 12^o. Figure 9 shows an example of the power distribution with an angle of 12^o and a peak heat flux of 330 Mw/m^2.

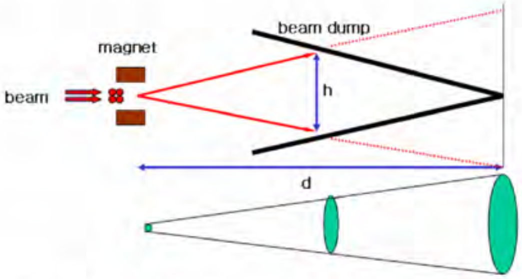


Fig.7 Schematic Diagram of the Beam Direction

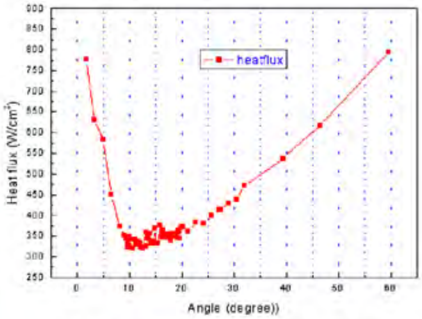


Fig.8 Peak Heat Flux vs. Angle

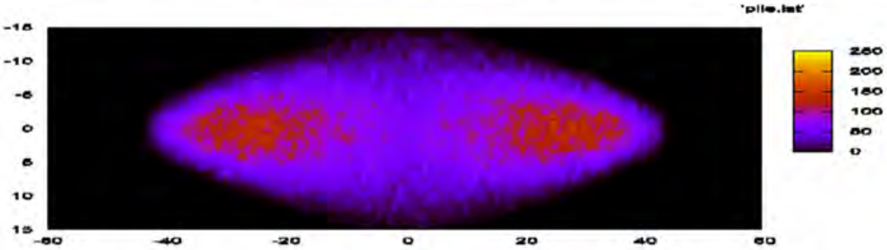
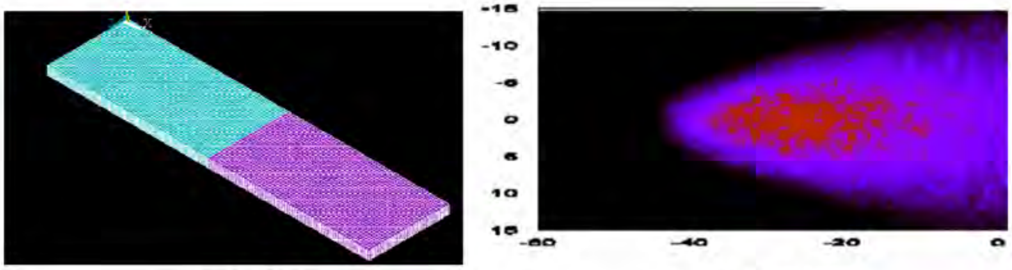


Fig.9 Power Distribution, Peak Heat Flux=330 MW/m^2 (angle=12^o)

HEAT TRANSFER AND STRESS ANALYSIS

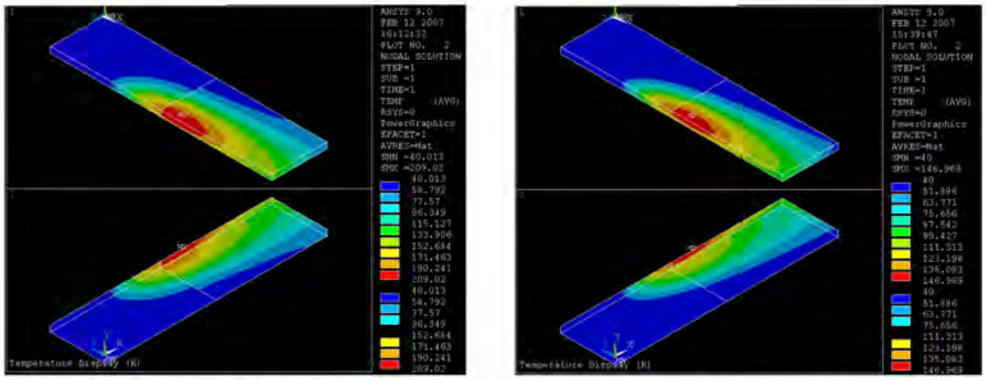
A preliminary heat transfer and the stress analyses were performed to assess the structural integrity of the 100 MeV beam dump by using the ANSYS code[4]. A half of the beam dump assembly was modeled by considering a symmetric condition, and a plane70 element and an equivalent structural element were used. Figure 11-(a) is the finite element model and Figure 11-(b) is the heat input.



(a) FEM Model (b) Heat Input

Fig.11 FEM Model and Heat Input

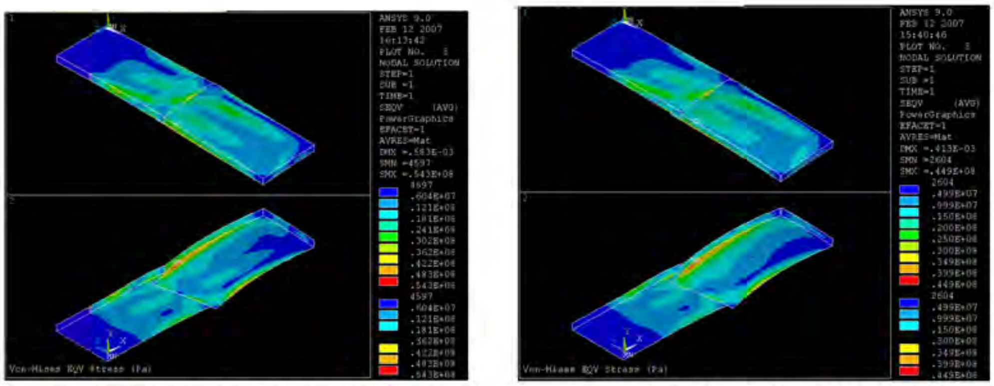
Figure 12 shows the heat transfer analysis results with a dump thickness of 16 mm and a cooling water temperature of 40°C, and a heat transfer coefficient of 10,000 W/m^{2o}C for (a) and 20,000 W/m^{2o}C for (b). The calculated maximum temperature is 209°C for (a) and 147°C for (b). These results show that the high proton beam energy is efficiently dispersed and cooled by the cooling jacket of the designed beam dump. Figure 13 shows the stress analysis results. Since the maximum stress is 54.3MPa for case (a) and 49.9MPa for case (b), which is 68% and 63%, respectively, of the yield stress of copper, the beam dump is structurally safe.



(a) t=16mm, h=10,000 W/m^{2o}C
max. temp. = 209°C

(b) t=16mm, h=20,000 W/m^{2o}C
max. temp. = 147°C

Fig.12 Temperature Distribution



(a) t=16mm, h=10,000 W/m^{2o}C
max. stress = 54.3 MPa

(b) t=16mm, h=20,000 W/m^{2o}C
max. stress = 49.9°C

Fig.13 Stress Distribution

SUMMARY AND CONCLUSIONS

A design concept for a 100 MeV PEFP beam dump was presented. For a selection of the beam dump material, the 100 MeV proton power density distribution analysis, a stopping range calculation, a neutron and photon yield analysis, and a residual activity analysis were carried out for 6 different materials such as water, graphite, copper, nickel iron, and aluminum. For the structural integrity assessment, an erosion test for a nickel coated surface, a preliminary heat transfer analysis, and a thermal stress analysis were also carried out. From the results of the material selection analysis, copper was determined as a relatively better beam dump material in view of its residual activity. It is concluded from the results of the structural integrity assessment that the beam dump is structurally safe since the high proton beam energy is efficiently dispersed and cooled. Further studies such as a beam dump sizing and a detailed finite element analysis will be carried out, and the beam dump prototype for a performance test will be manufactured during the next stage.

ACKNOWLEDGEMENT

This work was carried out under the Proton Accelerator Development Project by the Korean Ministry of Science and Technology.

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