CONCEPTUAL DESIGN OF BEAM DUMP FOR HIGH POWER ELECTRON BEAM

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Abstract

A high power CW (Continuous Wave) electron linac has been developed at PNC and its injector section has been completed in 1996. This paper presents the conceptual design of beam dump for a high power low energy beam (200 kW of 10 MeV electron). It has a Ring and Disk structure. The thermal analysis, stress analysis showed that 200 kW electron beam could be securely stopped in the beam dump. The temperature rise at highest position was estimated to be 343 degree.

Introduction

Design and construction of a high power CW electron linac to study feasibility of nuclear waste transmutation [1] was started in 1989 at PNC. The injector has been completed and started its operation at 3.5 MeV beam energy in summer 1996 and the whole facility is planned to be commissioned at 1997. Main specification of the accelerator is shown in Table 1.

Table 1

Main specification of the electron linac

Energy	10 MeV
Maximum Beam Current	100 mA
Average Beam Current	20 mA
Pulse Length	100ms ~ 4 ms
Pulse Repetition	0.1 Hz ~ 50 Hz
Duty Factor	0.001 ~ 20%
Norm. Emittance	50 π mm mrad *
Energy Spread	0.5%*

* estimated value by simulation

As the beam is a considerably high power and of low energy electron, the average power density of heat generation due to the energy deposition is quite large, so that it is of extreme importance to realize the beam dump to be secured by removing the heat very efficiently. At the same time, radiation shielding of the beam dump is also of the major concern.

Design

The conceptual design of the beam dump is based on the following design criteria:

(1) to disperse the beam by magnet in front of the beam entry
(2) to stop the beam part by part in spatially separated blocks
(3) to minimize the induction of radioactivity

The first criteria is for making the power density smaller by defocusing/spreading the beam. It is also assuring to avoid mishaps of the pin point beam hitting the component. The second criteria makes also a reduction of power deposition in a small region of the beam dump. The third criteria eliminates the use of water to stop the beam. Liquid target does necessarily increase the total inventory of the radioactive materials.

The concept of the present design is, as shown in Figure 1, Ring and Disk (RD) system: The part where energy is deposited consists of 17 rings and 5 disks (thickness of 5 cm). Each plate is made from OFHC (Oxygen Free High-purity Copper). All the rings have different inside diameters (the beam runs inside this ring.). The frontmost ring has the inside diameter of 19.6 cm and other rings have smaller diameter with increment of 1.2 cm from upstream to downstream.

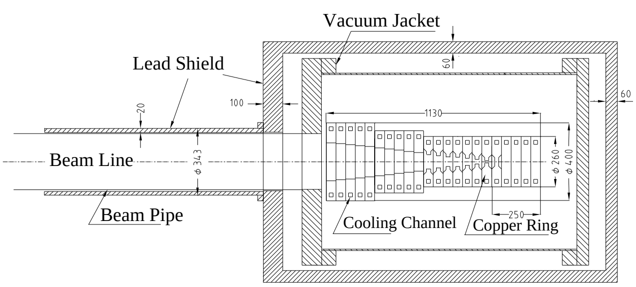

Fig. 1. Beam Dump in cross-section.

The beam enters into the cylindrical vessel through a dispersion magnet which is located 2 m front of rings. Since the beam has spatially a Gaussian profile, the inner front edges of rings stop the narrow annual lobe of the beam, from outside as going to the backward. Finally the beam is stopped by the disk set at the backend of the block. Figure 2 is a front view of the inner front edges.

These rings and disks are formed into 4 modular units. Each module is electrically insulated from each other in order to measure the beam current deposited on
them. It can be replaced/exchanged as a unit. In a module a cooling water flows in series from ring to ring. In order to reduce radiolysis of cooling water and to eliminate the vacuum window between the beam dump (target) and the accelerating tube, cooling water is not exposed to direct incident electron beam.

Fig. 2. A front view of the inner front edges.

These modules form a total target block and it also electrically insulated from the main body of the beam dump. A total view of this target block is given in Figure 3 and the PNC beam dump is shown in Figure 4.

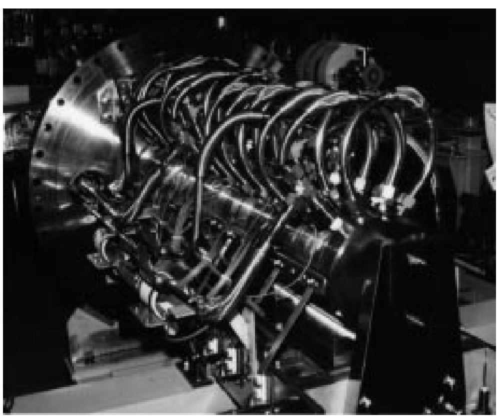

Fig. 3. A total view of target block.

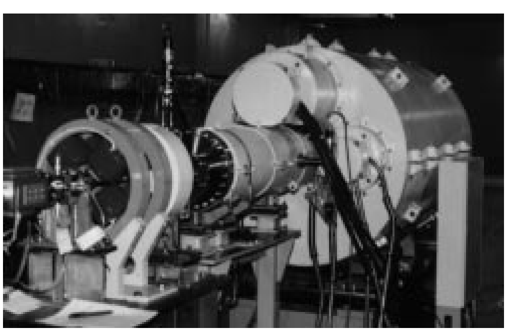

Fig. 4. View of the PNC beam dump.

The problem of connecting between the beam dump and the accelerator (the pressure difference between 1×10^{-5} torr and 1×10^{-7} torr in the accelerating tube) was solved by using a differential pumping stations and a low conductance beam transport tube.

Thermal and Stress Analysis

Several computer codes were used in order to estimate the temperature rise and the stress of rings with full beam power. This calculation assumed that the transverse beam intensity is Gaussian distribution and the electron is injected to the target block with the angle of incidence varied between 0° and 3°.

Firstly, the power density in the target block is calculated using the EGS4 [2] code. The EGS4 code performs Monte Carlo simulations of the radiation transport of electrons, positrons and photons in any materials. Then we applied the PRESTA algorithm (Parameter Reduced Electron-Step Transport Algorithm) [3], which was developed by Bielajew and Rogers to improve the electron transport in EGS4 in the low-energy region. The maximum power density was estimated to be 2.2 kW/cm^3.

Using the power densities from the EGS4, we proceeded to the thermal analysis using the finite element method code ANSYS [4]. Examples of the results of the analysis are shown in Figures 5 and 6. They are cross-sectional views of a ring in which stress is estimated to become maximum. The results predicted that the maximum temperature rise in the ring is at the inner front edge of ring and is 343 degree, and peak stress of 2.3 kg/mm^2.

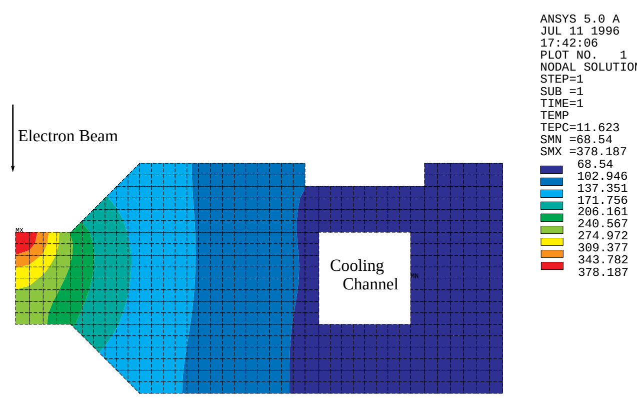

Fig. 5. Thermal analysis of a ring.

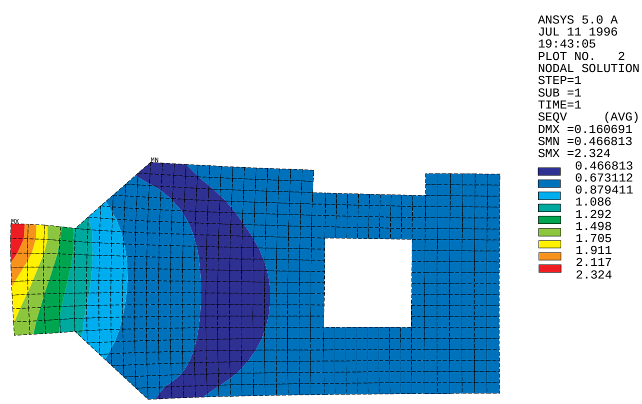

Fig. 6. The Von Mises stresses for the heat loads calculated with ANSYS.

Since the Von Mises stress exceeds the yield stress of copper (0.63 kg/mm^2), a plastic deformation might be induced over a major portion of the ring. As it is considered that the thermal stress cracking could be generated by this deformation, we design the beam dump such a deformed disk is easily replaced with a new one.

Photon Production

The energy distribution of photons (γ-rays) generated by incident electrons in the target block are studied using the EGS4 code. Figure 7 shows the relationship between its energy E and the scattering angle θ of the photon, where θ is the angle from the incident direction of electron beam.

Electrons are particularly susceptible to a large angle deflection by scattering from nuclei and they are backscattered out of the target block. In this context, Figure 7 shows the concentration of backscattered photons in the direction of 180°. A preliminary estimate of the absorbed dose rate in the backward direction (180°) at 1 m is 9000 Gy/h with full beam power.

Conclusion

A beam dump at PNC, employing the Ring & Disk system, has been designed for the high power low energy beam (200 kW of 10 MeV electron). The beam could be stopped at the inner edge of the rings which are cooled by water.

The maximum power density in the target block is 2.2 kW/cm^3 with full beam power assuming Gaussian distribution of the transverse beam intensity. The maximum temperature rise in the ring (at the inner front edge of ring) is estimated to be 343 degree.

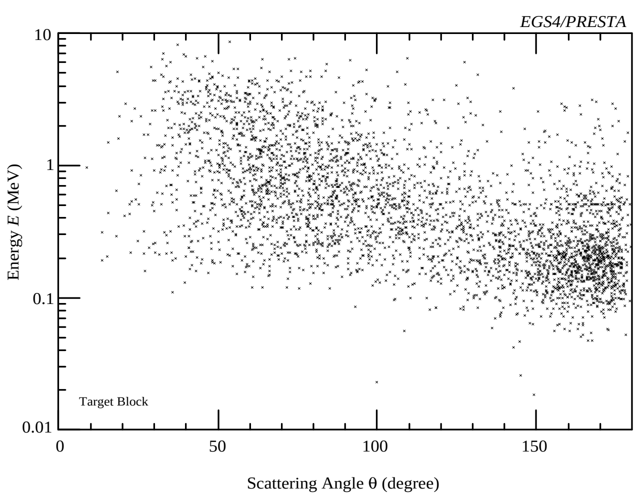

Fig. 7. Correlation between the photon energy E and the scattering angle θ.

References

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[2] W.R. Nelson, H. Hirayama and D.W. Rogers,"The EGS4 Code System", SLAC-Report-265, December 1985.

[3] A.F. Bielajew and D.W.O. Rogers, "PRESTA: The Parameter Reduced Electron-Step Transport Algorithm for electron monte carlo transport", Nucl. Instr. and Meth., **B18** (1987) 165.

[4] ANSYS, Ver. 5.0a, Swanson Analysis Systems. Inc.