The 12th Symposium on Accelerator Science and Technology, Wako, Japan 1999

Beam Dump for High Power Electron Beam at JNC

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Abstract

A high power CW (Continuous Wave) electron linac has been developed at JNC, and the test operation of the accelerator was started at a maximum permissible output of 2 kW in January 1999. This paper presents the 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. And the absorbed dose rate in the backward direction is found from calculation to be 7700 ± 200 Gy/h .

1 Introduction

High current electron beams are required for transforming fission products by gamma-rays. Element technology to efficiently and stably accelerate the high current beam is under development for the linac constructed at JNC.

The conceptual design of the accelerator was started in 1989. The test operation of the linac was started at a maximum permissible output of 2 kW, in January 1999, after many research efforts. In the future, the performance of the accelerator is to be confirmed at a rated output of 200 kW. Main specification of the accelerator is shown in Table 1.

Table 1 Main specification of the electron linac

Parameters	Design values
Energy	10 MeV
Maximum Beam Current	100 mA
Average Beam Current	20 mA
Pulse Length	100μs ~ 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.

2 Design

The conceptual design of the beam dump is based on the following 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 criterion 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 criterion makes also a reduction of power deposition in a small region of the beam dump. The third criterion 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.

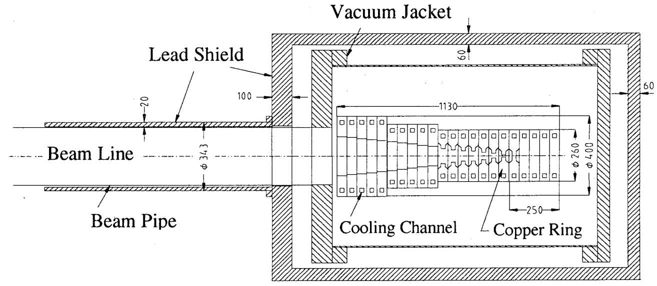

Fig. 1. Beam Dump in cross-section

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.

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 JNC beam dump is shown in Figure 4.

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.

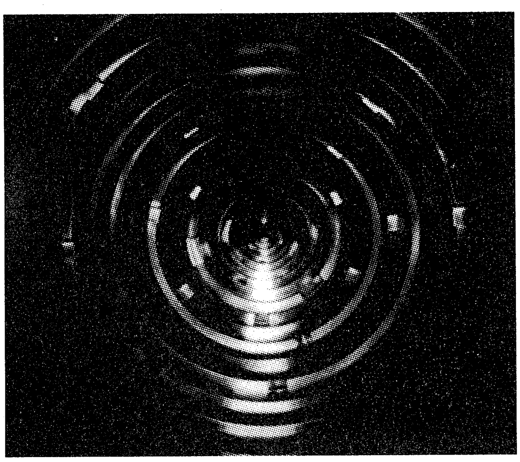

Fig. 2. A front view of the inner front edges

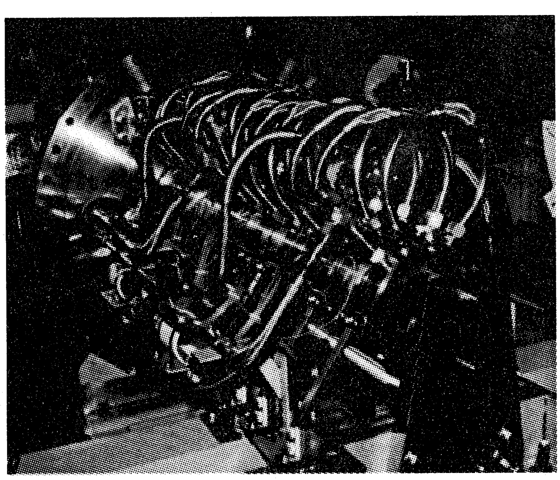

Fig. 3. A total view of target block

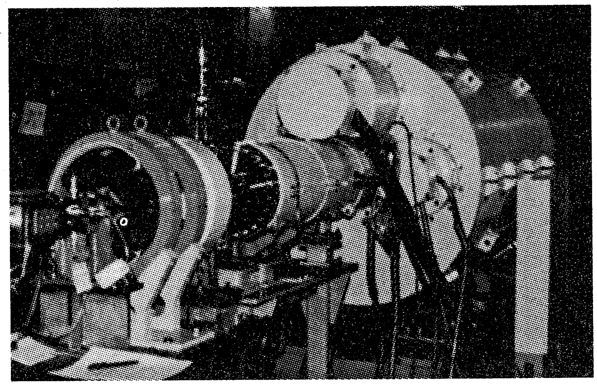

Fig. 4. View of the JNC beam dump

2.1 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.

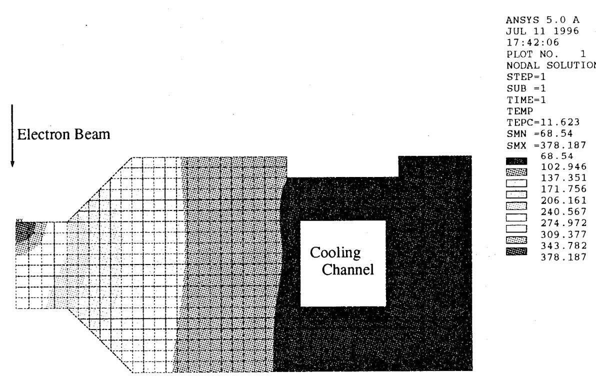

Fig. 5. Thermal analysis of a ring

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.

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 a deformed disk is easily replaced with a new one.

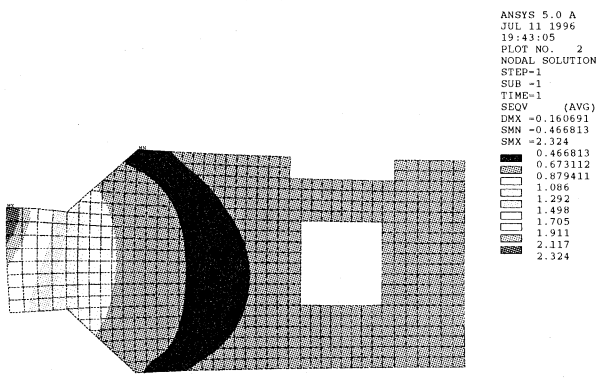

Fig. 6. The Von Mises stresses for the heat load calculated with ANSYS

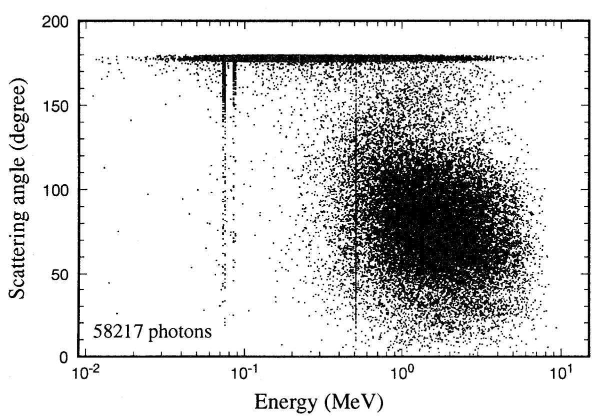

Fig. 7. Correlation between the photon energy and the scattering angle, provided that 4.7×10^7 electrons of 10 MeV are injected onto the beam dump.

2.2 Photon Production

The energy distribution of photons (γ-rays) generated by incident electrons in the beam dump is studied using the EGS4 code. Figure 7 shows the relationship between its energy and the scattering angle θ of the photon, where θ is the angle from the incident direction of electron beam. Emitted photons tend to concentrate on 2 regions in Figure 7. One is the upper region; the other is lower right-hand region. The former is the group of photons generated by a following process. Electrons injected onto plates are particularly susceptible to a large angle deflection by scattering from their nuclei, and they are backscattered out of the target block. Photons generated by such electrons are concentrated in the direction of 180°. In accordance with the scattering angle, the latter is the group of photons which passed through the copper and the lead. And photons around 80 keV are characteristic X-rays of the lead.

Table 2 shows the absorbed dose rate at a distance of 1 m from the center of the beam dump. The absorbed dose rate is 28.9 $\pm$0.1 Gy/h, on average in the angle θ, while the value in the backward direction is found to be 7700 $\pm$ 200 Gy/h.

Table 2 The absorbed dose rate at a distance of 1 m from the center of the beam dump

Scattering angle	Absorbed dose rate
$0 \le\theta\le 30$ (degree)	13.8±0.5 (Gy/h)
$30\le\theta\le60$	26.7±0.4
$60\le\theta\le120$	31.4±0.2
$120 \le\theta\le150$	6.2±0.2
$150 \le\theta\le170$	8.3±0.3
$170 \le\theta\le175$	27±1
$175 \le\theta\le179.1$	2800±20
$179.1 \le\theta\le180$	7700±200

Conclusion

A beam dump at JNC, 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. And the absorbed dose rate in the backward direction is found from calculation to be 7700 $\pm$ 200 Gy/h with full beam power.

References

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

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