PROTOTYPE BEAM DUMP FOR 10 kW LINAC

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Abstract

A 10 MeV, 10 kW electron beam accelerator (Linac) has been developed at RRCAT, Indore for developing applications in the area of radiation processing of agricultural products and medical sterilization. This paper presents the functional requirements, design and manufacture of beam dump for this LINAC. Activation of beam dump, conversion of electron energy into primary bremsstrahlung and radiation damage are important parameters for selection of material. Other parameters considered are thermal conductivity, corrosion in ozone environment, manufacturability and mechanical strength. Thermal, hydraulic, structural and engineering design was done. FEM based analysis was performed for calculating temperature rise and stresses. The maximum temperature in beam dump is estimated to be about 325 K. A prototype beam dump was manufactured and installed and it is being tested in actual operating conditions.

INTRODUCTION

Beam dump is installed in front of scan horn after the product as shown in Figure 1. The pulsed electron beam obtained from Linac has a diameter of 30 mm. It is scanned in scan horn mounted at the end of beam transport line. The scanning system comprises of a scanning electromagnet that provides 600 mm wide radiation field at the product surface in its path. The electron beam will be dumped on beam dump in the absence of product. The scanned electron beam field has approximate size of 100 mm x 900 mm at the location of beam dump. Considering this, size of beam dump is kept as 120 mm by 1000 mm. The beam dump shall stop most of the electrons so that the electrons transmitted in nearby structure are minimised. Maximum power incident on beam dump will be 14 kW. Specifications of Linac are given in Table 1 [1].

Table 1: Specifications of Linac

Nominal energy of accelerated electrons	MeV	10
Maximum beam power	kW	14
Pulse current of accelerated electrons in nominal mode	A	0.33
Duration of beam current pulse	µs	14
Pulse repetition frequency	1/s	300

DESIGN FEATURES

Activation of beam dump and conversion of electron energy into primary bremsstrahlung are important parameters for selection of material. Radioactivity may be induced in beam dump irradiated by electron beam or bremsstrahlung beam due to γ-n reaction. The activity induced in beam dump depends on energy and power of incident beam. The threshold energy for γ-n reaction in copper, stainless steel and aluminium is 9.9 MeV, 10.57 MeV and 13 MeV respectively. Copper and stainless steel are susceptible to activation at 10 MeV energy while aluminium is insusceptible [2]. Keeping this in view, aluminium was selected. Other parameters are thermal conductivity, corrosion in ozone environment, manufacturability and mechanical strength. The thermal fatigue behaviour of the material is also an important consideration, which will be taken care of in design of regular beam dump. Practical range of 10 MeV electron beam in aluminium is 20 mm, hence beam dump thickness (including water) was kept as 30 mm.

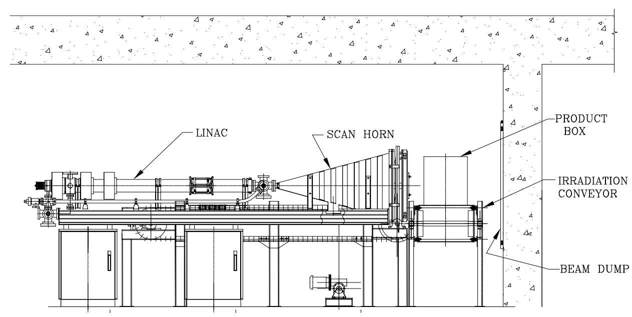

Figure 1: Location of beam dump

THERMAL AND STRUCTURAL ANALYSIS

Dittus-Boelter correlation [3] has been used for calculation of average heat transfer coefficient in the turbulent region over the cooling channels:

$$h= 0.023\,(k/d)\,(Re)^{0.8}\,(Pr)^{0.3}$$

Where h is average heat transfer coefficient, k is thermal conductivity of fluid, d is hydraulic diameter and Re is Reynolds number, Pr is Prandtl number.

Reference temperature was taken as 303K. Flow rate of 30 Litre/minute results in turbulent flow with water velocity of 3 m/s. Reynolds number of 40,000 and heat transfer coefficient of 8000 $W/m^2.K$ is achieved with this flow. The pressure drop in entire circuit is about 0.1 MPa. The beam dump cooling circuit can take a maximum pressure of 0.5 MPa, hence a separate coolant supply with low circuit pressure will be provided for beam dump. The normal cooling circuit in the building operates at a pressure of 1 MPa.

Finite element code ANSYS [4] was used for analysis. Second order quadrilateral element Plane77 were used to model the structure and obtain temperature rise in beam dump. Sequential coupled field analyses were performed to calculate thermal displacements and stresses.

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Following properties were used for aluminium [5].

Thermal conductivity	= 231 W/m.K
Coefficient of thermal expansion	= 23×10^{-6}/K
Young's modulus	= 69 GPa
Yield strength	= 103 MPa

Assuming uniform distribution of power on beam dump due to scanning, the top surface of beam dump is exposed to heat flux of 11.6 W/cm^2. The heat is removed by water-cooling. Temperature contour due to power deposited is shown in Figure 2. The maximum temperature is estimated to be about 325 K. For the heat load of 14 kW and flow rate of 30 lpm, a 9 K water temperature rise and aluminium-to-water temperature difference of 8 K are expected. Displacement contour and stress intensity contour due to temperature rise and water pressure are shown in Figure 3 and Figure 4. Maximum displacement of 0.2 mm and general stress intensity of 60 MPa is observed in beam dump due to thermal distortion and water pressure.

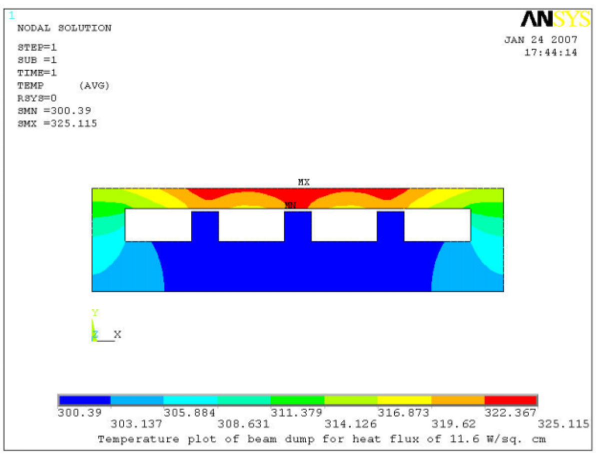

Figure 2: Temperature contour of beam dump

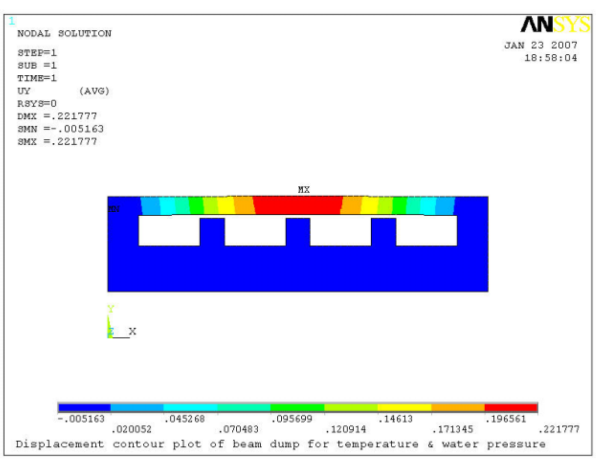

Figure 3: Displacement contour of beam dump due to thermal distortion and water pressure

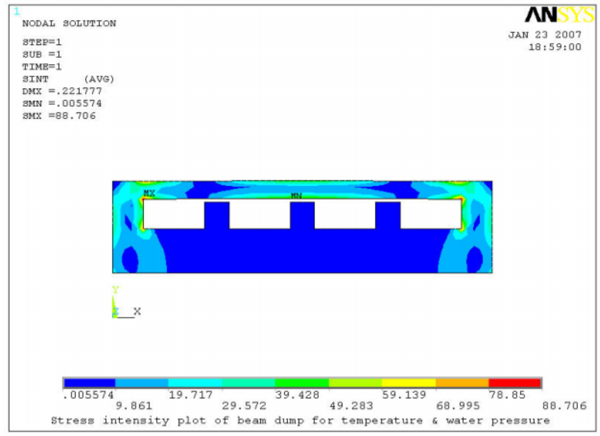

Figure 4: Stress intensity contour of beam dump due to thermal distortion and water pressure

FABRICATION

Beam dump consists of an aluminium block in which cooling channels are machined and a top plate that is welded to the block to create closed path for water flow. The machined components and assembled beam dump are shown in Figure 5 and Figure 6.

The material used in the fabrication of beam dump is commercial aluminium alloy as per ASTM B209. Filler alloy 4043 was used for Welding. Hydro test was carried out to ensure leak tightness of cooling circuit. The cooling circuit was pressurized at 0.5 MPa and kept at that pressure for 15 minutes. No leakage was observed. Care has been taken to select materials that are not far away in galvanic series. Stainless steel connectors are used to connect beam dump to braided hose. Polymers are avoided in beam dump assembly since the beam dump lies in region of high radiation dose. Radiation at location of beam dump is 1.1×10^8 kGy/year in electron mode [6]. Ozone level at beam dump location is ~1 ppm during operation. Beam dump is electrically isolated and is used to measure the beam current deposited on it. Mounting features are provided on beam dump to mount it on wall.

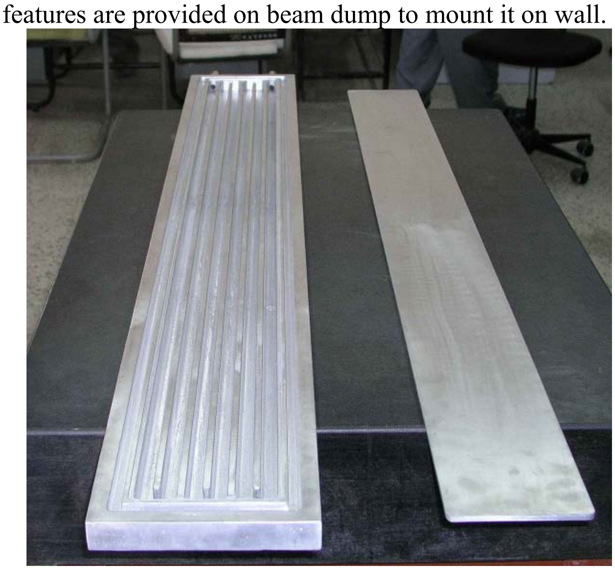

Figure 5: Components of beam dump before joining

Figure 6: Beam dump assembled in front of Linac

CONCLUSION

The beam dump has been designed, manufactured and installed in IMA Lab and is put to regular use. It is planned to develop another beam dump in near future for actual plant use, based on this experience of design, manufacturing and use.

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