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BEAM-DUMP/DIAGNOSTICS ASSEMBLY FOR A 10 kA, 50 MeV, 50 ns ELECTRON BEAM

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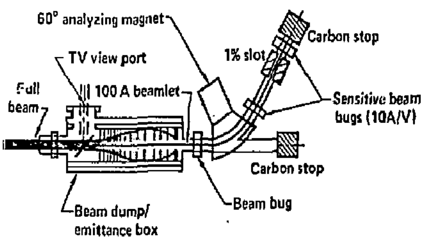
SUMMARY

We have developed a dump for the ATA[1] beam that consists of a series of carbon plates whose collective thickness totals approximately 1.5 ranges at 50 MeV. The energy dissipated in the plates is radiated to a water-cooled wall. The dump is designed to dissipate up to 175 kW of average power. A small hole along the axis of the plates forms a beamlet that passes through an energy analyzer. The analyzer consists of a 60° bending magnet and two high-sensitivity beam-current/positon monitors. The ratio of the beamlet current to full current is used to estimate the beam emittance.

INTRODUCTION

The ATA beam dump is designed to absorb up to 0.5 TW peak (175 kW avg.) beam power and produce a collimated beamlet from the full beam. These capabilities have lead to the development of a beam dump/diagnostic assembly that will be used to stop the ATA beam, measure the beam energy as a function of time, and obtain an estimate of the beam emittance. Figure 1 is a schematic of all the components conjoined to stop and diagnose the beam.



Beam Dump/Diagnostic Assembly

Fig. 1.

The beam current and position at the entrance to the dump/diagnostic assembly are measured with a resistive beam current monitor (beam bug). This instrument [2] has been developed during the course of the electron beam research at Lawrence Livermore National Laboratory on the Astron and ETA accelerators. Beam bugs in use on ATA develop one volt/kiloamp and have a response time of less than 0.5 ns. They are also capable of locating the beam centroid inside the drift tube to within one millimeter.

After passing through the beam bug, the beam enters the dump which consists of a series of range thin carbon disks. The total thickness of the disks is greater than 1.5 ranges at 50 MeV. The first disk is placed at an angle of 45° to the beam and is used to develop an image of the beam. This image is viewed with a gated television that is capable of obtaining a picture in less than 5 ns. This system will be used to measure the beam size and profile as it strikes the dump. A small hole (1/4" diameter) along the axis through all of the carbon disks is used to form a collimator that produces a beamlet of approximately 100 Amperes.

After leaving the dump, an analyzing magnet then bends the beamlet through an angle of 60° and into a secondary beam line. The beamlet is detected by a pair of high-sensitivity beam bugs. The first of these is located close to the exit of the analyzing magnet and is used to measure the total current of the beamlet passing through the collimator. The ratio of the beamlet current to the primary current is used to obtain an estimate of the beam emittance of the on axis component of the primary beam. The beamlet continues through the secondary beam line and then through a slot designed to accept an energy variation of up to 1%. The second sensitive current monitor is used to measure the time variation of the beamlet within the 1% energy acceptance set by the slot. The beamlet is finally stopped by a six-inch thick (~1.25 ranges) solid carbon dump.

BEAMLET OPTICS

The current of the beamlet is determined by the acceptance of the collimator and the emittance of the primary beam as follows: Assuming a uniform beam profile, the current entering the collimator is simply $I_c = I_b (r_h/r_b)^2$ where r_h is the hole radius and r_b is the beam radius.

Of this current, only the fraction within the solid angle subtended by the collimator will pass through. If we assume that this current is equally distributed within the angular spread of the primary beam, then the current i that passes through the collimator is given by $i = I_c(\Theta_c/\Theta_b)^2$ where Θ_c is the acceptance angle of the collimator and Θ_b is the angular beam spread. We then find that $i = I_b(\alpha/\varepsilon)^2$. Here α is the acceptance of the collimator and ε is the emittance of the primary beam. The collimator acceptance is given by $\alpha = r_h^2/2L$ where L is the collimator length.

This analysis is only approximate and requires that the angular beam divergence be considerably greater than the acceptance angle of the collimator. Moreover, any misalignment of the primary beam with respect to the system axis must be smaller than the sum of the angular beam divergence and the collimator acceptance angle. In this limit, the ratio of the beamlet and primary currents and the geometrical properties of the collimator can be used to approximately obtain the primary beam emittance.

After passing through the collimator, the beamlet drifts freely until bent 60 degrees by the analyzing magnet. This magnet focuses the beam in the plane of the bend to an image at the plane of the 1% slot. This focus is assured by arranging the center of the collimator, the center of the bending radius of curvature and the 1% slot to be along a straight line (Barber's rule). Lengths are such that a beam energy variation of one percent will cause a 1.68 cm shift of the position of the image in the bend plane. The beamlet is not focused in the direction perpendicular to the plane of bending.

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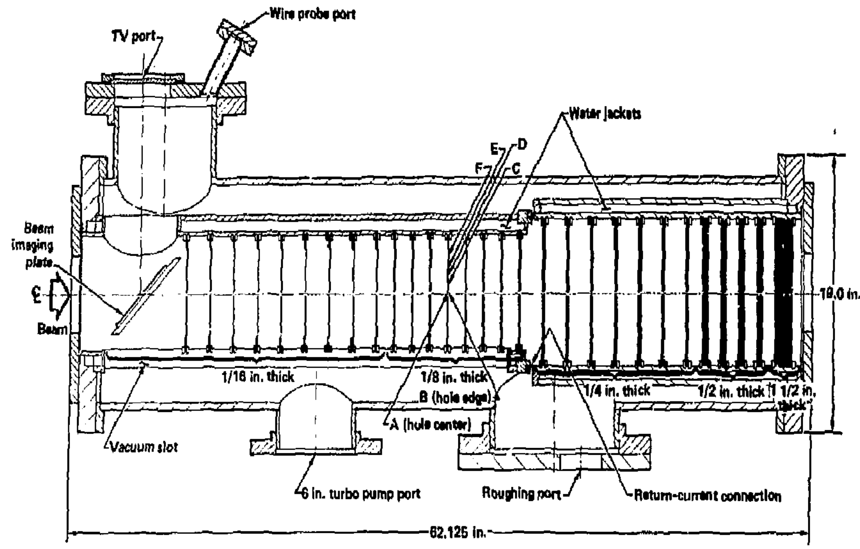


ATA Beam Dump/Emittance Box

Fig. 2.

BEAM DUMP DESIGN

The design of the dump centers primarily around two physical requirements. First, it must stop 6×10^7 to 1×10^8 full parameter (50 ns, 50 MeV, 10 kA) ATA pulses which may vary in beam radius from 2 to 5 cm. These pulses may repeat at a maximum rate of ten in 10 ms, time averaged to 5 pulses per second. Second, the dump must pass approximately 100 Amperes of a 5 to 25 mrad-cm emittance primary beam. In addition, the dump must preserve the 2×10^{-6} torr vacuum integrity of the accelerator under conditions of no beam and 1×10^{-2} torr maximum in the region of the dump during pulsing. Finally, the beam return-current path must be maintained.

There is no solid material which can conduct the beam energy away to an actively cooled wall at a rate sufficient to prevent melting of the dump material. Since the dump must pass a beamlet through a solid aperture, a phase change is not allowed. The choice of a dump design which relies upon thermal radiation, rather than convection, was made because of a decision to have the coolant (water) out of the beam path. This way, in the event of a failure of the dump material, there would not be a spill of coolant into the accelerator vacuum.

There are only two solid materials which will withstand ten ATA pulses in 10 ms at the minimum entrance radius of 2 cm, beryllium and carbon[3]. Carbon was chosen because of its generally superior thermal properties, lower toxicity, and lower neutron production.

The dump/emittance box must withstand a radiation dose of approximately 2×10^{11} Rads (gamma, electrons, and neutrons) over its design life of five years. To minimize the residual radiation hazards, aluminum is used for the dump walls and the vacuum chamber. Because of the heavy radiation environment, no organic materials are used; including the black paint which is used on the inside diameter for thermal absorptance. All seals for both water and vacuum are metal.

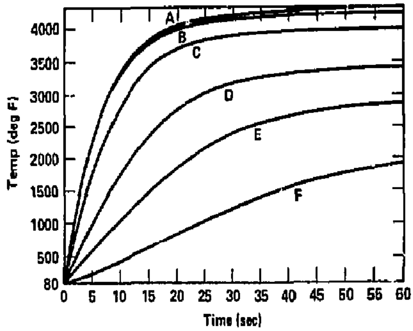
The innermost walls of the dump, which support and absorb heat from the carbon disks are protected against beam scrapes by the continuous water jacket surrounding them. A vacuum slot (approximately 2" wide through the water jacket) allows evacuation of the volumes between disks.

Snap rings fit into grooves on the dump's inside diameter and support the carbon disks axially. The disks themselves are suspended on their O.D. by BeCu finger stock, which allows thermal expansion. Because the finger stock provides support over 360°, the disks and their 1/4-inch diameter through holes are centered, aligned, and kept in alignment during thermal expansion.

HEAT TRANSFER ANALYSIS

The electron-photon transport code SANDYL[4] was used in calculating the power-density profile within the dump. The complete results are presented in Reference 3. These calculations show that the power density decreases rapidly after the first 0.15 ranges in carbon. Figure 2 shows the final assembly of the ATA dump/emmitance box. Where the 1/16-inch thick disks end, the beam has already passed through 0.133 ranges. By the time the beam has passed the 1/8-inch disks, it has scattered to roughly an additional 3 cm in radius from that at which it entered the dump. The power density is quite uniform across the profile of the 1/4-inch and 1/2-inch discs. The 1 1/2-inch disk forms the end of the collimator aperture and stops secondary and low-energy primary electrons. Because of the scattering, it is necessary that the disks be larger in diameter beyond the 1/8-inch disks, in order that the beam does not scrape the dump walls.

The results of the electron-photon transport calculations were used as input for a heat transfer analysis using the code TACO2D[5]. Figure 3 shows an example of the surface temperature as a function of time for an 1/8-inch disk. See Figure 2 for the locations of the points A-F. The curves in Figure 3 are smooth because the analysis was carried out assuming a continuous power input. In reality, the power will be deposited in 10 pulse bursts (worst case). This means that momentarily, the temperature will actually be 1100 to 1200°F higher than that shown in the figure. Completing the analysis involved iterating on the thickness and center-to-center spacing of the disks in order to minimize peak temperatures and the overall length of the dump.



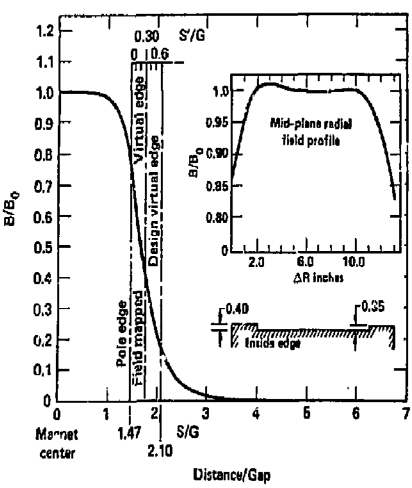
1/8 in. Thick Disks, 1 1/2 in. on Center

Fig. 3.

60 ANALYZING MAGNET

The analyzing magnet is a normal entrance/exit, C-type, sector magnet. Design parameters and construction data are listed in Table 1. The pole profile and the mid-gap field profile in the radial direction are shown in the inset of Figure 4. The field profile compares favorably with a computer simulation using the two-dimensional magneto-static program, TRIM(6).

Field mapping was accomplished by a digital read-out, rotating coil gaussmeter mounted on a



60° Analyzing Magnet Field Profiles

Fig. 4.

moveable carriage. The gaussmeter used in the field mapping will be permanently installed to continuously monitor the field at a specific location in the magnet gap.

For the want of an adequate three-dimensional field code, the classical "short-tail" curve(7) was arbitrarily selected to represent the fringing field in the drift spaces. This places the actual pole edge 0.62 x gap, or five inches from the effective edge. This assumption proved to be incorrect, as may be seen in Figure 4, where the effective edge is 0.3 x gap as obtained by the actual field mapping and subsequent integration of $B(Z)dz/B(0)$. A residual magnetic field of up to 6 gauss was measured in the central gap. This will be removed by a degaussing coil at each pole.

The small bending radius selected, coupled with the large gap, geometrically imposed a relatively unfavorable pole width and particle path length. To enhance the field uniformity, shims were placed at the inner and outer radial pole edges.

The magnet coils are water cooled and placed directly adjacent to the pole gap. They are insulated with fiber-glass tape and cloth and vacuum impregnated with alumina loaded epoxy for enhanced radiation resistance. The coils can be easily replaced, requiring simple unbolting of poles and yoke components which are keyed precisely by "Dutchman" dowels.

TABLE 1

BENDING MAGNET PARAMETERS

Mean Bending Radius	32 in.
Deflection Angle	60°
Full Gap	8 in.
Maximum Gap Field	3.8 kG
Pole Radial Width	13 in.
Maximum Current	861 A
Maximum Voltage	52.7 V
Turns/Coil (3 Pancakes x 7T)	42
Conductor (Square Hollow Copper)	0.340 in. sq. x 0.1875 in. bore
Magnet Weight	4850 lb.

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