HIGH POWER ELECTRON BEAM DUMPS AT CEBAF

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Abstract

The CEBAF accelerator produces a very small emittance CW electron beam of up to 200 μA average current. The resulting beam power, up to 1 MW at 5 GeV, and the very high beam power density, pose challenging problems for beam dump design. Two styles of high power dumps have been developed. The first, rated for 100+ kW, is used for beam tune-up and accelerator commissioning. The beam power is entirely contained in metal in this dump, minimizing the problems associated with radioactive water handling. Full power 1 MW dumps are used with the experimental halls. In these dumps, one-third of the beam power is directly absorbed in water. Both dump designs require the beam to be rastered when the smallest beam sizes are used. Design details for each of these dumps will be presented.

1 COMMISSIONING AND TUNE-UP DUMP

The commissioning and tune-up dumps at Jefferson Lab were designed to help commission the Continuous Electron Beam Accelerator Facility's first linac. The same design was also employed as a tune-up dump for commissioning the entire accelerator. One dump is located at the end of the first linac and can be used to test CEBAF's injector and first linac to its full current rating of 200 μA and 600 MeV, or 120 kW. The second commissioning and tune-up dump is located in the beam switchyard just upstream of the experimental halls, which allows full accelerator operations without sending beam to one of CEBAF's three end stations. It is rated at 6 GeV and 100 kW of beam power. The full energy ratings of these dumps are given in FIGURE 1. Note that below 600 MeV the dump is current limited to protect the first copper window. The northeast stub dump has been in operation since early 1993. The beam switchyard dump has been in operation since the fall of 1994 and has been used at up to 5500 MeV and 100 kW of power. Further description of these dumps can be found in CEBAF Tech Notes [1,2].

A cross sectional view of the commissioning and tune-up beam dump is given in FIGURE 2. The dumps consist of a copper window section, 87 cm of drift space with an aluminum jacket, a solid aluminum core section and finally 29 cm of copper. The entire dump is edge cooled by two separate deionized (DI) water circuits. The first circuit supplies 0.3 L/s for the copper windows and rear copper section, and the second, 1.3 L/s for both the aluminum sections. Two individual circuits are used to avoid any galvanic corrosion resulting from copper ions and aluminum. An EGS run for 0.6 and 4.0 GeV into the dump is shown in FIGURE 3.

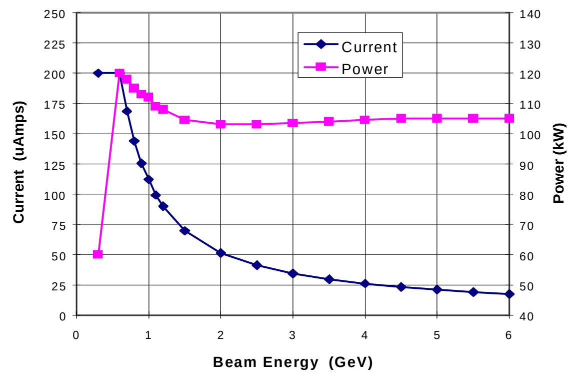

FIGURE 1. Current and power ratings for the commissioning and tune-up dumps.

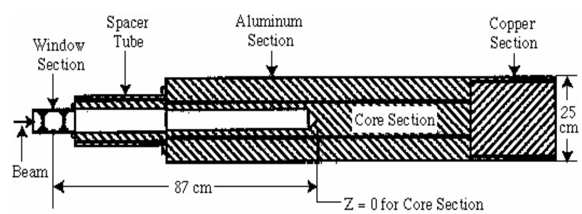

FIGURE 2. Cross sectional view of the commissioning and tune-up dump.

The window section consists of two 0.3 cm thick edge cooled windows brazed into a stainless steel jacket. The window section serves three purposes. First, it seals the accelerator vacuum. Second, the two windows scatter the beam before it reaches the main aluminum body, eliminating the possibility of melting the main body. Finally, the two windows provide a trapped gas interlock to detect a possible burn through of either window. The space between the two windows is filled with pressurized helium gas. If the first window fails, the accelerator vacuum will spoil and quickly shut down the beam. If the second window fails, a pressure transducer will detect the loss of pressure and provide an alarm. The beam is rastered on a 2 cm diameter circle at

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60 cps to help alleviate any possibility of any burn through. With rastering and a 200 μA beam, the average temperature in the window is 110 C.

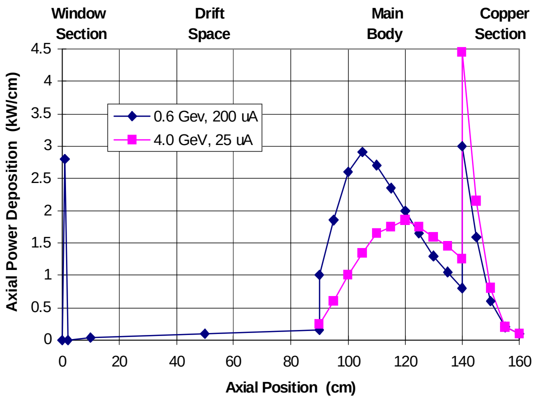

FIGURE 3. Axial power deposition in the commissioning and tune-up dumps.

The aluminum drift space region provides room for the beam to spread radially to lower the power density in the main body. The section is filled with helium gas at just over 1 atm, less than the pressure in the window section. Only scattered beam is intercepted in this region. The main aluminum body absorbs most of the beam energy. Aluminum was used for the main body to allow the beam power at 600 MeV to be distributed along the length of the dump so that the peak heat fluxes into the water were at conservative levels, no greater than 100 w/cm^2. For the worst case beam power of 120 kW, 200 μA and 600 MeV, the peak temperature in the aluminum section at shower maximum is predicted to be 480 C, 12.5 cm into the body of the aluminum. At the start of the main body, temperatures are predicted at 300 C, about half the melting point of aluminum.

The copper section at the rear of the dump absorbs up to 27 percent of the power at 4 GeV. This section was added at the end of the dump, were the beam is fully dispersed, to reduce the overall length of the dump. It consists of a solid cylinder of copper with machined water channels on the diameter, brazed into a stainless steel jacket. This section is not thermally stressed, with maximum heat fluxes to the water at less than 60 w/cm^2 at 4 GeV.

2 END STATION BEAM DUMPS

Two of Jefferson Lab's three experimental halls, Halls A and C, are capable of running experiments at CEBAF's design energy of 4 GeV and 200 uA. The third, Hall B operates at a much lower current. In order to safely dissipate the beam in the high power end stations, beam dumps capable of absorbing 1 MW, 5 GeV and 200 μA are used. These dumps are also capable of dissipating energies up to 10 GeV with reduced currents so that the maximum power is held constant at 1 MW. The dumps are housed at the end of 33 m, heavily shielded tunnels after the end stations. Each dump is cooled by a closed loop DI water circuit. The Hall C dump has been in service since the fall of 1994 and the Hall A dump since the fall of 1995. To date, the dumps have been used at 4.05 GeV and up to 180 μA, or 728 kW.

The cross sectional view on an end station beam dump is given in FIGURE 5. The dump consists of an internal aluminum plate heat exchanger surrounded by an all aluminum pressure vessel. Heat exchanger designs from 30% to 100% water were explored with the final design being a 50/50 ratio by volume. The final design was decided on to seek a practical maximum in the fraction of total beam power absorbed in the metal. There are 20.8 rl of aluminum and 3.1 rl of water in the heat exchanger so that 70 % of the power is absorbed directly in the aluminum. This design minimizes tritium production, hydrogen evolution, and short term activation in the cooling water, as well as the long term activation trapped in the DI filters.

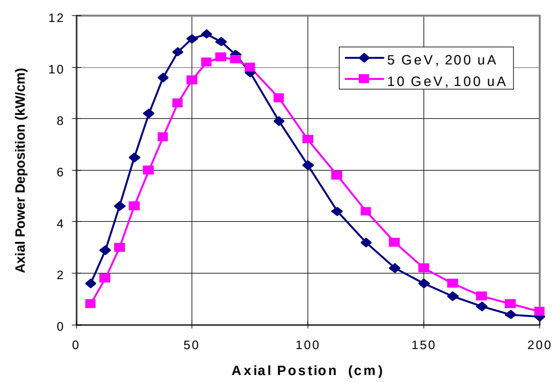

FIGURE 4. Average derivative axial power for 50% Al, 50% water by volume beam dump.

An EGS run for 5 GeV and 10 GeV beams into a 50% Al, 50% water by volume beam dump is given in FIGURE 4. During operations the beam is either rastered, or scattered so that the spot size on the dump face is a minimum 4 cm diameter to an 8 cm diameter maximum. The beam dump was designed based on a beam spot of 4 cm. The maximum power deposition occurs approximately 55 cm into the dump and is 11.3 kW/cm average, or 15.4 kW/cm in the aluminum. Using the EGS calculations, the thicknesses of the plates were sized so that the maximum heat flux to the water was less than 200 w/cm^2. The plates range in size from 0.48 to 2.54 cm. For the first 70 cm of the dump, the 5 GeV beam governs the plate thickness, with the remainder of the heat exchanger design based on the 10 GeV case. Peak temperature in the aluminum plates is

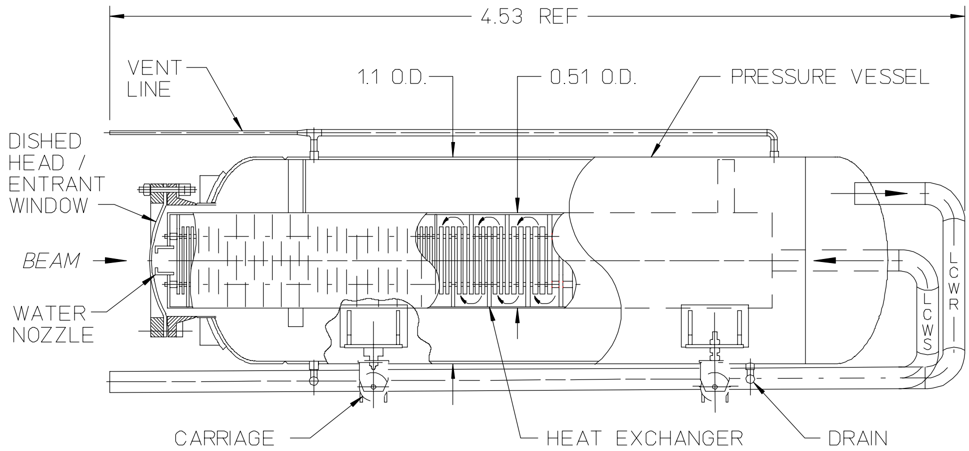

FIGURE 5. Cross sectional view of the end station beam dump.

190 C. The flow rates through the heat exchanger range from 0.9 to 2.3 m/sec with a volumetric flow of 13.9 L/s, yielding a 17.6 C rise in the water at 1 MW. A 7.6 cm nozzle at the end of the heat exchanger focuses the cooling water at 3.6 m/sec onto the entrance window of the dump. The water is then returned to the rear of the dump before being returned to the pump building.

The pressure vessel, as well as the heat exchanger, is made entirely of 6061 aluminum in the T6 condition whenever possible. Aluminum was chosen because the radiation levels in aluminum are about one-eighth of those of stainless steel within two to seven days after running beam. The vessel was designed to the ASME Pressure Vessel Code, Section VIII for an internal pressure of 1 MPa gauge at 93 C with an extra 0.16 cm external corrosion allowance added due to concerns of nitric acid evolution in the dump tunnel. In practice the dump pressures are between 0.34 and 0.41 MPa gauge.

The beam window of the dump is a fine grain forged 6061-T6 flared and dished head. The fine grain forging was used to reduce radiation damage effects which propagate at the grain boundaries [3]. It has a code required nominal thickness of 1.6 cm which is reduced to 0.95 cm for the central 10 cm of the head where the beam enters the dump. The central part of the head was reduced in thickness to lower the amount of beam energy deposited in the metal. At 1.6 cm, the calculated temperature in the window would be above that allowed for the corresponding pressure vessel stresses. At 0.95 cm, the expected power in the window from a 200 μA beam is 1.6 kW with peak temperatures in the window below 150 C. The membrane stresses in the window are then within those allowed by the code for that temperature. The window is sealed using a Helicoflex type gasket and bolted with 3.8 cm 2024-T6 aluminum studs and silicon bronze bolts. Aluminum studs were used in order to match the thermal responses of the rest of the aluminum vessel.

3 SUMMARY

Two types of beam dumps have been in use at Jefferson Lab for several years. The intermediate power dumps have been used successfully through their entire design rating. The end station beam dumps have seen three quarters of their design power and plans are in place to commission them to their full current rating this year.

11 ACKNOWLEDGMENTS

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REFERENCES

[1] Sinclair, C.K. and Vetterlien, R.J., "CEBAF Intermediate Power Beam Tune-up Dump", CEBAF TN# 93-003.
[2] Sinclair, C.K. and Vetterlien, R.J., "Operation of the Intermediate Power Beam Dumps at High Beam Energies", CEBAF TN# 94-049.
[3] Conversation with Dieter Walz, Stanford Linear Accelerator Center.