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BEAM DUMPS, STOPPERS AND FARADAY CUPS AT THE SLC*

D. R. Walz, A. McFarlane and E. Lewandowski
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94309

ABSTRACT

This presentation features most of the beam dumps and stoppers necessary to absorb and dissipate SLC $e^{\pm}$ beams with transverse sizes from several tens to a few hundred microns (μm). Solutions are based on electromagnetic cascade shower calculations for $N = 5 \times 10^{10} e$/bunch and momenta ranging from 1.2 GeV/c in the damping ring transport systems to 50 GeV/c in the arcs matching sections and the Final Focus region.

1. INTRODUCTION

There are a number of locations in the SLC where it is desirable and/or necessary to park and dump the $e^{\pm}$ beams for extended periods of time, preferably at full intensity and bunch repetition rate. The most important, of course, are the beam dumps at the very end of the Final Focus (FF) extraction transport systems which absorb and dissipate into heat the spent beams after having collided at the interaction point (IP). Another pair of beam dumps are required to temporarily park the beams beyond the end of the linac but far ahead of the IP and the detector. This is to provide "quiet" time for the detector electronics when an event is being processed. Then there is, at times, a need to do beam tune-up in the FF region to study the behavior of the arcs or the various subsystems of the FF without burdening the detector. Further, there is a requirement for machine physics studies in the damping rings which, with appropriate dumping facilities, can be carried out while the remainder of the machine is off, affording personnel access to the BSY, arcs and FF regions. Each of these dump facilities has unique features dictated by the desired mode of operation and local beam parameters. The most important of these is perhaps the transverse size of the bunch which, when coupled with the large bunch population, gives rise to very high current densities. Extensive studies of cascade showers were carried out to identify suitable materials for these applications, covered in more detail in another presentation contributed to this conference.[1]

2. FINAL FOCUS EXTRACTION BEAM DUMPS

After the electron and positron bunches have been brought into collision at the IP in the FF the "spent" bunches depart through the transport system of the opposite polarity. At a distance of ~106 m from the IP they are deflected by a current loop kicker magnet (1.2 mrad) into a dc septum magnet for further separation from the primary beam and are finally targeted on a beam dump for safe disposal and dissipation into thermal energy.

The pertinent beam parameters for this dump were: E_o = 50 GeV, N = $5 \times 10^{10} e$/bunch, PRR = 180 Hz, and resulting P_{av} ~72 kW. In order to allow for future increase in energy the dump was actually sized for 70 GeV and P_{av} ~100 kW. Suitability of various materials and geometries were analysed using the Monte Carlo computer code EGS. An aluminum cylinder was chosen as primary power absorber. For an expected nominal transverse beam size of σ ~1 mm the maximum temperature rise per bunch in a simi-infinite medium was found to be ~ 15°C at a depth of $\sim 3X_o$ in a volume element extending from $0 < r \leq 200$ μm. The length of the cylinder was terminated at $16X_o$(~1.45 m) based on total residual power in the shower at that depth, $\sim 0.027P_{av}$. A $10X_o$-long steel cylinder was added to absorb and dissipate the remaining power. Selection of the transverse dimension of the dump was influenced by three criteria. The first was adequate radial attenuation of the electromagnetic cascade. The second was minimization of direct power deposition by the shower particles in the cooling water to avoid significant hydrogen generation by radiolysis[2] (3×10^{-4} lH_2/kW-sec) thereby eliminating the need for a hydrogen recombiner.[3] The last criterion was ready commercial availability of the material in the desired size. A compromise of the above resulted in a diameter of 380 mm. Beyond, the dump is then peripherally cooled by a helical flow channel, semicircular in cross section with r = 19.1 mm, and contained on the outside by an aluminum tube with an outside diameter of ~425 mm. Figure 1 shows the dump cylinder and tubing during fabrication. Water cooling extends only over the length of the aluminum. The steel cylinder is bolted to the downbeam end of the aluminum cylinder and heat transfer is by conduction into the aluminum. The amount of direct beam power deposited in the water is $\sim 8 \times 10^{-4} P_{av}$ which, at 100 kW, results in a rate of hydrogen evolution of ~2l/day. This presents no problems since the gas space on top of the surge tank of the radioactive water loop is open to the tunnel atmosphere. Finally, the amount of beam power escaping radially from the dump is $\sim 0.015P_{av}$. The resulting flux is ~ 0.06 W/cm^2. This is less than the somewhat arbitrarily set limit of 0.1 W/cm^2 which is to thermally protect nearby support structures cooled only by a combination of natural convection to air and thermal radiation. The design flow rate is ~ 1.25 lH_2O/s. The resulting velocity is ~2.2 m/s and $N_{Re} \sim 62 \times 10^3$ (highly turbulent flow). The bulk temperature rise is ~ 20°C for P_{av} 100 kW.

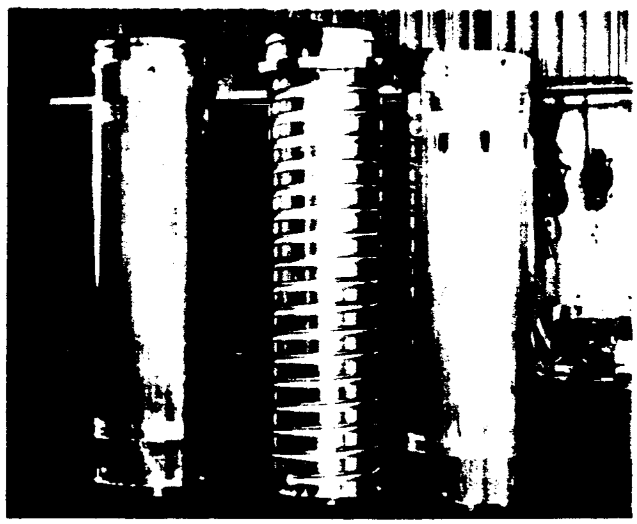

Fig. 1: 100 kW extraction beam dump absorber

Both beam dumps are housed in dump caves. They are separated from the main tunnel in the direction of the IP by ~3 m concrete with only a small passage for the beam to enter. This is to cut down on background to the collider experimental hall. Concrete thickness in the transverse direction is ~0.6 m which is sufficient to attenuate the residual radioactivity dose rates to the main tunnel to levels acceptable for personnel traffic.

3. FINAL FOCUS TUNEUP DUMPS AND FARADAY CUPS

Two tuneup facilities were needed in the FF region to aid machine operations. The first is TD23 located in the eta-matching section, ~145 m from the IP. The second is ST4 which is in the final transformer, ~20 m from the IP. Both beam dumps were designed to continuously absorb 5×10^{10}/bunch at 10 Hz for each beam polarity or a total of 8 kW at 50 GeV. Longitudinal space is very limited at these locations and thus a high-Z material was desirable to keep the beam dump compact. The small transverse dimensions of the beam at TD23 ($\sigma_x \sim 300$ μm, $\sigma_y \sim 90$ μm)

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and to a lesser degree at ST4 ($\sigma \sim 1$ mm) give rise to excessive single bunch temperature spikes at shower maximum in high-Z materials and dictated a composite material approach. The beam encounters first $\sim 3X_o$ of a free- machining tungsten. At that point the temperature rise per bunch is $\sim 100°$C (from EGS). The tungsten is brazed to an $\sim 18X_o$-long block of copper which dissipates most of the energy of the cascade shower. It in turn is followed by another $\sim 3X_o$ long slab of W to complete the dump and also provide the same material combination for the beam of opposite polarity arriving from the other direction. The transverse dimensions of the absorber block are $\sim 150\times$ 150 mm. The fraction of the total energy leaking across the downbeam face is $\sim$0.004, that which is backscattered at 180°C $\sim 4\times 10^{-4}$, and $\sim$0.008 is lost across the four sides. The energy capture efficiency is $\sim$0.987.

The beam stoppers for the two locations are identical with the exception of two features. The absorber block in ST4 is electrically insulated by a 12.7-mm-thick ceramic plate (Al_2O_3, 99% pure). This allows it to also be used as a crude Faraday cup for measurement of average charge delivered to the IP. Relative current measuring devices such as toroidal current transformers can be calibrated against ST4. The second feature is a luminescent beam profile monitor screen mounted to both ends of the absorber which allow visual monitoring of the parked beam. Figure 2 shows an absorber block, insulator and heat sink assembly. The absorber block is housed in a vacuum chamber and can be remotely inserted (pneumatically) to block the beam passage. The heat is conducted across the insulator to a water-cooled plate. Water is brought into and out of the vacuum system in a stainless steel manifold free of any water-to-vacuum joints. The nominal flow rate is $\sim$0.2 l/s and the steady state bulk temperature rise for $P_{av} = 8$ kW is $\sim 10°$C.

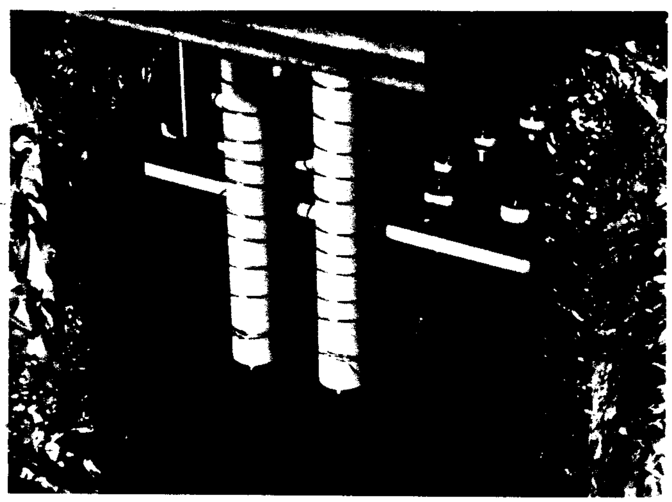

Fig. 2: Absorber and heat sink of 8 kW Faraday cup

4. SINGLE BEAM DUMPER

A beam dump facility was constructed in the beam switchyard to absorb the full 72 kW SLC beam just ahead of the first magnet in each arc. These dumps are stationary, off-axis, and part of the vacuum system. The beams are deflected onto them by air-core pulsed magnets. They are powered when the detector needs quiet time and the beams need to be kept alive in the linac. The power absorber is a modified single jaw of the type used in momentum slit SL–2 and described in more detail elsewhere.[1] It is a hollow copper cylinder filled with a water-cooled packed bed of 1-cm-diameter copper and copper-plated aluminum spheres backed by tungsten.[3] The distance from the nominal beam trajectory to the jaw face is 5 mm. When deflected onto the dump the beam impinges $\sim$4 mm from the face of the jaw. The small transverse size of the beam ($\sigma_x \sim 110$ μm, $\sigma_y \sim 40$ μm) dictated a low-Z material solution for which there was not enough longitudinal space available. Instead, a beam "spoiler" in the form of a $3/4X_o$-long titanium slab was installed $\sim$1.4 m ahead of the dump, appropriately offset from the nominal beam trajectory. A second spoiler, $\sim 1.2X_o$ aluminum, was attached to the upbeam end of the dump to create conditions favorable for longterm exposure of a material such as copper. To minimize potential wakefield effects the dump is faced by an image plate located 5 mm to the opposite side of the nominal beam trajectory. The plate required a transverse thickness of $\sim 3X_o$ and is water-cooled since much power is scattered out the front face of the dump and deposited in the image area.

5. DAMPING RING TRANSPORT AND LINAC BEAM-STOPPERS

Several personnel protection system beam-stoppers were built for the damping ring transport system (linac-to-ring) and the linac. Their design is similar to the one previously described for TD23. The absorber block is downsized to reflect the lower energies in that part of the machine, namely 1.2 GeV at the damping ring and 15 GeV at Sector 10 of the linac. The absorber is a $\sim 13X_o$-long copper block with transverse dimensions of $\sim 100\times 100$ mm. These blocks have a feature not found in other devices. They contain a "disaster monitor"[3] which consists of two cavities built into the block near shower maximum. The first cavity is connected to a source of compressed gas (dry N_2) at 1.4×10^5 Pa [20 psig] via a small diameter supply manifold. The larger return manifold is connected to a pressure switch. The two cavities are separated by a 12.7-mm-thick copper slab. The second cavity is either open to the vacuum system or connected to the tunnel atmosphere via a 4.7 mm inside-diameter tube. Should either excessive amounts of beam power be deposited in the dump or the cooling water flow be off (undetected), then the wall separating the two cavities will in due time melt. This results in loss of gas from cavity number one and also in a signal from the pressure switch (at 10^5 Pa [14.7 psig]) which turns off the beam.

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