The LEP Beam Dumping System

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Abstract

In the framework of the LEP2 project, CERN has installed a beam dumping system capable of absorbing simultaneously the energy of the counter-rotating electrons and positrons, from injection at 20 GeV/c up to storage at 100 GeV/c. At the quasi-symmetric center of the system, a fast kicker magnet powered by the discharge of a storage capacitor, deflects vertically each bunch of leptons onto a spoiler of boron carbide situated roughly 35 m from the kicker, and then, 10 m beyond, onto an aluminium dump. The spoilers are composed of 8 trapezoidal blocks 24 mm thick, located 25 mm below the circulating beam. The forged aluminium dumps, 40 cm square and 2.1 m long support brass shielding blocks on their downstream ends. In front of each dump, a luminescent screen coupled to a video camera provides visual monitoring of each bunch: the first being deflected by about 65 mm and the last by 45 mm. This presentation describes the general disposition of the system, the fast kicker magnet and its generator, the luminescent screens, and the control system. It emphasizes particularly the spoilers and the beam dumps, and the methods of calculation which define their dimensions.

1 GENERAL DESCRIPTION

With the improvement of LEP performance (higher energy, higher intensity, more bunches) it became necessary to dump the lepton beams in a fully controlled way. Therefore, a beam dumping system was designed, built, and installed in straight section 5 between the half-cells 557 and 560, the selection criteria of this location being: no experimental area (odd interaction point), minimum beam instrumentation equipment, and easy vacuum intervention. A fast kicker, located near the defocusing QL8 quadrupole, vertically deflects at the same time both electron and positron bunches; these traverse focusing quadrupoles QL7 and QL9 respectively, which give an additional vertical deflection. In order to avoid dangerous energy deposition densities in the absorbers, beams are first diluted by passing through spoilers, before being swept onto the dumps, just upstream of QL6 and QL10 respectively. Energy deposition calculations were made for three different beam energies (20, 50, 100 GeV) associated with different number of bunches and with different beam sizes at the entry of the spoilers (see tab. 1); each bunch is assumed to contain $8.3 \cdot 10^{11}$ particles. The first bunch is deflected by 1.05 mrd and the last one by 0.727 mrd.

Table 1: Beam characteristics for calculations

Energy [GeV]	20	50	100
No. of bunches	4	18	8
σ_{fwhm} size [mm]	0.1	0.25	0.5

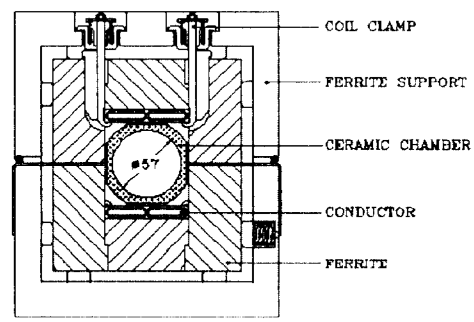

Figure 1: Cross-section of the kicker magnet

2 KICKER MAGNET SYSTEM

The kicker magnet (IKDM), fig. 1, is composed of a ferrite yoke in air and a two-turn excitation coil. It can be opened vertically to allow installation and bakeout of the vacuum chamber. The coil insulation is made of hot-pressed resin-rich mica tapes. To retain the electrical field in the insulation, its surface is coated with a conductive paint, which is earthed by the coil clamps. The vacuum chamber is composed of two ceramic tubes, glass bonded together in the center. Metal flanges are brazed at both ends providing connection to further beam line elements. The inner wall of the chamber is metallized with a 2 μm thick titanium layer by means of magnetron sputtering. The metallization provides a conducting path for the wall currents of the lepton bunches and screens the ferrite against their wake fields. The magnet is energized by the discharge of a storage capacitor. Before triggering, the capacitor is charged to a voltage proportional to the beam momentum. The rise time of the current pulse is determined by the interval between two successive bunches. To generate and to control the long fall time of the current pulse, a free-wheel diode stack with a series resistor is connected in parallel with the magnet. The fall time of the magnetic field is adjusted such that the deflected bunches are deposited in the absorber block over a range of 20 mm within one LEP turn of 89 μs. A detailed description of the kicker magnet system is to be found in reference [1].

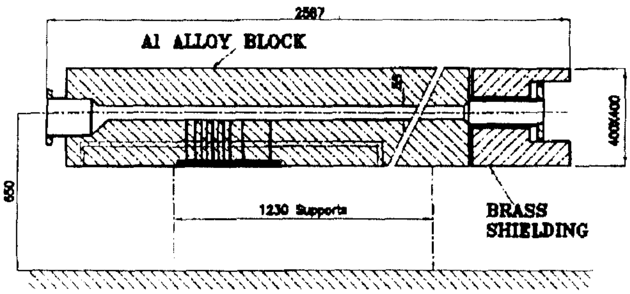

Figure 2: Beam absorber sketch

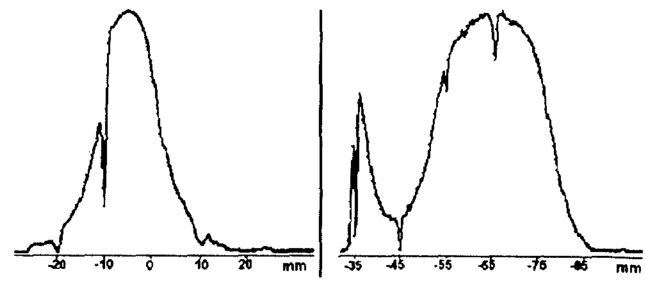

Figure 3: Horizontal (left) and vertical (right) projections of a dumped beam

3 SPOILERS

A spoiler (TSLV) is composed of eight trapezoidal boron carbide blocks installed 25 mm below the circulating beam axis, in a stainless steel vacuum tank (⌀ 159 mm, 440 mm long) inserted in the vacuum line by means of two flanges, ⌀ 253 mm. These blocks (35 mm high, 24 mm thick, 50 mm base, 15 degrees lateral slope), are hot pressed, rectified N6 surface finish, baked at 1000°C in vacuum, and subjected to an ultrasonic micro-scan in order to detect possible cracks. They are dovetailed onto a stainless steel plate, which provides geometrical alignment and thermal conduction with the upper part of the spoiler support, shaped to act as a radiator. The first and last B_4C blocks are rounded, as well as the extremities of the plate, in order to minimize transverse impedance phenomena. Regardless of beam energy and number of bunches, the first and last bunches should be deflected by 46 mm and 32 mm respectively, below the circulating beam axis; therefore, according to tab. 1, the swept bunch pitch would be 4.7 mm, 0.82 mm or 2 mm, depending on the number of bunches. Some physical and mechanical properties of B_4C are given in table 2.

4 BEAM MONITORS

In order to observe the correct functioning of the beam dump system, a beam profile monitor (BPED) is positioned in front of each absorber. A luminescent screen observed with a CCD camera has been chosen for this task. The screen material, Al_2O_3 (Cr), has been selected as it has a remanence greater than the duration of a TV frame, so as to record all dumped beams. A 10 × 10 mm grid is deposited on the screen, except on the 20 mm wide by 40 mm high centre part, to provide an independent and precise reference grid. The spatial resolution of the system is equal to 250 μm in both directions. The dynamic range covers single injected pulses to whole stored beams by remotely adjusting the iris of the CCD camera as a function of the circulating beam and by using the decay time of the screen when saturation of the camera has nevertheless occurred. It is possible to memorise the image of a dumped beam either on a TV recorder or on a VME digitiser and frame grabber. The dumped beam can be viewed either on a TV screen or on a workstation. For precision measurements, the horizontal and vertical projections are used. An example is given in fig. 3 for an eight bunch beam of 1 mA. The peak at the left of the vertical profile is the synchrotron light signal generated in the kicker and passing above the spoiler. The dips in the profiles are generated by the fiducial marks of the screen. The vertical profile demonstrates that the beam is spread over 20 mm.

5 BEAM ABSORBERS

The absorbers (TDLV), fig. 2, were obtained from aluminium alloy ingots (6% copper, low magnesium) of the same melt. Initially of 1365 × 990 × 410 mm, they were three-axially forged at 320°C, solution heat treated at 535°C, pre-machined, cold worked once on a 65 000 ton press to 2500 × 400 × 400 mm, and finally, age hardened at 175°C. Before being bored and machined, these blocks were submitted to various analysis and tests: chemical, mechanical, dye-penetrant, ultrasonic and helium leak. One of the more delicate phases of machining was the electro-erosion of ten slots, in the underside of the block. These slots are foreseen to prevent dangerous elastic stress waves effects, in the region of maximum energy deposition (see chapter 6). Several prototype electrodes of various shape were tested, before acceptable life-time and required accuracy were obtained; it took nevertheless about twelve hours to electro-erode one slot of 189.5 × 45 mm, 3 mm thick (1 mm over the last 45 mm depth). While each absorber is incorporated in the LEP vacuum line by means of two flanges ⌀ 225 mm, the slot volume is separately vacuum sealed and can be pumped independently. Although the minimum interval between two consecutive beam discharges is currently about half-an-hour, water cooling is incorporated in order to cope with an eventual higher dumping frequency. A pair of horizontally articulated brass shielding blocks (400 × 400 × 200 mm) are mounted on the downstream end of each dump, to absorb the more penetrating particles. On the conical entry of the absorber, the first and last bunches are vertically deflected by 65 mm and 45 mm respectively, resulting in a swept bunch pitch of 6.7 mm, 1.2 mm or 2.9 mm, depending on the number of bunches. Some physical and mechanical properties of Al alloy are given in tab. 2.

Table 2: Some physical and mechanical properties of B_4C and Al alloy, around room temperature

Property:	Units:	B_4C	Al alloy
density	[g/cm^3]	2.5	2.82
specific heat	[J/g·K]	1.85	0.96
therm. conductivity	[W/cm·K]	0.92	1.28
therm. expansion	[m/m·K]	$4.5 \cdot 10^{-6}$	$21.6 \cdot 10^{-6}$
elastic modulus	[daN/mm^2]	44000	7240

6 ENERGY, THERMAL AND MECHANICAL CALCULATIONS

The dumped beam is absorbed by developing electromagnetic cascades in which the energy of the primary electrons is transferred to bremsstrahlung photons, secondary e^+e^- pairs, annihilation photons, photoelectric, δ-ray or ionization electrons. In order to estimate the spatial distribution of the deposited energy, all these processes were simulated by the FLUKA high energy particle shower programme [2] (down to 0.1 MeV cutoff for electrons and 0.01 MeV for photons). Beam was assumed to consist of monoenergetic electrons. Half-maximum widths σ_{fwhm} of gaussian transverse profiles, same in both planes, are given in tab. 1. The simulations were performed for different points of incidence (from 21 to 7 mm below the upper edge of the spoiler) which correspond to the successively dumped bunches. The density of deposited energy was scored in cartesian bin meshes of lateral size 0.1 mm for the spoiler and 2 mm for the absorber, and longitudinal size 1 cm for the spoiler and 10 cm for the absorber. The final energy deposition was obtained from the superposition of the bunches, each containing $8.3 \cdot 10^{11}$ electrons. The simulations show that in the shower induced by a 100 GeV electron, only 0.25 GeV (on the average) of the primary energy is absorbed in the spoiler, and 96.5 GeV is contained in the absorber; the remaining energy (about 3 GeV) is either absorbed in the non-simulated parts of the structure behind the absorber, or escapes from the system as photons. The maximum energy deposition densities (per 8 bunches) are about 79 J/g for the spoiler and 159 J/g for the absorber. Taking into account the specific heat of B_4C and Al, the instantaneous temperature rises are about 43°C for the spoiler and about 165°C for the absorber. These correspond to an hydrostatic compression of 9 daN/mm^2 and 26 daN/mm^2, respectively. The latter value is the more critical one for the absorber; it would be about 55% higher without spoiler. For the spoiler, the higher instantaneous temperature rise occurs at 20 GeV: *i.e.*, about 153°C, corresponding to 30 daN/mm^2. Fig. 4 shows the laterally integrated energy deposition as a function of longitudinal depth in the absorber, for two beam energies.

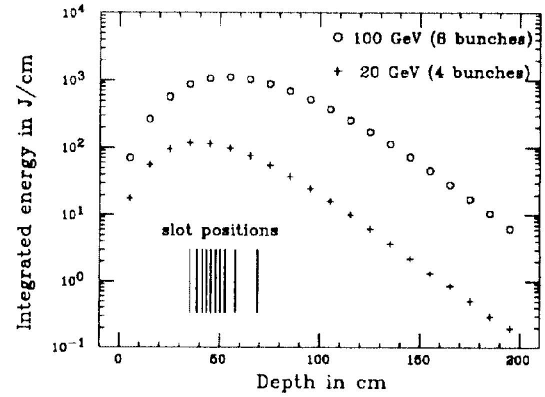

Figure 4: Integrated energy deposition in absorber

7 CONTROL SYSTEM

Since fast pulsed magnet systems such as beam dumps generate very high electrical noise levels, a careful design of their electronics is necessary [3]. The electronic components are divided into two groups: the power electronics which are nearest and physically connected to the pulse generator (thyratron heater, thyratron power trigger, thyratron grid polarization, high voltage power supply, *etc.*) and the control electronics which perform data acquisition and remote equipment control (timing, slow and fast interlocks, emergency interlocks, tracking system, *etc.*). To prevent noise propagation between the different parts of the electronics and to gain flexibility, a modular design is used and a physical separation is imposed between control and power electronics. The two parts are electrically isolated from one another with two different ground planes, and are linked together with plastic fiber optics. The remote control of all the electronics is performed with an industrial 486 type PC running under LynxOS, with a MIL1553 field bus for the control of the equipment and data logging, and a GPIB bus for instrumentation control and signal diagnostics. The software is divided into a modular hardware dependent equipment level, and a hardware independent control level built into the framework of a data-driven generic software tool kit.

8 ACKNOWLEDGEMENTS

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9 REFERENCES

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[3] "The Control System for the LEP Beam Dump", CERN SL/93-49 (BT).