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RECENT DEVELOPMENTS OF BEAM DUMPS AND TARGETS AT THE SPS

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Summary

Proton intensities of about three times the original design value of 10^{13} protons/pulse (ppp) have recently been achieved in the CERN-SPS. Failures due to the resulting elevated energy deposition densities in targets and absorbers are reported and the design and construction of new, fail safe equipment is described.

1. The Absorbers for a Beam Dump Experiment

A beam dump experiment was made at the CERN-SPS to study the production of prompt neutrinos. The dump blocks were made of a forged, high strength copper alloy Cu-Cr-Zr with the following dimensions: length 3025 mm, height 415 mm, width 320 mm. To measure the neutrino yield at different nuclear absorption lengths, the effective density of two of the three blocks was reduced to 1/2 and 1/3 of the original copper. This was achieved by machining a series of equidistant slots laterally through the blocks, thus leaving their outside dimensions identical. Fig. 1 shows the density "1/3" block.

Fig. 1 The density "1/3", air-cooled copper absorber block for the beam dump experiment.

The incident proton beam (momentum 400 GeV/c, intensity 1.5×10^{13} ppp) deposits about 820 kJ/burst in the density "1/1" block. With the SPS-cycle time of 12 s this corresponds to a time averaged power of 68 kW. In the blocks with reduced density the energy depositions are somewhat lower.

Computations of the instantaneous temperature rise due to each proton burst with a duration of 23 microsec. were made with a Monte Carlo cascade program¹. Values of about 240°C/burst were obtained with an r.m.s. beam radius of 10 mm.

Initially, the blocks were cooled via water channels which were deep drilled through the total length of the top and bottom faces of each block. With the estimated temperature difference of 60°C between the centre of the block and the cooling channels as well as a water temperature of 15°C, peak temperatures of about 320°C must have been reached during each proton burst. This comes close to the level where the copper alloy starts to loose its mechanical strength. Moreover, each burst induces in the block thermal stresses and in particular, violent shock waves which were clearly

audible even at a distance of about 50 m behind the heavy radiation shielding.

Fig. 2 shows the layout of the dump area where the blocks of different densities were placed beside each other in their support frame. The latter was suspended from a remotely controlled mobile chariot which could move any one of the three dumps into the beam. Downstream of the main dumps, an additional block was placed for further background reduction. The dump area was covered by a 1 m thick mobile top shield which could be opened sideways to permit access with the overhead crane.

Fig. 2 Layout of the absorber area of the beam dump experiment.

Already after a very short running period of 36 hours, one of the four water inlets at the upstream face of the density "1/1" block developed a water leak. After unsuccessful attempts to repair the fault, a new set of beam dumps was constructed which, this time, were cooled by air. Two ROOTS-pumps provided each an air flow of 2000 m³/h. The air was directed with a velocity of about 60 m/s through the nozzles upstream of the block along cooling fins which were machined into the top and bottom faces of the copper. Rigid connections between the air nozzles and the dumps were avoided by leaving a gap of about 20 mm between them, accepting some tolerable air losses.

The temperatures, measured on the cooling fins were about 80°C at 10^{13} ppp. Therefore, at the scheduled intensity of 1.5×10^{13} ppp the estimated maximum temperature in the centre of the block was about 400°C.

To allow for some decay of the remanent radioactivity the blocks were inspected about six months after the end of the experiment. Still, with surface doses of up to 30 Rem/h, remotely controlled T.V. cameras and a manipulator had to be employed. It appeared that most of the 4 mm thick cooling fins of the density "1/1"-block were cracked at their bases over a length of about 50 cm (see Fig. 3). A dye penetrant check on the front and side faces of this block showed, however, no further cracks.

Likely, excessive stress concentrations and thus fatigue occur at the base of each fin. No detailed calculations have yet been made to understand the involved phenomena. Moreover, experiments to measure the response of massive

Fig. 3 Side view of the damaged density "1/1" absorber block, showing the crack along the outermost cooling fin.

blocks to the impact of the proton burst as well as "post mortem" inspections are severely hindered by the level of induced radioactivity.

2. The High Intensity Target

The target for the CERN narrow band neutrino beam consisted initially of a string of beryllium rods with a diameter of 3 mm, which were cooled by a helium gas stream. When, however, the intensity of the fast extracted proton beam (momentum 400 GeV/c, burst duration 23 microsec.) was raised to about 1.5×10^{13} ppp, the rods started to warp and finally broke due to excessive thermal stress and shock. Therefore, a new target has been built which is designed for future beam intensities of up to 2×10^{13} ppp.

As target material, graphite was selected which has an excellent thermal shock resistance and mechanical strength at elevated temperatures and has successfully been applied for similar purposes² elsewhere. The target rod has a diameter of 3 cm and a length of up to 100 cm.

The temperature rises in the target due to the energy deposition of the primary protons and the secondaries have been calculated³. For a beam diameter of 2 mm (4σ of a Gaussian density distribution) a maximum temperature rise per pulse of about 1330°C is expected in the target centre. The time averaged longitudinal power density is at most 60 W/cm.

To prevent substantial oxidation of the graphite when exposed to air at elevated temperatures, the target rod is mounted in a thick walled aluminium tube closed at both ends with 0.1 mm thick titanium foils. Over-pressure valves on the target container will release any possible pressure due to excessive heating or beam induced outgassing of the graphite.

The heat deposited in the target rod is conducted radially into the wall of the aluminium tube. An excellent thermal contact between the target and the container is achieved by shrink fitting the tube around the graphite cylinder². The outside surface of the aluminium container is cooled by an air stream, produced by a ROOTS-pump and directed through a nozzle upstream of the target into cooling channels machined in the circumference of the aluminium container.

Laboratory tests were made with an electrical heating element which dissipated about 70 W/cm. With an air velocity of about 10 m/s the average temperatures on the outer surfaces of the graphite and the aluminium container were about 120°C and 110°C respectively. The temperature of the aluminium should be kept well below 130°C since if it expands radially too far it loses its thermal contact with the graphite.

It has been proved to be very useful to provide in a target station several target heads as well as a "target out" position, which can be selected remotely. In the described device two adjacent target rods are mounted in a common frame which can be displaced horizontally. The principle of the target unit is shown in Fig. 4. The support carrying the two targets is suspended by flexible metallic hinges which allow the required horizontal displacement. The support is moved by pneumatically driven stainless steel bellows, pressurised from a remotely controlled manifold. The latter is placed upstream of the highly radioactive target area and is connected to the target unit by metallic pipes. As shown in Fig. 4, the displacement is performed free of friction and therefore, cannot grip or suffer from corrosion.

Fig. 4

Schematic front view of the high intensity target with its pneumatically driven displacement mechanism.

Fig. 5 shows a side view of the target unit. The target support frame rests on a base plate which carries also the air nozzle. The beam, incident from the left side enters through a thin titanium window at the back of the air pipe. To allow the horizontal displacements of the targets, a small gap of 5 mm has been left between the nozzles and the air inlet of the target, accepting a tolerable air loss. The nozzle is connected to the air supply duct in the target station via a "floating" flange which is mounted underneath the base plate via a bellows. Thus, the pressure due to the weight of the heavy flange provides an adequately leak tight seat.

The target support frame and its base plate can both be handled by a remotely controlled and T.V. assisted overhead crane. The use of this target unit in the beam is foreseen in the middle of 1983.

Fig. 5 Side view of the air-cooled high intensity target unit.

3. The High Intensity External Dump

The presently available fast extracted proton beams of 2.8×10^{13} ppp would cause in the aluminium cores of the external SPS-dumps temperature rises of about 500°C and thermal stresses of about 60 daN/mm^2 . In fact, due to the violent stress waves the bolted water connections of one of the blocks started to leak. Moreover, an assembly of test blocks placed in the fast extracted beam showed local plastic deformation along the axis of the incident beam with an intensity of 2×10^{13} ppp and a diameter of about 6 mm (see Fig. 6). The aluminium core of the present dump is expected to be damaged in a similar way.

Fig. 6 Beam induced plastic deformation in an aluminium absorber block.

An improved dump block⁴, designed to absorb beams with intensities of up to 3.5×10^{13} ppp is now under construction.

The general layout of the new absorber is shown in Fig. 7. Its core consists of a stack of different materials, chosen to provide a gradual absorption of the beam without overstressing any of its components. The first core element hit by the beam consists of a graphite^{5,6} cylinder. It has a diameter of 80 mm and an overall length of 2527 mm. It is subdivided longitudinally in several shorter parts of 140 mm to avoid the transmission of longitudinal stress waves. To absorb further the beam energy which escapes radially and longitudinally from the graphite, a second core element made from aluminium is placed around and behind the graphite cylinder. It is also subdivided in modules to avoid the transmission of stress waves and to ease the assembly. The third core element consists of a copper cylinder with a central hole into which the graphite-aluminium core is inserted. The whole is surrounded by a cast iron shield.

Fig. 7 Longitudinal and transverse cut through the high intensity beam absorber.

Fig. 8 Press fitting of the cooling tube.

A special effort has been made to design a reliable cooling system for the core. The graphite core is not directly cooled but shrink fitted into the aluminium modules in order to achieve the required thermal contact. The aluminium containers are water-cooled. However, to avoid a risk of leakage in case of cracking of this material, stainless steel water tubes are inserted into holes which are drilled longitudinally through the aluminium. A sufficient thermal contact between the stainless steel pipes and the aluminium is achieved by a specially developed press-fitting technique⁷. It consists of pulling a conical tool of a high strength steel through the tube as shown in Fig. 8. Since the diameter of the tool is slightly larger than that of the tube the latter is tightly pressed against the wall of the channels in the aluminium. The pressures obtained are of the order of 3 to 6 daN/mm^2 . The heat transfer coefficients ranged, in the case of smooth tubes, from $4 \text{ W/cm}^2\text{C}$ at ambient temperature to $0.6 \text{ W/cm}^2\text{C}$ at high temperature (200°C around the cooling channel). However these values could be doubled by using tubes with corrugated outside surfaces which benefit from an increased contact surface.

The advantages of the cooling method to press fit stainless steel tubes into absorber blocks can be resumed as follows: No water leaks in case of cracks in the absorber material, no corrosion of the block material, the absorber can consist of a stack of several shorter parts of even different materials which all can be cooled by one single cooling circuit, easy assembly, low cost.

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