CHAPTER 27

TRANSFER LINE DUMPS, SAFETY STOPPERS AND COLLIMATORS

27.1 EXTERNAL BEAM DUMPS (TED)

Three new external beam dumps (TED) will be installed in TI2 and TI8. These beam obstacles are the natural evolution of the existing SPS ones, placed in TT20 and TT60 [1]. The TED will be located in TT40, at the end of the TI8 tunnel and at the TI2 exit. The existing TT60 dump will act as the upstream TED for TI2.

The TED are required to intercept the high energy beam extracted from the SPS. This is concentrated in very short pulses (in the range 7.8 µs to 10.5 µs) at high intensities. In the extreme case the TT40 TED has to withstand the impact of the CNGS beam with up to 7×10^{13} protons every 6 seconds at 400 GeV. The dumps should withstand these conditions for several hours, for example during extraction setting up, without alteration of the properties of the core.

The new transfer tunnels are rather small and pose significant space and transport difficulties for large, heavy items such as the TED. In spite of this, an effort was made to keep the new TED for the LHC compatible with the present SPS ones. This has the advantage of equipment standardisation and allowed the saving of one complete assembly by sharing a spare TED between the SPS and the LHC. However, the dimensions and material composition of the absorber core have been improved in order to cope with the LHC beam parameters.

A schematic view of the TED geometry is presented in Fig. 27.1. The outer cast iron shielding is identical to the present SPS one with two 4300×960×480 mm yokes each weighing 9.5 tons and providing handling and positioning facilities. Cooling is provided by four independent circuits using Ø16 mm diameter tubing. The shielding fully encloses a polycrystalline graphite core (type R7500 by SGL), which is split into twenty cylinders Ø80 mm, 145 mm long. These cylinders are thermally shrink-fitted at about 200°C into five aluminium tubes (EN AW 6082-T6) Ø80/160 mm, 600 mm long, which are connected lengthwise. In addition, a downstream solid cylinder of same length and same alloy is added. The six elements are assembled by means of elastic pins, and by four press fitted [3] stainless steel tubes Ø14/16 mm, which are twin-linked to form two independent water-cooling circuits. The compete 160 kg assembly is fitted into a copper tube made of four CuOFE elements Ø160/310 mm, 900 mm or 940 mm long and of a downstream solid cylinder, 790 mm long. Elastic pins and press fitted tubes keep these five elements together, which are also cooled by two independent water circuits. This assembly method avoids expensive electron beam welding of the special (and fairly brittle) copper alloy. A Ø58 mm insert, 250 mm long, made of high-strength (UNS C17200) Cu-Be alloy, is shrink fitted by liquid nitrogen in the upstream part of the solid copper cylinder.

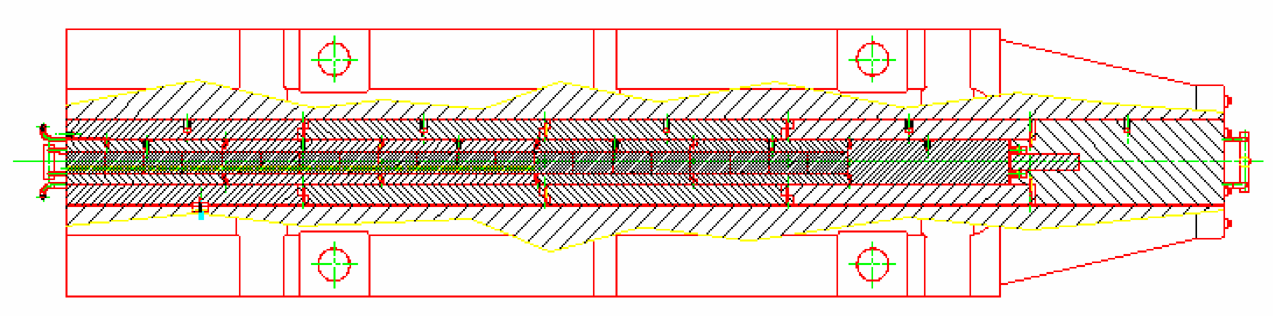

Fig. 27.1: TED schematic side view. The beam direction is from left to right.

The copper part of the dump core weighs about 2.4 tonnes and the complete TED therefore weighs about 21.6 tonnes. The eight independent water cooling circuits are fed by a collector located at the downstream end of the external shielding. This provides a heat transfer coefficient of 0.8 $\mathrm{Wcm^{-2}}$ per °C to each circuit, with a maximum water speed of 2 m/s. In practice, each TED requires a total flow rate of about 18 $\mathrm{m^3/h}$.

Since the core itself has no structural function, steady state temperatures around 200 °C can safely be accepted in the aluminium and 300 °C in the copper. Because of the small size of the beam spot, the maximum attained energy density in the graphite is quite high, while lower temperatures are reached in the aluminium and copper. At the ultimate LHC beam intensity, the adiabatic maximum temperature increases are: 800°C in graphite, 130 °C in aluminium and 165 °C in copper. Temperatures drop rapidly away from the beam axis, with very high thermal gradients. The ensuing thermal stresses are below those allowed [4] for standard fine-grain graphite and aluminium alloys, while in copper and iron they are not. For copper, a more resistant alloy was therefore selected. As it would be too expensive to replace the whole of the copper part, a 25 cm short cylinder Ø5.8 cm, made of special Cu alloy, was thermally shrink fitted into the upstream part of the standard copper block, where equivalent stresses remain <70 MPa.

Only 1.5 % of the beam energy is estimated to escape from the TED. The graphite core absorbs 21.9 % of the beam energy, while the aluminium, copper and iron sections absorb 20.5 %, 36.1 % and 13.1 % respectively. The maximum allowed beam intensity for safe operation is given as a function of the pulse duration in Fig. 27.2. This graph is extended to show the slow extraction pulses as presently aborted on the SPS dumps.

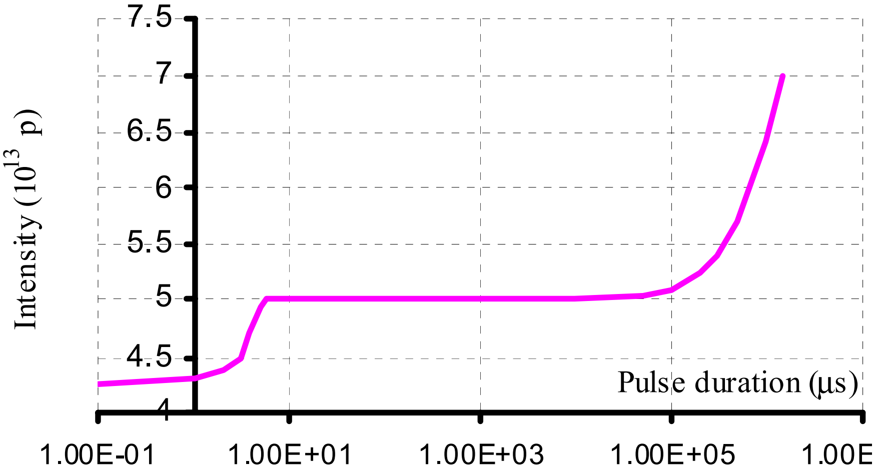

Figure 27.2: Maximum allowed intensity of a 450 GeV proton beam of radial size 0.58 mm, dumped every 16.8 s on a TED.

27.2 EXTERNAL SAFETY BEAM STOPPER (TBSE)

One safety beam stopper (TBSE) will be installed in the TI 8 beamline, immediately after the switch magnets and just before the entrance to the TI 8 tunnel. A second TBSE is planned for the entry of the TT41 neutrino tunnel [2] as a safety protection for the CNGS facility. It will be identical to the LHC one. The closure of the SPS west experimental area means that TT60 now serves only TI 2 with beam. As a result, the TED in TT60 can also act as a safety stopper for TI 2. Like the TED, the TBSE beam obstacles are the natural evolution of the existing SPS ones, placed in TT20 and in TT60 [1].

The stopper, which is dedicated to personal safety, is only supposed to absorb the occasional (ideally never) pulse of beam. This would be a single shot of 450 GeV protons concentrated in a very short pulse (in the range 7.8 μs to 10.5 μs). Once again the extreme case would have an intensity of up to 7×10^{13} protons. The TBSE design adopts the same structure as the TED core, with the copper part substituted by iron for cost and technical reasons. A schematic side view of the TBSE is presented in Fig. 27.3. It is much simpler than the TED since it has neither external shielding, nor cooling circuit. The inner graphite/aluminium core is made in the same way as the TED one, the aluminium elements only being assembled by elastic pins. The outer steel (C45 W) core is made of two pinned elements: an Ø120/240 mm tube, 3620 mm long, nesting a downstream solid cylinder, 500 mm long. The complete TBSE core weighs about 1.2 tons.

The TBSE has less stringent requirements than the TED. Since it is expected to receive only single beam aborts, only adiabatic temperatures have to be taken into account, and no cooling is needed. Since copper and iron have very close density, atomic number and specific heats, the above considerations also apply to the

TBSE. The peak of energy deposition in iron is very close to the front, where the maximum temperature increase is about 130 °C; only 15 °C is found on the side. The lack of a massive cast iron shield results in a poor lateral containment. In this case 20 % of the beam energy escapes the TBSE. The aluminium and iron sections absorb 16.7 % and 36.3 % of the beam energy respectively.

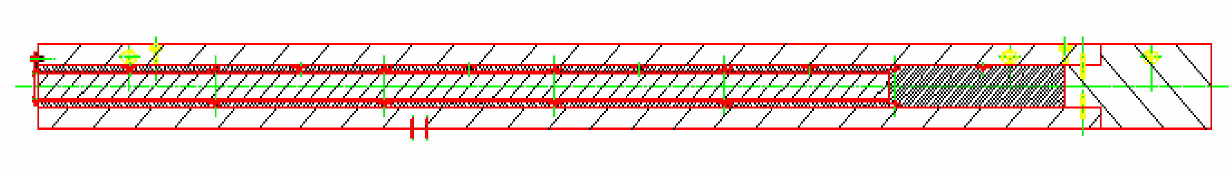

Figure 27.2: TBSE schematic side view. The beam direction is from left to right.

27.3 THE TRANSFER LINE COLLIMATION SYSTEM (TCDI)

The TI 2 and TI 8 transfer lines will be pulsed, with a close surveillance of power supply currents and beam parameters. Nevertheless, failure modes exist which could result in uncontrolled beam loss and serious damage to either the transfer line or the LHC equipment. To protect the equipment in the LHC injection regions and the LHC machine, a set of transfer line collimators (TCDI) will be installed.

Detailed studies and analyses [6,7] of the requirements for LHC protection have demonstrated that movable collimators are required in the transfer lines for protection in case of mis-steered beams. These will protect the LHC machine elements, including the small aperture MSI magnets, from damage. The aperture in the LHC arc at injection is just 7.5σ. The collimation requirements for the transfer lines have had to be adjusted accordingly. The nominal injected LHC intensity is about 20 times above destruction level and several orders of magnitude above the quench level of the cold magnets. Prior to injection into the LHC, scraping at about 3.5σ will be performed in the SPS, just before extraction. The transfer through the lines TI 2 and 8 and the injection into the LHC will be adjusted using pilot intensities, below the quench level and well below any damage level. Failures resulting in major beam loss at injection, for example by trips or wrong strengths of correctors in the pulsed transfer lines, cannot be completely excluded but are expected to be rare.

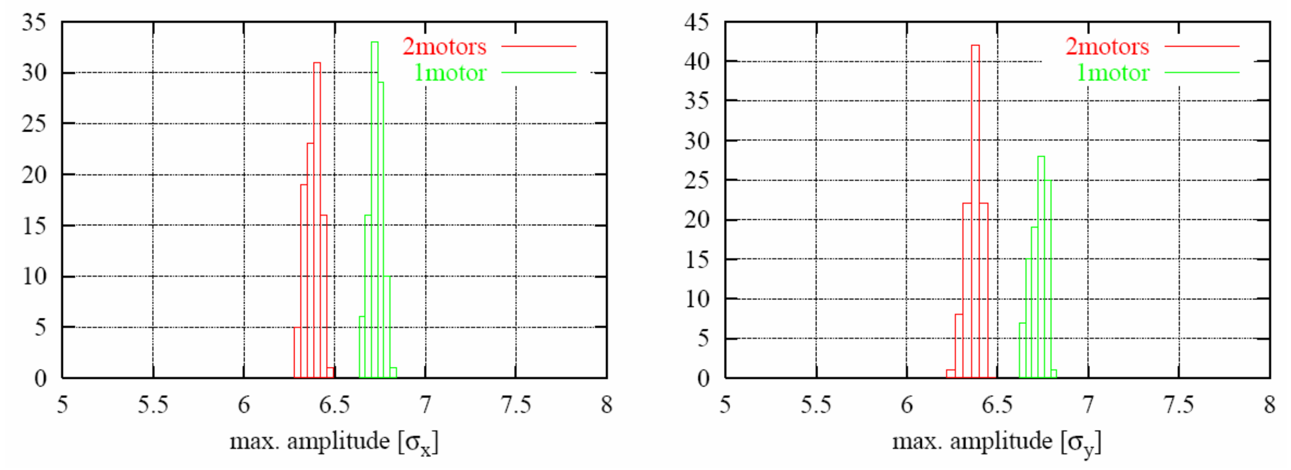

Figure 27.3: Distribution of maximum particle amplitude transmitted into the LHC for the 0-60-120 degree TCDI system, for horizontal and vertical planes.

The main function of the TCDI collimators is to dilute the beam sufficiently to avoid any destruction in such cases. The TCDI system will protect the LHC to 6.4 σ in each plane, with a total of 7 collimators per line. Momentum collimation will be performed in the first available space with high dispersion, and requires only one collimator. Betatron collimation will protect the tight MSI septum aperture, the injection region and the LHC cold aperture against bending errors upstream, and will therefore be placed towards the end of the line. A total of 6 collimators are necessary to achieve the required protection, using a phase coverage of 0-

60-120 or equivalent. For optics flexibility it is clearly an advantage to have a solution using 0-60-120, instead of the alternative 0-45-90-135, which has an extra phase advance constraint. For integration purposes the situation is also easier.

The protection level has been simulated by tracking beams through the collimators installed at ideal locations in TI 8. This tracking was performed with optical errors (beta-beating) included from the SPS and from sources in the line. The 0-60-120 solution provides an adequate protection, with maximum transmission below 6.4σ, for a nominal (i.e. guaranteed minimum) aperture of 4.5σ at each collimator. The results are shown in Fig. 27.3. The chosen solution uses TCDI equipped with 2 motors per jaw. The tracking results for the case when a single motor per jaw is used are also presented. For TI 8, the 0-60-120 option is easier to fit physically in the line, with the natural matching solution having very convenient locations for all devices, except the H120 collimator. However, the location for the alternative H300 is available. For TI 2 the natural positions are at 240 and 300 degrees in both planes, to avoid difficult matching and integration. The provisional locations for the TCDI collimators in TI 2 and TI 8 are given in Tabs. 27.1 and 27.2 respectively.

Table 22.6: Provisional TCDI collimator locations for the transfer line TI 2.

Name [m]	**s [m]**	**Δμ to TCDI$_{MSI}$ [°]**
TCDIMOM	403.1	-
TCDIH300	2818.0	300
TCDIH240	2852.0	60
TCDIHMSI	3108.8	0
TCDIV300	2844.0	300
TCDIV240	2893.0	60
TCDIVMSI	3110.8	0

Table 22.7: Provisional TCDI collimator locations for the transfer line TI 8.

Name [m]	**s [m]**	**Δμ to TCDI$_{MSI}$ [°]**
TCDIMOM	668.8	-
TCDIH300	2385.5	300
TCDIH060	2547.0	60
TCDIHMSI	2622.1	0
TCDIV120	2441.5	120
TCDIV060	2498.3	59
TCDIVMSI	2620.1	0

To protect local elements from damage arising from particles scattered from the TCDI jaw secondary TCDIM shields are required downstream of the TCDI collimators. With the exception of the last TCDIM these will be low-technology, low-cost objects around the beam pipe. The last element immediately upstream of the MSI must withstand higher temperatures than the others. Fig. 22.13 shows the temperature rise simulated in magnets downstream of a TCDI collimator and TCDIM mask, for a full LHC ultimate beam impact. A detailed functional specification and a preliminary design of the TCDI collimators with 1.2 m long graphite jaws (similar to the secondary LHC collimators) followed by a 50 cm long iron shielding outside the beam pipe can be found in [8].

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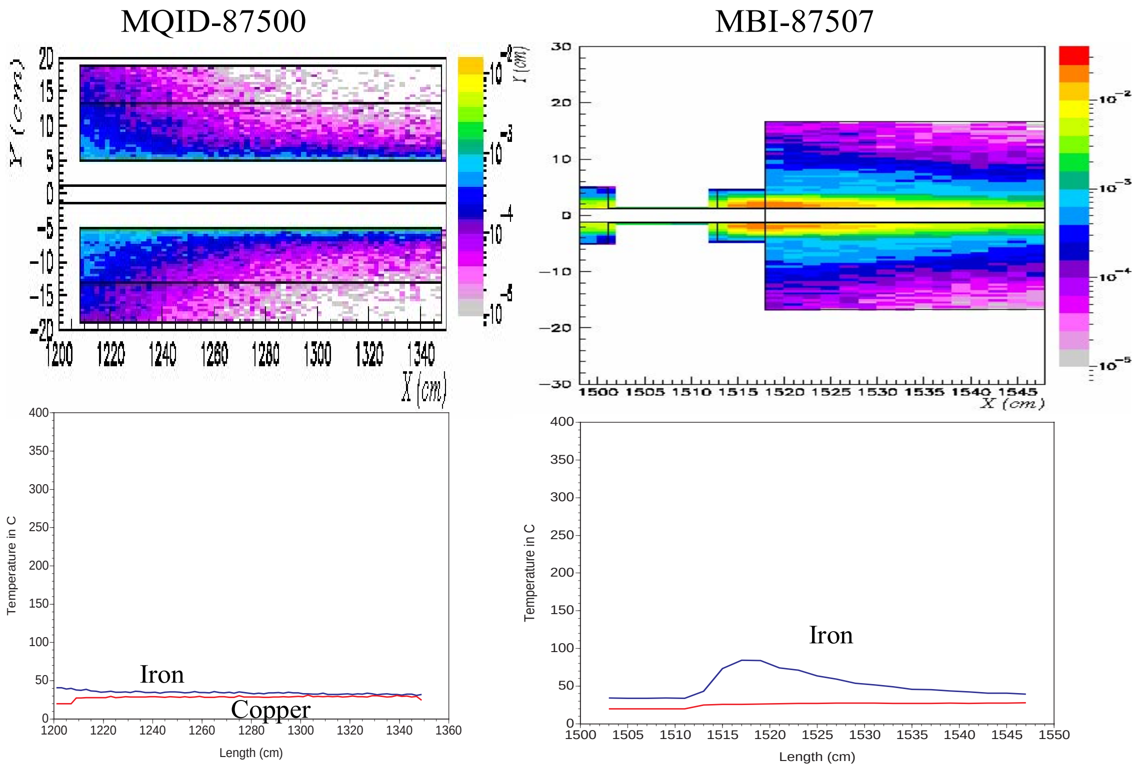

MQID-87500

MBI-87507

Figure 22.13: Energy deposition maps and maximum temperature rise profiles in MQID87500 and MBI87507, for full LHC ultimate beam impact on the graphite jaw of an upstream TCDI collimator.

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