PROPOSAL FOR A NEW EXTERNAL SPS BEAM DUMP

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1. Introduction

The present external dump TED in the TT-60 beam transfer line of the SPS was designed for a maximum intensity of $10^{13}$ protons/pulse (ppp). The upstream part of the dump core consists of an aluminium cylinder which absorbs a large part of the incident energy. To back up this aluminium, the downstream part is made of copper. Both blocks are embedded in a massive cast-iron shield which provides sufficient protection against remanent radioactivity. Both parts of the core as well as the shield are water cooled.

Over the past years, the SPS intensity has continuously been increased and fast extracted beams of up to $2.2 \times 10^{13}$ ppp, largely exceeding the design value, have been dumped onto the TED. As a result of the violent thermal shocks which are induced by these intense fast extracted beams, water leaks developed which temporarily could be closed with Araldite.

Calculations show that excessive temperatures and stresses are reached in the centre of the aluminium block when fast extracted beams of $2 \times 10^{13}$ ppp are absorbed:

- Temperature increase per pulse: 475°C
- Local thermal stress: 55 daN/mm²

Moreover, an aluminium test block (Spoiler) had been irradiated with fast extracted beams of $2.2 \times 10^{13}$ ppp which resulted in local plastic deformation of the absorber material as shown in fig. 1.

For these reasons, a new design for the external dump is proposed which permits to absorb fast extracted beams of up to $3.5 \times 10^{13}$ ppp at 450 GeV/c.

2. Description of the new TED cores

For the principal absorber material in which the highest energy deposition densities occur, graphite is proposed. This material resists extremely well to the elevated temperatures and the thermal shocks.

Around the 80 mm thick graphite core and beyond its length of 2.5 m the energy deposition density is sufficiently small to allow the use of aluminium as back-up material.

To evacuate the heat from the graphite into the surrounding aluminium, an adequate thermal contact between the two materials is required. This is conveniently achieved by shrink fitting the thick walled aluminium container around the graphite core. Moreover, to cool the aluminium, stainless-steel water pipes are press fitted into longitudinal channels which are drilled through the aluminium. This cooling system is highly fail-safe since it is not affected by cracks which may develop in the graphite-aluminium core. Laboratory tests and experiments with the spoiler proved the merits of the press fitted stainless steel pipes.
Finally, to minimise the escape of energy at the rear of the dump, the downstream end of the core consists of a 1.25 m long copper cylinder.

Similarly to the present TED, the entire ensemble of the graphite-aluminium-copper core is placed inside a cast iron shield, which already exists.

Following this principle, two variants of the beam dump core have been studied:

Variant 1: The graphite/aluminium core has an outside diameter of 310 mm which fits exactly into the central aperture of the existing cast-iron shield as shown in fig. 2.

Variant 2: The diameter of the graphite/aluminium is reduced to 160 mm, to make space for an additional copper shield placed between this core and the cast iron shield as shown in fig. 3.

Longitudinal cuts of these two variants are shown in fig. 4.

The variant 2 is more complicated and expensive, but it has the advantage that the additional copper improves the shielding around the core. This reduces the power which is deposited in the cast-iron shield and thus makes failures of the cooling circuit of the cast-iron less likely. Moreover, the remanent radioactivity on the dump surface will be reduced. There the average radioactivity levels are at present about 200 to 300 mrem/hour. Similar levels can be anticipated with a dump core of variant 2 even with intensities of about $3 \times 10^{13}$ ppp. With a dump core of variant 1, however, these levels will be about two or three times as high.

Finally, the smaller diameter and weight of the graphite-aluminium cylinder of variant 2 may ease the handling and exchange of the core, if ever required.

3. The energy deposited during the absorption of one pulse

For the calculation of the deposited energy the Monte Carlo program ZYKAZ4 was used with the following parameters:

- Beam intensity: $3.5 \times 10^{13}$ ppp
- Duration of fast extraction: 23 micro seconds
- SPS repetition rate: 15 seconds
- Proton momentum: 450 GeV/c

The total energy of $2.5 \times 10^6$ J/pulse, corresponding to an average power of 167 kW, is distributed over the different parts of the TED in the following way:
The deposited energy in the iron shielding of type 1 is about twice that of type 2.

4. The expected temperatures

The maximum temperatures will be reached with fast extraction. The following lateral r.m.s. beam sizes have been assumed:

\[ \sigma_h = 1.2 \text{mm} \quad (\text{horizontal emittance}: \varepsilon_h = 0.4 \text{ mm mrad.}) \]
\[ \sigma_v = 1.7 \text{mm} \quad (\text{vertical emittance}: \varepsilon_v = 0.2 \text{ mm mrad.}) \]

The maximum temperature rises in each part of the dump have been calculated and are summarised in the table below:

<table>
<thead>
<tr>
<th>variant</th>
<th>total energy (%</th>
<th>average power (kW)</th>
<th>energy in hottest cross section (J/cm.pulse)</th>
</tr>
</thead>
<tbody>
<tr>
<td>variant 1</td>
<td>C-Al Core</td>
<td>Cu Core</td>
<td>Fe Shield</td>
</tr>
<tr>
<td>variant 2</td>
<td>C-Al Core</td>
<td>Cu Core</td>
<td>Fe Shield</td>
</tr>
<tr>
<td>C-Al core</td>
<td>45.3</td>
<td>12.5</td>
<td>39.3</td>
</tr>
<tr>
<td>Cu core</td>
<td>76.1</td>
<td>20.9</td>
<td>66.0</td>
</tr>
<tr>
<td>Fe shield</td>
<td>4472</td>
<td>3628</td>
<td>2598</td>
</tr>
</tbody>
</table>

The maximum temperature rise due to one proton pulse. Adiabatic temperature rise due to one proton pulse. Additional temperature difference between the hot spot and the rim of the cooling hole in the steady state. Temperature difference between the rim of the cooling hole and the cooling water in the steady state. Temperature difference between the cooling water at the inlet and at the outlet in the steady state. The flows are adjusted to give the same temperature increase in each circuit.
The maximum temperature found after dumping of one pulse is the sum of the "One pulse" temperature increase and the "Inlet water temperature". When dumping continues for a longer time a steady state will be reached and the absolute maximum is the sum of all the given temperature increases.

The peak temperature in the graphite of 757°C may cause some oxidation of this material when exposed to air. Therefore it may have to be sealed at the upstream end with a titanium window.

The aluminium and copper downstream of the graphite are sufficiently protected by the latter and their temperatures will stay well below any critical limits.

5. The expected thermal stresses

The thermal stresses which occur at the location of the maximum temperatures given in section 4 are:

<table>
<thead>
<tr>
<th>Thermal stress (daN/mm²)</th>
<th>Variant 1</th>
<th>Variant 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core C -- Al</td>
<td>Fe shield</td>
<td>Cooling tube</td>
</tr>
<tr>
<td>1.2</td>
<td>3.5</td>
<td>1.2</td>
</tr>
</tbody>
</table>

The stresses given for the stainless steel cooling tubes of the cast iron shielding are caused by the difference in expansion between the stainless steel and the cast iron. The values shown are the highest ones and are found at the cold water inlet side if the water enters at the minimum temperature of 10°C. At the outlet side where the water temperature has risen by 10°C, the stresses are less due to the relatively large expansion of the stainless steel compared to that of the cast iron.

6. The effect of a deficient thermal contact between the cast iron and the cooling tubes

The radial stresses between the cast iron and its stainless steel cooling tubes are about half the equivalent stresses in the stainless steel tube given above. These radial stresses tend to separate the cast iron from the tube. Actually, the quality of the stainless steel/cast iron bond is not known. For illustration the rather pessimistic case has been considered where a local air gap of 0.05mm separates the tube from the cast iron at the hottest cross-section:

<table>
<thead>
<tr>
<th></th>
<th>Variant 1</th>
<th>Variant 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Additional temperature rise (°C) across the air gap.</td>
<td>53</td>
<td>27</td>
</tr>
<tr>
<td>Maximum total temperature (°C) in cast iron shield.</td>
<td>136</td>
<td>94</td>
</tr>
<tr>
<td>Stress in tube wall. (daN/mm²)</td>
<td>17</td>
<td>8</td>
</tr>
</tbody>
</table>
The weight of variant 2 is 22'050 kg and close to the maximum permitted weight. Therefore little room is left for possible future additions or modifications of version 2.

The TED in the North extraction channel TT-20 will not need to be replaced by a new one as the actual type is expected to stand the slow extracted beam without problems, the peak temperatures being much less than in the case of fast extraction.

8. Acknowledgements

We would like to thank P. Gerdil for the preparation of the press fitting tests and the assembly of the spoiler and H. Fritz for the hardness tests on the spoiler material. We are grateful to W.C. Middelkoop and E. Weisse who contributed through stimulating discussions and continuous encouragements.

9. References

1. Absorber blocks for internal and external beam dumping at the SPS. K. Teutenberg, P. Sievers, W.C. Middelkoop. CERN-LAB II/74-4.

2. The design and prototype tests of the CERN Antiproton Production Target. R. Bellone, G. del Torre, M. Ross, P. Sievers, CERN-LAB II/74-4.


4. Author: J. Ranft. See also H. Schoenbacher, CERN-LAB II-RA/TM/74-5.
It appears that the stresses in the tubes increase due to the elongation which is forced upon them by the expansion of the iron block. They stay however within the elastic limit even under the above rather pessimistic assumptions.

7. Discussion

The two variants for the core of the external beam dump described are both designed to absorb fast extracted beams of $3.5 \times 10^{13}$ ppp at 450 GeV/c.

Version 1 is the most straight-forward one, technically less complicated and less expensive than version 2. It has three cooling circuits for respectively the graphite-aluminium core, the copper core and the iron shielding. The graphite-aluminium core is subdivided over its length to suppress longitudinal shock waves. In order to avoid the transmission of longitudinal shocks via the press fitted cooling pipes, the latter should be placed as far as possible from the centre of the core. In version 1 they could be located on a relatively large radius of at most 110 mm.

The weight of variant 1 is 20'800 kg. The maximum permitted weight is given by the capacity of the goods lift (25'000 kg). Taking into account the weight of the transport chariot (2'200 kg) of the dump it results that additions with a weight of 2000 kg are possible for future improvements.

Version 2 is somewhat more elaborate. It is equipped with the additional copper shield, subdivided in a top and a bottom part which can be separated to introduce the core. Consequently this version has two more cooling circuits. Again the core is subdivided over its length to suppress longitudinal shock waves, but the press fitted cooling tubes approach more the hot centre (60 mm) and risk more to transmit longitudinal shock waves. The extra copper provides an additional radial shield which reduces the level of the induced radioactivity of the outside surface of the block to about half that of version 1. Therefore, with version 2 and proton intensities of $3.5 \times 10^{13}$ ppp similar doses can be expected as presently with $2 \times 10^{13}$ ppp. In addition the copper shield protects better the iron shielding where the reliability of its cooling circuit is not totally known for the expected elevated energy deposition levels. On the other hand, these shieldings never failed during the past six years of SPS operation.

Due to the small diameter and weight of the core of variant 2 it could be envisaged to remove this core "in situ", if necessary. In this case, however, special tools and a shielded chariot are required in order to cope with the elevated remanent radioactivity of the core, which may be of the order of 10 to 20 rem/h. In general there is no necessity to replace a faulty TED immediately in situ since the SPS can continue to operate under, however, somewhat restricted conditions. A repair or exchange can in most cases be arranged for the next following shut-down. Moreover it will be possible to continue dumping without cooling for about 3.5 hours after which the average temperature will have been risen by only 100°C due to its large mass.
Fig. 1 The Vickers hardness in the centre of the aluminium test dump (Spoiler), measured across the beam paths. The tests were made with fast extracted beams of $2.2 \times 10^{13}$ ppp (horizontal beam size 4.8 mm, vertical beam size 6.8 mm).
Fig. 2 Cross-section of the Graphite-Aluminium absorber core Variant 1.
The aluminium is cooled via press-fitted stainless steel tubes.
Fig. 3 Cross-section of the Graphite-Aluminium absorber core with an additional copper shield (variant 2). The aluminium is cooled via press-fitted stainless steel tubes.
Fig. 4 Longitudinal sections of the absorber block
Variants 1 and 2.

TED-Variant 1 Weight 20'800 kg.

TED-Variant 2 Weight 22'050 kg.