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THE NEW ISR ABSORBER BLOCKS FOR HIGH INTENSITY BEAMS

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Summary

With the continual improvement of the ISR, one may hope that proton beams of intensities greater than 50 A (2.5 times the design value) will soon be obtained. The kinetic energy stored will then be 4 MJ and the instantaneous power at dumping greater than 1.3 Terawatt. New absorber blocks, able to stop 26 GeV/c beams of intensities up to 80 A, have been installed in the ISR in 1979. This paper describes the technical solutions adopted taking into account space, vacuum and operational constraints. Choice of materials criteria for the block itself, the vacuum chamber and the associated collimator are also presented.

1. Introduction

The design intensity value for the stacked beams of the CERN Intersecting Storage Rings (ISR) is 20 A ($4\ 10^{14}$ protons). The present record intensity, achieved during machine development runs, is over 44 A and with the continual improvement of the ISR, it is hoped that 26 GeV/c proton beams of intensities greater than 50 A will soon be obtained. The kinetic energy stored will then be 4 MJ. This energy can produce major breakdowns and high radiation levels if lost anywhere in the machine. The instantaneous power at dumping is greater than 1.3 Terawatt. These large values create a high stress level in the absorber block, thus greatly reducing the safety margin and it was, therefore, decided that these blocks should be changed. This report gives a description of the design of the newly installed absorber blocks, which are able to stop 26 GeV/c beams of intensity up to 80 A.

2. General

Design parameters have been extrapolated from their past and present values. Circulating beam sizes remain unchanged: rectangular-shaped horizontal distribution over 70 mm and Gaussian vertical distribution with a minimum value of the standard deviation σ_V of 1.2 mm. At dumping, the beam is spread by the kick and σ_V increases up to 1.7 mm. Higher beam intensities are obtained by increasing the longitudinal density up to 1.8 A mm^{-1}. The beam energy taken for most of the computations in this report is 26.6 GeV/c.

Space constraints are very tight: the downstream bending magnet limits the permissible length to less than 3 m and the fast kickers for dumping of the other ring restrict the permissible front-end width.

The main feature of this absorber block is that the beam is dumped through a window and stopped by materials outside the vacuum chamber.

Figure 1 shows an overall view of the absorber block assembly. Only its main parts will be described in this paper.

3. Absorber Block Materials

Proton absorption efficiency increases with the quantity of material seen by the protons. A too heavy material, however, breaks or even melts when struck by a dense beam. The short length available for the absorber block leads to a compromise: a first, light material spreads the beam which is stopped by a second, dense material.

In order to avoid difficulties inherent in powdered or liquid material (containment, etc.), solid materials are preferred. The selection is based on the maximum temperature increase at dumping time and the resulting thermal stresses. Hadronic cascade computations[1] give the maximum energy deposition density E_0 for a given geometry. Then, it is possible to compute the temperature increase ΔT and an estimation of the thermal stresses σ:

$$\Delta T = \frac{E_0\ n}{\rho\ c}\ ,$$

$$\sigma = E\ \alpha\ \Delta T\ ,$$

where:

- n = number of incident protons,
- ρ = material density,
- c = specific heat,
- E = Young's modulus,
- α = thermal expansion coefficient.

The uncertainties at all the steps of the computation lead to the choice of a simple criterion: the elastic limit of the material is compared to the computed thermal stress. Excluding beryllium for safety reasons,

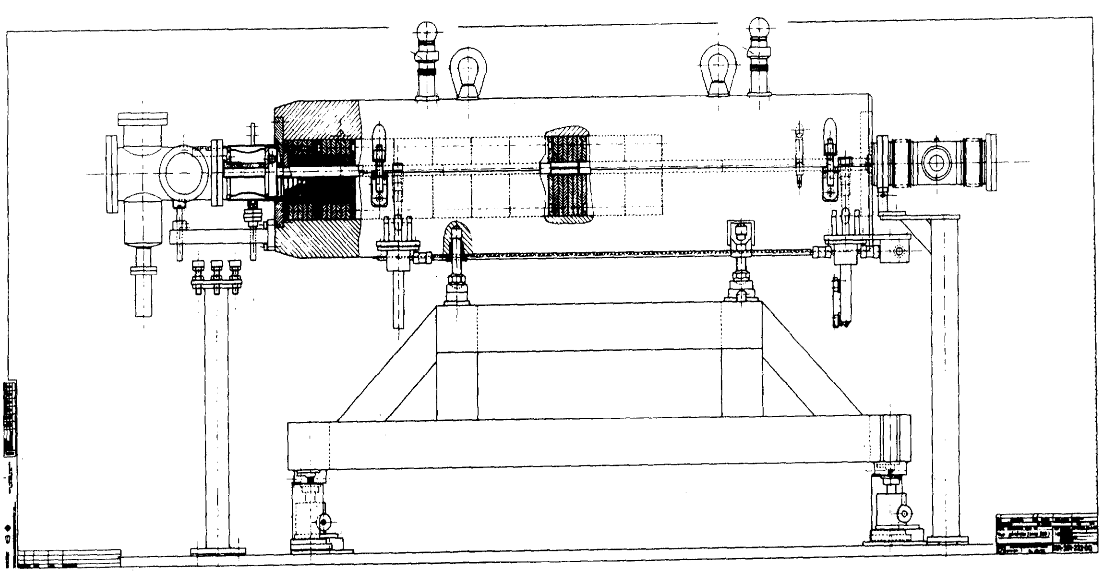

Fig. 1 Overall View of the Absorber Block Assembly

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aluminium and titanium are two possible light materials. Table 1 gives the maximum energy deposition density, an approximation of the maximum beam intensity admissible and the corresponding temperature increase and elastic limit.

TABLE 1

Material	Al	Ti
E_0 [MeV cm^{-3} per proton]	3.5	6
I [A]	30	80
$\Delta T(I)$ [°C]	130	520
$\sigma_{0.2}(\Delta T)$ [hbar]	22	40

Computations done for materials denser than titanium give a much lower admissible beam intensity. Titanium is, therefore, the best candidate and the strong commercial alloy Ti 6 Al 4 V (6 % aluminium, 4 % vanadium) has been chosen.

The second material must be dense, reliable and corrosion-resistant. A stainless steel, type AISI 304 (18 % Cr, 10 % Ni), has been chosen. The same computations as above show that it has to be protected by 1.1 m of titanium in the beam direction and 90 mm radially. Induced activity considerations lead to a 300 mm external radius for the block.

Complete hadronic cascade computations[1] give the energy deposition density in all the block for any energy. Figure 2 shows the iso-density curves generated by a 26.6 GeV/c beam.

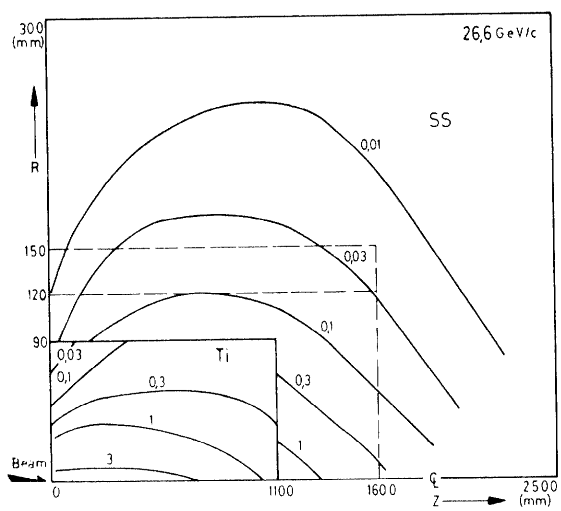

Fig. 2 Energy Deposition Density [MeV cm^{-3} per proton]

Table 2 gives the maximum energy deposition density, the corresponding maximum acceptable beam intensity and the absorption efficiency of the block for three standard beam energies.

It must be noted that to increase the absorption efficiency by 1 %, the external radius has to be increased by 10 %.

The titanium cylinder, made of slotted plates, is inserted in slotted stainless steel plates (dashed lines in Fig. 2). All these plates are inserted into a stainless steel yoke. The cylindrical block is cut into two parts to allow vacuum chamber insertion and bakeout. It weighs 5.4 t. Figure 3 shows a front view of the block in its open position without the vacuum chamber. The titanium plates are visible in the middle of the lower half-yoke.

TABLE 2

	11 GeV/c	26.6 GeV/c	31 GeV/c
E_0 titanium [MeV cm^{-3} per proton]	5	6	8
E_0 stainless steel [MeV cm^{-3} per proton]	0.6	1.2	2
I_{max} [A]	>100	80	50
Absorption efficiency [%]	95	92	91

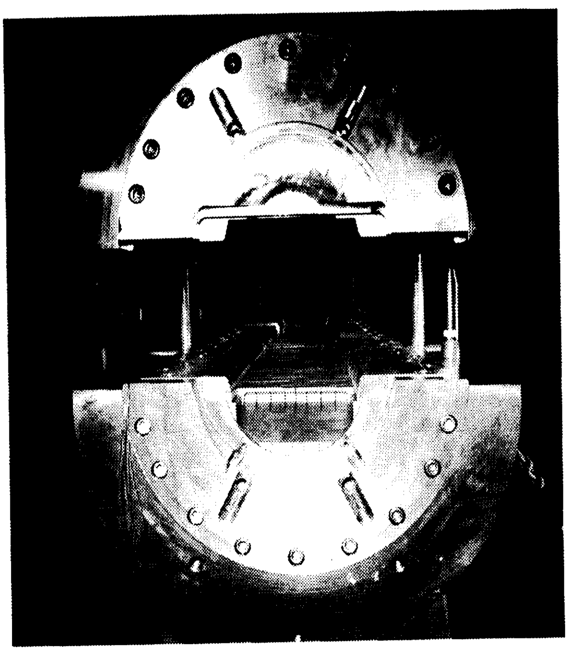

Fig. 3 Front View of the Absorber Block

As a final remark, it must be mentioned that hadronic cascade computations are reasonably accurate for small beam sizes. The extension to ISR beam conditions will be verified during the first runs using thermocouples inserted into the slotted plates. After these measurements, an estimation of the maximum safe beam intensity will be possible.

4. Vacuum Chamber

Being 'killed' by a block outside the vacuum chamber, the proton beam must pass through a thin window. The material used for this window is also the vacuum chamber material because this zone is very critical and any bi-metallic connection must be avoided.

As before, the choice criteria are based upon the maximum temperature increase and the resulting thermal stresses. In the case of a thin plate (thickness << radiation length) crossed by protons, the main phenomenon is the energy loss by ionization. Neglecting other phenomena, the temperature increase is given by

$$\Delta T = d \frac{1}{c} \frac{dE}{dx} ,$$

where:

d = number of protons passing through the ejection window per unit area,

c = specific heat,

$\frac{dE}{dx}$ = minimum ionization energy loss,

and an approximation of the resulting thermal stresses by

$$\sigma = E \alpha \Delta T .$$

Taking into account the parameters of Chapter 2, the maximum density is

$$d = 9 \; 10^{12} \text{ protons mm}^{-2} .$$

Excluding beryllium for safety reasons and aluminium, which does not withstand long bake-outs, titanium, stainless steel and nickel are considered.

Table 3 shows that titanium is the best candidate and Ti 6 Al 4 V is again chosen. The window shape is determined by the possible beam impact zone. Stresses in the ejection window have two origins: mechanical (vacuum) and thermal. The first one decreases with the thickness while the second one increases. Extrapolation from prototype measurements gives a maximum bending stress of 6.1 hbar for the 1.8 mm thick window. Hadronic cascade computations[1] based on the Monte-Carlo method give fluctuating results, but they are in reasonably good agreement with the assumptions made above. Sophisticated methods (FEM)[2] to compute thermal stresses also show a good agreement between them and their estimated value $E \alpha \Delta T$. The safety factor on thermal buckling is well over 4.

TABLE 3

Material	Ti	Fe	Ni
ΔT [°C]	340	390	510
$E \alpha \Delta T$ [hbar]	28	112	111
$\sigma_{0.2}(\Delta T)$ [hbar]	60	14	95

The rectangular vacuum chamber has a 5 to 10 mm thick wall to reduce its deflection under vacuum and, therefore, to avoid too large a clearance with the absorber block itself. Locally, at dumping (80 A, 26.6 GeV/c beam), the temperature increases up to 160°C.

The vacuum chamber is entirely manufactured from forged blanks. After machining, parts have been assembled by electron beam welding.

The vacuum chamber edges are protected by a collimator. This collimator, integral part of the absorber block, forms part of the ISR collimator system[3] and is used as the vertical aperture restriction. It receives protons in the scraping mode, but the downward deflected beam at dumping must avoid it, its lower plate, therefore, has a thickness limited to 5 mm.

A good collimation is obtained with a heavy material[3], but this material should also be a good heat conductor. Copper with traces of chromium and zirconium has been chosen. Scraping 6 10^{12} protons creates a temperature increase of 23°C but, even for a long operation period at a repetition rate of 2 s, the temperature remains below 100°C. The massive upper part of the collimator, electron beam welded to the lower plate, is used as a heat sink. Planeity and alignment achieved are accurate to some hundreths of a millimeter over the 180 mm collimator length. Figure 4 shows the front part of the vacuum chamber with the copper collimator in place.

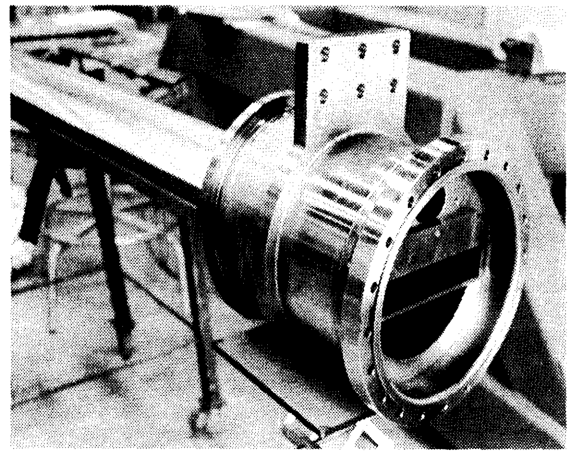

Fig. 4 Front Part of the Vacuum Chamber With the Copper Collimator in Place

Ultra-high vacuum conditions are obtained after a 300°C, 24-hour bake-out. This bake-out is done by direct heating (Joule effect) of the vacuum chamber with the block in its open position. The block temperature stays below 80°C and natural convection is sufficient to cool it down in two days after bake-out. At dumping, the temperature increase and the resulting pressure bump are kept to a minimum while the hottest points of the block are outside the vacuum chamber.

Acknowledgements

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