ISA BEAM SCRAPER SYSTEM

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Introduction

Inherent in the goal of obtaining high beam-beam interaction luminosity is the objective of attaining the highest possible phase-space density of the beam stack at injection. This can be better achieved if the possibility of "overstacking" in the ISA exist, i.e. a lossy stacking mode whereby up to 50% of the injected beam may be discarded, predominantly during a time of recentering the beam stack after completion of the stacking process. This is only possible in a superconducting magnet system environment if a near 100% effective beam scraper-cascade shield system is incorporated in the ISA design. The basic concept of this is outlined here.

Scraper-Cascade Shields

Consider a beam scraping off an absorber which is thick enough to attenuate adequately the nuclear cascade. Then the beam coming out of the scraping edge will look like that shown in Fig. 1. Immediately following the absorber there is a "quiet" zone where a superconducting coil could be located. Assuming no magnetic field anywhere, the beam spray cone will enlarge as r^2. To locate another coil downstream, another quiet zone must be created by means of an additional shield. This shield should also be thick enough to attenuate sufficiently the cascade. A new spray cone is formed composed of all particles going through the opening

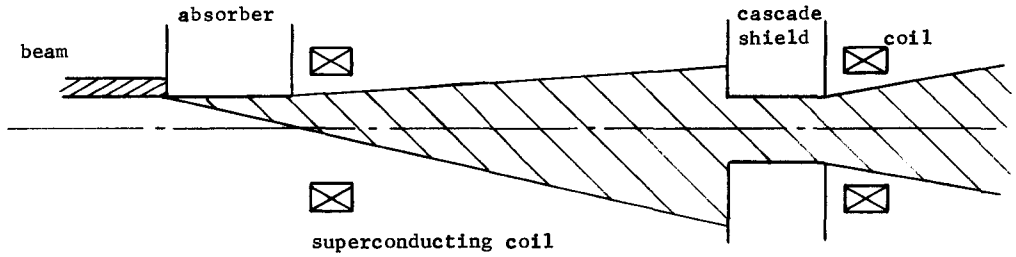

Fig. 1. Scraper-cascade shields.

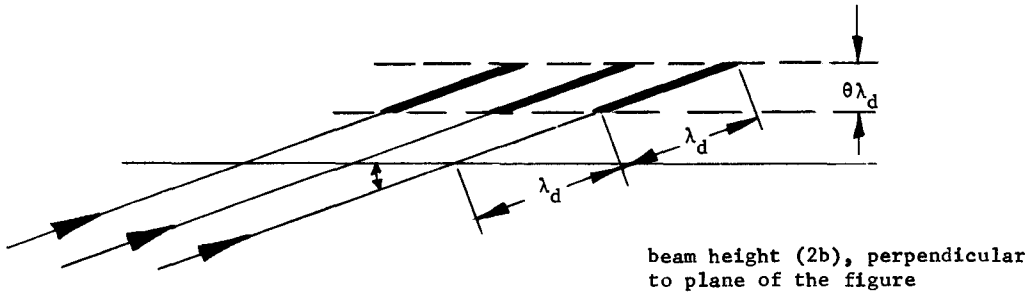

Fig. 2. Beam incident on superconducting coil.

in the shield and those coming out of the edges of the opening. It is assumed that a sequence of shield-coil sets is located downstream.

Neglecting the particles coming off the edges of all the shields, the amount of beam going through the opening of the last shield is given by the ratio of the solid angle subtended at the absorber by this last opening to the solid angle of the original cone from the absorber. The particles coming off the edges of the shields will add to this estimate. Thus shields must be placed in front of each successive downstream magnet at least to the location where the $(1/r^2)$ dependence reduces the particle flux to an acceptable value. [Again, particles coming off the edges of the shield will make the fall-off of the particle flux less rapidly than $(1/r^2)$. On the other hand, the presence of the dipole fields will make the charged particle fall-off faster, so that the $(1/r^2)$ law may be a reasonable approximation of reality.]

With a 30 GeV incident beam and a mean value of secondary particle energies of 15 GeV coming off the absorber edge, then the initial cone solid angle will be $(300\ \text{MeV}/15000\ \text{MeV})^2 = 4 \times 10^{-4}$. If the last shield has an opening of 20 cm^2 and is located 30 m downstream of the absorber, the solid angle subtended by the opening is $(20 \times 10^{-4}/900) \simeq 2 \times 10^{-6}$, and the particle flux is reduced by $(2 \times 10^{-6}/4 \times 10^{-4}) \simeq 5 \times 10^{-3}$. Note that this ratio is independent of the number of shields existing within the 30 m length. The number of shields depends only on the number of magnets one has to shield within the 30 m length following the absorber edge.

Tolerable Particle Flux from the Beam Scraper

In order to obtain now an estimate of the permissible particle flux downstream of the beam scraper, consider a beam of protons with a flux value of F (number/cm^2) incident on the superconducting coil at an impact angle of θ (see Fig. 2). The maximum energy

deposition is in a layer $\lambda_d\theta$ thick where λ_d is the caloric absorption length of the material. Thus the cross-sectional area of the beam contributing to the energy deposition is $\sigma = (\lambda_d\theta) \times (2b)$ where (2b) is the height of the beam (see Fig. 2). The energy deposition is therefore $J(\sigma).F.\sigma$, where $J(\sigma)$ is the energy deposition per proton, which is a function of the cross-sectional area of the beam, and $F\sigma$ is the total number of protons impacting on the wall. Because the superconducting coil is shielded by the Al vacuum chamber and stainless steel dewar inner wall the energy deposition in the coil is taken to be 0.1 times this, on the basis of the known character of radial fall-off of the nuclear cascade.

Limited guidance exists for the maximum tolerable caloric deposition into the superconducting matrix. On the basis of the conclusions of the Radiation Effects group of the ISA Summer Study the following numbers will be used:

Maximum acceptable caloric deposition into NbTi-Cu matrix:

3 mJ/cm^3, "fast" deposition

30 mJ/cm^3, "slow" deposition

(or $\sim$ 1 mJ/cm^3sec steady state) .

Consequently, for Cu, $\lambda_d \simeq 19$ cm; with $\theta \simeq 1$ mrad and 2b = 0.6 cm it follows $\sigma \simeq 1\ mm^2$. For 30 GeV protons[1], with $\sigma = 1\ mm^2$, $J \simeq 0.1\ GeV/cm^3$. Therefore F is given by

$$(0.1F) \times (10^{-2}) \times (0.1) \times (1.6 \times 10^{-10}) = 3 \times 10^{-3} \text{ or,}$$

$F \simeq 10^{11}$ protons/cm^2. With an aperture in the "last" shield of $\simeq 20\ cm^2$, the tolerable number of protons in the beam cone through this opening is 4×10^{12} particles. Using now the flux reduction factor arrived at in the foregoing of 5×10^{-3}, for the geometrical parameters as given, yields the tolerable particle flux from the absorber edge in case of a "fast" beam scraping occurrence as $(4 \times 10^{12}/5 \times 10^{-3}) \cong 10^{15}$ particles. Since only approximately 3×10^{14}

1. A. van Steenbergen, "ISA Beam Dump Absorber," these Proc.

protons would be subjected to the scraper operation, the number of energetic particles coming from the absorber edge will be significantly less than the 10^{15} flux limit arrived at here, also the $J(\sigma)$ value used here was for 30 GeV protons only, consequently it is too large a value considering the realistic momentum spectrum.

Conclusion

On the basis of the foregoing model of energy deposition into the superconducting matrix, an order of magnitude estimate is provided for the permissible particle flux into the regular superconducting structure downstream of a beam absorber edge and the following sequence of cascade shields. Provided the superconducting elements over an extent of approximately 30 m downstream of the absorber edge are individually "pre-shadowed" by an Fe cascade shield, it is concluded that the beam scraping operations as required for high density beam stacking (low p scraper) can be carried out without exceeding the maximum caloric deposition tolerance of the superconducting magnets. Detailed cascade calculations are in progress (for preliminary results, see Ref. 2) to verify these conclusions.

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2. L. Blumberg, J. Ranft, A. Stevens, A. van Steenbergen, "Caloric Deposition Downstream of the ISA Beam Scrapers," these Proc.