Subject

VACUUM AND SHIELDING REQUIREMENTS FOR 100 GEV PROTON STORAGE RINGS

General Considerations

To simplify the following discussion I will freely utilize the numerical calculations from the CERN publication by E. Fischer, i.e., Residual Gas Scattering, Beam Intensity and Interaction Rate in Proton Storage Rings, ISR-VAC/67-16.

The interactions between a circulating proton beam and the residual gas can be divided into two classes: (a) Multiple Coulomb Scattering which leads to a growth in beam size and (b) Nuclear Interactions which lead to a loss of protons and the reaction products. The cross section for (a) is well known whereas the total cross section for (b) is assumed constant at high energies.

If we assume that the vertical aperture of the vacuum system is large compared with the initial size of the stacked beam and that the orbit parameters of almost any proton storage ring, i.e., β_{av} β_{max}, are similar then from Fischer equation (27) we see that:

$$Z \propto \frac{\sqrt{P t}}{p}$$

where P is the residual gas pressure

t is time

p is proton momentum

Z is RMS beam height

As the horizontal beam size is usually larger than the vertical then the growth in that plane is neglected and the rate of change of luminosity from this vertical growth is

$$\left.\frac{d\ell}{dt}\right|_{MS} \propto \frac{P}{p^2} \qquad (1)$$

At 10^{-9} torr and 28 GeV $\left.\frac{d\ell}{dt}\right|_{MS}$ = 50% in approx. 40 hours (2)

(Fischer Fig. 7)

At 10^{-9} torr and 100 GeV $\left.\frac{d\ell}{dt}\right|_{MS}$ = 50% in approx. 400 hours.

Nuclear interactions lead to an exponential decay of beam current but as we shall be interested in times short compared with a time constant we will use a linear approximation. This gives that the current in each beam $I \propto 1 - Pt$ and the rate of change of luminosity from this effect

$$\left.\frac{d\ell}{dt}\right|_{NI} \propto P \qquad (3)$$

At 10^{-9} torr $\left.\frac{d\ell}{dt}\right|_{NI}$ = 50% in 130 hours (4)

(From Fischer 52 → 56)

Cycle Time

From the above one might hope to determine what would be an efficient cycle time, i.e., time between fillings of the storage rings, and a maximum operating vacuum pressure.

To achieve a reasonable luminosity it would appear that we must fill each ring to the single beam limit, i.e. $\sim 10^{15}$ protons.

Taking the NAL accelerator at 10^{13} protons per pulse it is seen that the filling operation is very short. Even allowing for stacking the total time required for filling both rings is less than 15 minutes and therefore will not enter into the following arguments.

From the point of view of an experiment, data taking will become inefficient when the cycle time allows the luminosity to decay significantly. This is because the background rates will be decaying at half the rate of the real events, i.e., backgrounds are proportional to current I and luminosity to I^2. I will therefore assume that the cycle time is determined by the time taken for the luminosity to decay a factor of two.

Radiation

Now let us consider the other effects of the beam loss due to nuclear interactions with the gas; viz. radiation and residual activity. I believe it is reasonable to assume that, regardless what the average pressure in the vacuum system, there will be localized high spots which will contribute a large percentage of the total number of molecules in the system. These high spots could occur anywhere in the structure and from the point of view of radiation from 100 GeV incident protons could be considered point targets, i.e., 100 to 200 meters long.

For the purpose of calculation let us assume that 50% of the molecules are localised, 10% of the ring at 10 times the average pressure for example. Also from Table 12-1 of the NAL Design Report one sees that to maintain a reasonable level of residual activity in the machine components, the maximum permissible proton loss rate at a 100 GeV is between 10^7 and 6×10^9 protons /sec. If we have 10^{15} protons in each beam ofter stacking and we allow ℓ to decay by 50%, i.e., I by 25%, in one cycle, then 12.5% of these protons will be lost in this region of poorer vacuum. Taking the upper limit on acceptable proton loss rate as 6×10^9 protons/sec then these 12.5% or 1.25×10^{14} protons must be stretched over a cycle time of 5×10^4 secs. The cycle time as determined by radiation effects must therefore be greater than 12 hours. This corresponds to an average pressure of 10^{-8} torr (from (3) and (4)) or in the above example 90% the ring at 5×10^{-9} torr and 10% at 5×10^{-8} torr.

Conclusions

The decay rate of the luminosity of 100 GeV proton storage rings is determined by the nuclear interactions with the residual gas. At lower energies, e.g., 28 GeV, it is determined by multiple coulomb scattering, cf. (1) and (3).

The minimum useful cycle time and the maximum operating vacuum pressure are determined by the requirements of the experiments and the practical limitations of allowable residual activity in the machine components.

The vacuum system must be designed to achieve a pressure of $< 10^{-8}$ torr. The interaction regions must have a pressure which is much less, i.e., $< 10^{-9}$ or $< 10^{-10}$, to reduce backgrounds and therefore contribute little to the average pressure of the system.

This rather stiff vacuum requirement is a rather strong argument against the use of the 200 GeV accelerator main ring as a storage ring in association with a bypass.

Assuming a cycle time equal to 12 hours, then we could lose 10% of the intensity during injection and stacking and still just equal the proton loss rate due to nuclear interactions.

The shielding associated with the storage rings will constitute a problem similar to the main ring of the accelerator. That is with 20 to 30 feet of soil cover one is shielded against the maximum permissible beam loss which can be tolerated from the point of view of residual activity. The only area which will require special treatment is the beam-dump area where the beams will be extracted and dumped at the end of a cycle or during fault conditions.