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ABSTRACT

Experiments PS202 will install a molecular hydrogen gas cluster target in Straight Section 3 of LEAR. The impact on machine operation is discussed. It is shown that stochastic cooling is essential to maintain reasonable circulating beam lifetimes, and the advantages of a low beta insertion are also considered. Finally some initial studies have been made on the effects of a high field superconducting solenoid on the LEAR machine.

Key words : Molecular cluster target, LEAR, stochastic cooling, low beta insertion, solenoid.

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ABSTRACT

Experiment PS202 [1] will install a molecular hydrogen gas cluster target in Straight Section 2 of LEAR. The impact on machine operation is discussed. It is shown that stochastic cooling is essential to maintian reasonable circulating beam lifetimes, and the advantages of a low beta insertion are also considered. Finally some initial studies have been made on the effects of a high field superconducting solenoid on the LEAR machine.

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INTERACTION RATE AND ENERGY LOSS IN THE TARGET

The following parameters are assumed:-
Gas-jet density = $8.0\ 10^{13}$ atoms/cms^2 Thickness = 1 cms.
Total density = $1.3\ 10^{-10}$ g/cms^3
Total strong interaction cross-section at 609 Mev/c, sigma(S) = 200 mbarns.
Useful interaction rate in the experiment for a beam of $1.0\ 10^{10}$ particles
= 320000 events/sec at 609 MeV/c
This corresponds to a luminosity of $1.6\ 10^{30}$ cms^{-2}sec^{-1}
The energy lost in the target = $1.3\ 10^{-6}$ KeV/turn at 609 MeV/c
= 2.7 KeV/sec
This can be compensated by the longitudinal cooling system, but the resulting longitudinal distribution may not be symetrical. The total momentum spread then should be about dp/p = $\pm 1.0\ 10^{-3}$ (95% of beam).

OVERALL LOSS RATE DUE TO GAS-JET

For an internal target it is advantageous to reduce the beta values at the interaction point for two reasons. Firstly the beam dimensions must be smaller than the target dimensions to ensure optimum use of the available luminosity, and, secondly, smaller beam dimensions at the interaction point increase the machine acceptance angle, for coulomb scattered particles. This acceptance angle is given by in either H or V plane for a rectangular vacuum chamber :-

$$\text{Theta} = \sqrt{(A/\pi \times \text{beta})}$$

Where A = vacuum chamber acceptance (H or V)

For an elliptical chamber we can use a single acceptance angle Theta(E), which is approximately given by :-

$$\text{Theta(E)} = \sqrt{(\text{Theta(H)} \times \text{Theta(V)})} \quad [2].$$

Detailed calculations of various low-beta schemes for LEAR have been performed [2,3], using two low-beta quadrupole doublets in S23 and S24. The existing QDN and QFN fields have to be slightly modified, in order to match the insertion to the rest of the machine and maintain the standard working point. This means that the beta functions etc. all around the machine will be modified, which would have consequences for machine operation. E.g. efficient injection, with the low-beta scheme "on", would probably not be easy, so it would be preferable to switch on the full low-beta configuration, with circulating beam, after injection and acceleration. However small momentum adjustments could probably be performed with the low-beta "on".

Acceptance of the machine without low-beta is :-
$dp/p = 1.2\ 10^{-2}$, $Eh = 250\pi$ mm.mrads, $Ev = 45\pi$ mm.mrads
Acceptance of the machine with low-beta is :-
$dp/p = 0.7\ 10^{-2}$, $Eh = 90\pi$ mm.mrads, $Ev = 30\pi$ mm.mrads

The angular acceptance of the machine for scattering from an internal target at the low beta point is increased.

With normal beta values :-
beta(h) = 2.0m, beta(v) = 5.2m, D(p) = 3.7m, Theta(E) = 4.2 mrads.
With low beta insertion :-
beta(h) = 1.0m, beta(v) = 1.0m, D(p) = 1.7m, Theta(E) = 7.2 mrads.

In this way, although the overall machine acceptance is decreased, the losses due to scattering in the target are reduced, provided the stochastic cooling systems will maintain beam emittances below the reduced machine acceptances.

The Rutherford scattering cross-section for angles larger than the machine acceptance Theta is given by :-

$$\text{sigma}(R) = (4\times\pi\times r^2)/(((g - 1/g)^2)\times\text{Theta}^2)\ \text{cm}^2 \qquad [4]$$

r = classical proton radius, $g = 1/\sqrt{(1 - \text{beta}^2)}$

At 609 MeV/c :-
With standard beta values Theta = 4.2 mrads. sigma(R) = 130 mbarns
The total interaction cross-section is 130 + 200 = 330 mbarns.
With the low-beta insertion Theta = 7.2 mrads. sigma(R) = 45 mbarns
The total interaction cross-section is 45 + 200 = 245 mbarns.
Overall beam 1/e lifetime without low-beta = 5.0 hours
Overall beam 1/e lifetime with low-beta = 6.8 hours

At 1.5 GeV/c these lifetimes become (for sigma(S) = 120 mbarns) :-
Without low-beta sigma(R) = 10 mbarns 1/e lifetime = 8.0 hours.
With low-beta sigma(R) = 1 mbarn 1/e lifetime = 8.3 hours.

All these lifetimes are calculated assuming perfect stochastic cooling, which will maintain the beam emittance below the machine acceptance, at all times. Other loss mechanisms, such as betatron tune resonances, could well reduce these figures.

TRANSVERSE BLOW-UP DUE TO GAS-JET

Transverse emittance blow-up is given by Hardt's formula [5]

dE = emittance growth rate $b = v/c$
p = target density $g = 1/\sqrt{(1 - b^2)}$
d = target thickness

$$dE(h,v) = (19.2 \times \text{beta}(h,v) \times p \times d)/(b^3 \times g^2)\ \pi.\text{m.rads/sec}$$

At 609 Mev/c, without low beta insertion :-
$dE(h) = 2.2\ 10^{-2}$ π.mm.mrads/sec $dE(v) = 5.5\ 10^{-2}$ π.mm.mrads/sec
This means that the vertical emittance would exceed the machine acceptance in 15 minutes if no stochastic cooling were applied.
At 609 Mev/c, with low beta insertion :-

dE(h) = 1.1 10^{-2} π.mm.mrads/sec dE(v) = 1.1 10^{-2} π.mm.mrads/sec

The transverse emittance blow-up due to the pressure bump caused by gas-jet operation is given from [5] :-

$dE(h,v) = (beta(h,v) \times P) / (b^3 \times g^2)\ \pi.m.rad\ sec^{-1}$

P = (Nitrogen Equivalent pressure × Bump length) / Machine circumference

Without the low beta insertion this gives the blow-up due to the pressure bump as about 5% of the rates due to the target alone.

The time constant for the transverse stochastic cooling system is given by, ignoring mixing :-

$1/T = (2W/N) \times (2g - g^2 \times (1+U))$ [6]

Where U is the ratio of noise to signal power, in this way U is roughly proportional to 1/emittance. As a result of some measurements performed in December 1986 the cooling time constants at 609 MeV/c have been estimated empirically as follows :-

T(h) = 2500/(E(h) - 7.5) sec   T(v) = 2100/(E(v) - 8.0) sec

Where Eπ = emittance in mm.mrads (Eπ contains 95% of beam)

The cooling reduces the beam emittance by $dE/dT = -E \times (2/T)$. The equilibrium emittance with cooling and gas-jet on is reached when the blow-up rate due to the gas-jet is equal to the cooling rate :-

Without low-beta insertion :-

Equilibrium emittances are E(h) = 12π mm.mrads   E(v) = 15π mm.mrads

With the low-beta insertion :-

Equilibrium emittances are E(h) = 10π mm.mrads   E(v) = 10π mm.mrads

The resulting beam dimensions (for 95% of the beam) in the gas-jet interaction region are, for $\delta p/p = \pm 0.001$:-

Without low-beta	Total height = 9 mm	Total width = 10 mm
With low beta	Total height = 3 mm	Total width = 5 mm

SOME INITIAL STUDIES ON SOLENOID COMPENSATION

A longitudinal magnetic field excites linear coupling resonances of the form Qh ± Qv = n. This excitation can be compensated by the addition of skewed quadrupole fields [7,8]. The excitation coefficient for a linear coupling resonance is given by [9]:-

$$K = \frac{1}{8\pi} \cdot \frac{R}{|B\rho|} \int_0^{2\pi} \sqrt{\beta_x \beta_z} \cdot \left[\left(\frac{dB_x}{\partial x} - \frac{dB_z}{\partial z} \right) + B_\theta \left(\frac{\alpha_x}{\beta_x} - \frac{\alpha_z}{\beta_z} \right) + i B_\theta \left(\frac{1}{\beta_x} + \frac{1}{\beta_z} \right) \right] \cdot \exp i \left(\mu_x \pm \mu_y - e\theta \right) d\theta \qquad (1)$$

Where e = Qx ± Qz - n.

For a pure skew quadrupole field $B_\theta = 0$ and $\frac{dB_x}{\partial x} = -\frac{dB_z}{\partial z}$

For a pure solenoid, neglecting end effects, $\frac{dB_x}{\partial x} = \frac{dB_z}{\partial z}$

Since equation (1) contains a phase term (ux ± uy) the postions of the compensating skew quadrupoles must be carefully chosen w.r.t. the solenoid. For a 1.6 m. solenoid in the centre of Straight Section 2, the optimum coupling compensation has been calculated, using a pair of 45° skew quadrupoles placed 2.45 m. from the centre of the straight section. With the standard machine working point (Qx = 2.30, Qz = 2.73) only the resonance Qx + Qz = 5 has been compensated. These preliminary calculations have been "checked" by particle tracking using DIMAT [10]. The results look encouraging, and both calculation and simulation agree well. With this simple compensation scheme about 90% of the coupling excitation can be succesfully compensated. For example at 309 Mev/c for a 0.8 Tesla longitudinal field the calculated K for zero compensation is 54.8 10^{-3}. The value obtained from DIMAT with the optmised compensation is 5.7 10^{-3}. This is about the value of K measured in LEAR due to quadrupole misalignments [11], and machine operation could be feasible under these conditions. However only a very idealised form of solenoid was used both in the calculation and the tracking, and in particular no "end-field effects" were included.

This form of compensation scheme implies several constraints. There is no space for a low beta insertion, the place is used for skew compensators. Since the elements are not in dispersion free regions a vertical dispersion is introduced into machine, ie. the vertical beam dimension depends on the momentum distrubtion.

Also, operation with a high field solenoid would probably have to be restricted to momenta above 1.2 Gev/c, this means that the solenoid would have to be switched on after acceleration, with circulating beam, which may also pose problems.

One can conclude that the initial results of the compensation studies indicate that LEAR could be run with a solenoid, but a detailed design must be worked out, in order to study the "end-field effects", and the maximum possible field must be defined, as a function of required beam momentum, in order to design a realistic compensation scheme.

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