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OBTAINING SLOW BEAM SPILLS AT THE SSC COLLIDER

D. Ritson
Stanford Linear Accelerator Center
Stanford, CA 94309

1. INTRODUCTION

There is substantial interest in providing slow-spill external proton beams in parallel with "interaction running" at the 20 TeV SSC collider. The proposal is to cause a flux of particles to impinge on a target consisting of a bent crystal extraction channel.[13] Additionally, a slow spill onto a conventional internal target could be used as a source of secondary beams for physics or test purposes and might also be used for B-physics as proposed for HERA. The "natural" beam loss rates from elastic and diffractive beam gas scattering and IP collisions are not sufficient to provide suitably intense external proton beams. The presently favored scheme for providing sufficient spill intensity is to increase the emittance of the beam via rf noise excitation of the longitudinal synchrotron oscillations.[13]

To prevent loss of luminosity, the rf excitation is non-linear and preferentially blows up the halo of the beam. The "target" is to be located at a region of high dispersion forcing particles at the edge of the momentum space onto the target.

T. Lohse[24] in this workshop has described a proposed internal target to be used at HERA that will not employ rf excitation but will use the finite loss rates observed at the HERA machine.[24] The Hera losses are caused by a variety of sources in addition to beam gas scattering or IP interactions. These sources include machine imperfections, improperly centered IP collisions, tune modulation, poor chromaticity correction, beam-beam interactions etc. Initially, the beam lifetime at HERA was too short to obtain satisfactory integrated luminosities. Subsequently, through careful attention to detail, the beam lifetime was increased to > 20 hours. Even with these changes, present loss rates provide the required intensity onto an internal target. The Tevatron and SPS proton anti-proton colliders have had similar experiences with their investigations of loss rates and also find that beam lifetimes may be substantially shorter than expected solely from beam gas and IP interactions. This paper proposes deliberately introducing controlled errors like moving the betatron tune gradually closer to the edge of the operating diamond to provide the desired beam loss rates.

Qualitatively such errors move the edge of the chaotic region or dynamic aperture of the beam closer to the beam, effectively "scraping off" halo particles. The particles, once out of the dynamic aperture, diffuse into increasingly chaotic regions of the aperture until they impinge on an appropriately positioned internal target.

We discuss mechanisms available to shorten beam lifetimes, corresponding rates of diffusion out through the aperture, and target entry step distributions.

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2. LOSS MECHANISMS

A satisfactory loss mechanism should satisfy the following criteria:

1. The perturbation should be simply and precisely controllable.
2. The perturbation should not cause accumulation of the beam into stable island regions.
3. Ideally, the perturbation of choice should be simple to implement and economic.

We believe the approach most likely to satisfy all the above criteria is to use tune shifts that move the beam closer to the high order controlling resonances in the vicinity of the operating tune point, perhaps to be used in combination with errors in chromatic correction. Other approaches could involve the introduction of positive chromaticity into the lattice or the excitation of a high multipole magnetic element in the lattice. An overview of the physics and operational experiences of such approaches can be found in a number of publications.[14,15]

2.1 Effects of tune shifts.

Early studies at the SPS collider explored beam losses as a function of operating point.[16] These studies dramatically illustrated that moving the operating point close to resonances as high as tenth order strongly decreased the lifetimes of the beams while in collision mode. Subsequent simulations and operational work with hadron colliders confirm these observations.[15] The loss mechanism is not straightforward and appears to involve the generation of chaotic phenomena.

At the SSC, the bunch spacing is very small (5 metres), and this small spacing will basically determine the parameters of the interaction configuration. The "short-range" beam-beam forces come from the central collisions at the IP, and the counter-circulating beam is the source of "long-range" beam-beam forces at a large number of satellite collision points before the beams are bent apart into their separate rings. To minimize the long-range effects, the beams are to be crossed at the IPs with the largest crossing angles that are consistent with other physical constraints. Even then, the long-range tune shifts are comparable in magnitude to the beam-beam tune shift at the central collision point.

Figure 1 shows a figure taken from an SSC report by J. Irwin[25] showing the effects of high order resonances in combination with the long range beam-beam interactions in the tune plane in the vicinity of a typical operating point close to 0.26 in tune. Resonances up to eleventh order are included. Superimposed on the tune plane is the beam footprint calculated by Tennyson[17] with the tune as a function of both vertical and horizontal amplitude.[17] The most notable feature of the footprint is the "wings" in the tune space at large betatron amplitudes. These wings are the direct result of the strong long-range tune shifts encountered as particles pass close to the countercirculating bunches at large amplitudes.

Small changes in the operating point can move the high amplitude wings, but not the main core of the beam, to the boundaries of the tune space set by high order resonance lines and cause particles in the wings to become unstable. With increasing amplitude, such unstable particles move even closer to the countercirculating bunches and encounter increasingly strong non-linear forces that further destabilize their motion.

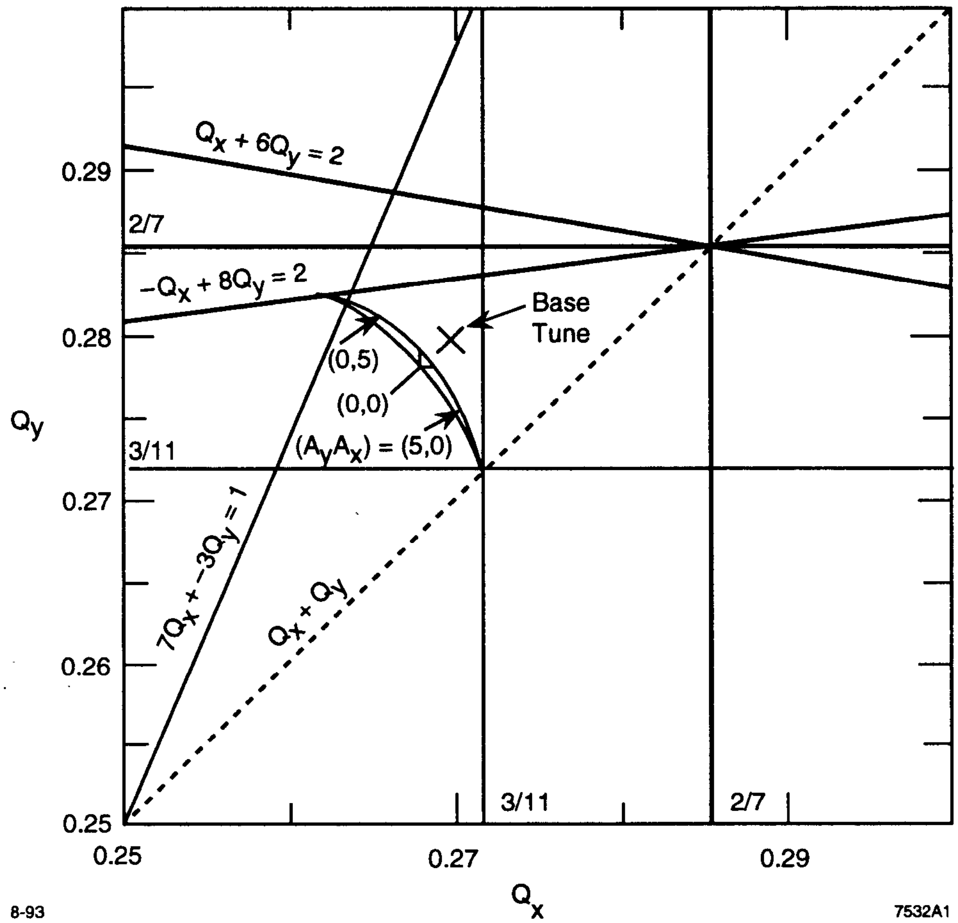

Figure 1. Tune space around the expected operating point at 0.26. Resonances are shown up to tenth order. The $Q_x = Q_y$ first order coupling resonance is shown as a dotted line.

A controlled movement of the SSC operating point should successively remove high amplitude particles and result in a required beam loss rate without at the same time affecting the central beam phase space and the luminosities.

2.2 Chromaticity Effects on beam life-time.

The same local and global SSC correctors designed to remove chromaticity can also of course be used to introduce non-zero first or second order chromaticity. Non-zero lattice chromaticity causes particles to modulate their tune in synchronism with their off momentum component at the synchrotron frequency while undergoing synchronous motion. Thus a machine with finite chromaticity is tune modulated at the synchronous frequency. Tune modulation gives sidebands to resonance lines that enhance the effects of these resonances, and if overlap with other resonances occurs, chaotic regions in phase space may be created. This has been investigated extensively both by simulation and experiment.[14,15,18]

Chromaticity errors alone in an SSC crossing configuration, although destabilizing the beams, could possibly result in trapping particles in stable "islands" in phase space. It might well prove advantageous to use chromaticity errors in combination with shifts in the operating tune to avoid island formation.

2.3 The use of strong non-linear multipole field errors.

The long-term dynamic aperture of a machine is decreased by the presence of high multipole magnetic field errors.[19] This has long been suggested as a means to provide "massless scrapers."[22] However, locating non-linear magnetic elements at the high beta points in the IR triplets is ruled out because they would simultaneously destabilize both the beam and the countercirculating beam. At other locations in the lattice, beta values are substantially smaller, and through simulation we find that very strong elements would be required. This is because the long-range forces present from the countercirculating beam at $\sim 10\sigma$ are very strong sources of non-linearity, and a significant modification of loss rates requires the introduction of commensurate-strength non-linearities. This does not exclude this option but does make it substantially less attractive.

3. DIFFUSION RATES AND ENTRY STEP DISTRIBUTIONS

Typically targets would be located 5–10 σ out from the beam orbit and $1-2\sigma$ in from the primary beam scraper. At such a location, rf noise excitation causes slow changes in beam size and entry steps of a few microns.[13] In terms of an effective diffusion velocity at the target, this corresponds to a few microns beam movement over a synchronous period, a velocity commensurate with or less than that expected from orbit movements caused by seismic or cultural noise.[20] Maintaining a uniform spill rate is likely to require stabilization of the orbit at the target by a feedback system sensing instantaneous spill rates. This is feasible but adds complexity.

Reference 23 discusses the use of a "spreader" target to increase the step size into the primary SSC collimator. We have investigated using a spreader target in combination with rf noise excitation and find that a 0.5-radiation-length tungsten spreader target positioned 30 microns in from the edge of the main target will increase step sizes by an order of magnitude. However, the effective diffusion velocity into the spreader target, in conjunction with orbit instability, sets the spill modulation. Therefore the spill pattern is unchanged by the addition of a spreader target.

For mechanisms that modify the dynamic aperture, the target is located beyond the edge of the long term dynamic aperture. We have simulated outward diffusion of particles at the target location with such mechanisms. Figs. 2 a and b show histograms of entry steps at nominal SSC interaction conditions with horizontal and vertical tunes set to 0.42 for targets located at 7 and 10σ from the beam respectively. The entry steps are now tens of σs in magnitude and correspond to effective diffusion velocities at the target of tens of microns over a few revolution periods. The effective velocities now substantially exceed the velocities of orbit movements expected from seismic or cultural disturbances. Therefore, obtaining a uniform spill does not require stabilization of the orbit at the target position.

With the small target entry steps that result from rf noise excitation, the crystal must be positioned with a horizontal beam offset for vertical bend.[21] In this configuration, there is substantial loss of efficiency if vertical entry angles exceed 1 microradian. For extraction of off-momentum particles (rf noise excitation), this is not a problem because the rms of

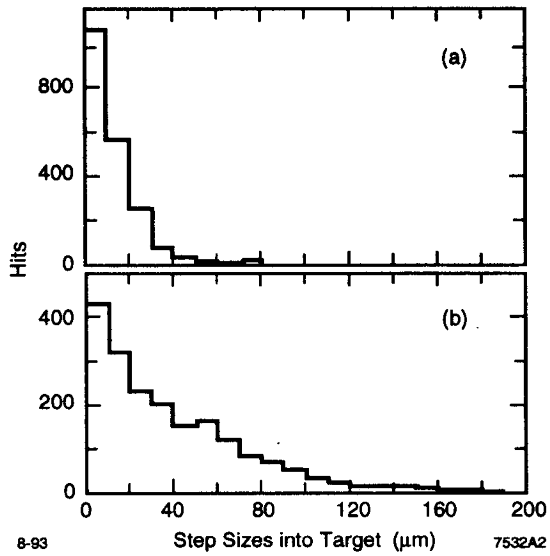

Figure 2. (a) and (b), derived from simulation, show histograms of the entry steps into targets located 7 and 10σ away from the central orbit, respectively. The conditions are for nominal SSC beam intensities, emittances and crossing angles, and for fractional tunes of 0.42 in horizontal and vertical.

the nominal vertical angular divergence is 0.3 microradians. For our suggested mechanisms that extract particles at large betatron amplitude, there could be problems with a target positioned in this way. In the presence of substantial cross-coupling, vertical entry angles could well exceed 1 microradian. However, with the now substantially larger entry steps into the crystal, the machining tolerances to be expected for the surfaces of the crystal permit good channeling efficiency for crystals positioned with a vertical beam offset for a vertical bend. In this configuration the channeling efficiency is naturally insensitive to horizontal beam divergence, and in the vertical plane particles enter the crystal only at extremes of their betatron orbit motion with directions closely parallel to the beam axis and therefore effectively with small vertical beam divergence. Thus the 1.0 microradian constraint on vertical entry angle does not cause substantial losses in chanelling efficiency.

4. WIRE INTERNAL TARGETS

HERA proposes to use a thin, high-A internal target for B-Physics. The high A provides an enhanced relative cross-section for B-production.[24] For SSC energies we have verified the HERA result that for a high Z target to be efficient, it should be located in a relatively low β region. This precludes its use in a SSC utility straight. However the use of carbon targets in a utility straight would give quite acceptable efficiencies, and locating a high Z target at the SSC close to secondary IP focii would be satisfactory.

5. CONCLUSIONS

In additon to rf noise excitation, other methods should be able to provide slow controlled beam spills onto SSC targets. The most convenient and easily controlled of such methods is to move operating tunes so as to keep the large amplitude beam halo on an edge of the "operating diamond." This positions the dynamic aperture to cause short lifetimes before loss for large amplitude particles. The target is naturally located for nominal SSC operation outside the edge of the dynamic aperture, where effective diffusion velocities are large. This ensures that spill intensities remain uniform and are minimally modulated by orbit movements from cultural and seismic disturbances.

We believe that both rf noise emittance growth and movement of the edge of the dynamic aperture are likely to satisfactorily provide controlled beam loss and that a final choice of choice of method may be determined by operational experience at current accelerators or with the SSC.

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