EMITTANCE REDUCTION BY H^- CHARGE EXCHANGE FOR HADRON-HADRON COLLIDING BEAMS

C. M. Ankenbrandt
Fermi National Accelerator Laboratory*
Batavia, Illinois 60510

Summary

Novel applications of charge-exchange injection of negative hydrogen ions are proposed in order to reduce proton beam transverse and longitudinal emittances to the values desired for a very high energy hadron-hadron colliding beam facility. For the beams which will be used in the collider, reducing the transverse emittances is most important; for the proton beam used to produce antiprotons, reducing the longitudinal emittance is paramount.

Introduction

The luminosity of a colliding-beam facility can be increased by raising the number of beam particles, by increasing the magnetic field strength for a given energy, thereby increasing the revolution frequency, and by reducing the beta function at the intersections. However, it is difficult to vary these quantities beyond certain practical limits, so shrinking the beam sizes by reducing their emittances is also advantageous until the beam-beam tune shift limit is reached. The emittances of an antiproton beam can be reduced by cooling in the accumulator ring; methods of reducing the emittances of a proton beam are discussed here.

The collection rate of antiprotons for an antiproton-proton facility can be improved by increasing the spatial density of the proton beam which strikes the antiproton-production target. A small transverse spot size on the target is important, but target damage, multiple scattering, and depth of focus determine the minimum effective spot size. The most important parameter of the proton beam is then its longitudinal density. Shortening the length of the proton beam reduces the required circumference of the accumulator ring, and tight bunching of the targeted proton beam facilitates RF manipulations of the resulting antiproton beam to reduce its momentum spread.

Accelerating H^- Ions

The density of synchrotron beams is limited at low energy by the incoherent space-charge tune shift, which is inversely proportional to the product of momentum, energy, and invariant emittance. What is needed is a way to reduce the beam emittances after accelerating to a high enough energy that the kinematic factor has reduced the tune shift to negligible proportions. This can be accomplished by accelerating a relatively low-density beam of negative hydrogen ions to several GeV in a synchrotron, then increasing the beam density in the process of charge-exchange injection into another ring. Considerable flexibility in tailoring emittances according to the intended use of the beam (colliding or antiproton production) can be achieved if the two rings share a common straight section, i. e. if they are tangent to each other.

The H^- accelerator should be rapid-cycling in order to maximize its average current. Its acceptance must be large to accommodate the high emittances required to reduce the space-charge tune shift at injection. The beam of large emittance and high intensity can be formed by stacking multiple turns of linac beam in transverse phase space. To avoid stripping the circulating hydrogen ions, the dipole field must be less than about 4 kilogauss and the average vacuum pressure must be better than about 10^{-9} torr. A similar machine was previously proposed as a preinjector for the Fermilab Booster.[1]

Preliminary tuning of antiproton transfer lines and beam manipulations could be done with H^- beam, so the energy of the H^- ring should be greater than or equal to the energy at which antiprotons are accumulated.

Beam Transfer Schemes

Several beam transfer schemes to reduce longitudinal and/or transverse emittances will be described. All of these schemes use a stripping foil in a straight section shared by the two rings; beam is transfered by bumping or kicking both beams so that they intersect the foil; the stripping process allows successive turns to be injected into the same phase space in the second machine, thereby increasing the beam density.

The required complexity depends on the relative circumferences of the two machines. The simplest way to reduce the beam length is to transfer it to a ring of smaller circumference and higher field. The H^- beam can be manipulated by RF just before the transfer to create shorter bunches which fall into matched buckets in the smaller ring. The transverse emittances can also be reduced by bumping the beam slowly onto the foil. The disadvantage of this straightforward approach is that a special ring is required which, because of its small circumference, does not serve as the next acceleration stage. However, it is possible that a ring which was already needed for other purposes, e. g. an antiproton debuncher, could also be used for this purpose.

More complicated but still straightforward schemes are necessary if it is desired to reduce emittances while injecting directly into the next accelerator stage of larger circumference. To reduce the transverse emittances without filling the whole circumference of the larger ring, H^- beam must strike the foil only when previously transfered beam circulating in the larger ring is also striking the foil. This can be achieved by exciting betatron oscillations in the H^- ring. Suppose for concreteness that the second ring is three times larger than the H^- ring. (The maximum field might be four or five times larger, so an increase in momentum by a factor of 12 to 15 is implied.) Then if the horizontal fractional tune is adjusted to be one-third, the H^- beam can be kicked to set up a betatron oscillation in which the H^- beam nears the foil only every third turn. If the H^- beam is then also bumped slowly onto the foil, a beam will be created having small transverse emittances and filling only one-third of the circumference of the larger ring. To create an even

*Operated by Universities Research Association, Inc. under contract with the U. S. Department of Energy.

shorter beam, it seems necessary to use kicker pulses of shorter duration than the revolution time of the H^- ring; successive pulses would then be synchronized with the circulating beam in the larger accelerator. In this case the circumferences of the two rings must be at least slightly incommensurate.

Conclusion

Reducing the emittances of proton beams by H^- charge-exchange transfer from one synchrotron to another is a viable way to increase the luminosity of a hadron-hadron colliding beam facility. It seems simpler than the alternatives of high-energy beam cooling or maintaining a small invariant emittance through the injectors.

Reference

1. C. M. Ankenbrandt, D. Johnson, and R. P. Johnson, Proc. 1977 Summer Study on Colliding Beam Physics at Fermilab, Vol. 2, p. 369 (1977).