ARTIFICIAL BEAM ENLARGEMENT

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Introduction

The counting rate for any reaction produced in a colliding-beam storage ring is a product of the cross section for this reaction and the luminosity of the storage ring. One of the main efforts in the design and operation of a storage ring is to maximize the luminosity which, for a fixed configuration, fixed beam energy, and equal currents is given by

$$\mathcal{L} = K_1 \frac{I^2}{A}$$

with K_1 a constant, I the beam current, and A the effective cross-section area of the beams at the interaction point. It has been found that there exists a maximum usable current density at the interaction region, called the beam-beam limit,[1] which can be written as

$$\frac{I}{A} \leq K_2 ,$$

where K_2 is a constant that depends upon the storage-ring parameters and its value defines the beam-beam limit. Assuming that we have enough RF power capability so that this is the most restrictive limit, the maximum luminosity is

$$\mathcal{L}_{max} = K_1 K_2^2 A.$$

The low-beta storage rings have been designed in order to increase the value of K_2, but to proceed even further we must also increase the beam cross section at the interaction region. While it is possible to design storage rings which for natural beam sizes have large interaction cross-sectional areas, these designs usually have other features that make them undesirable. It would therefore be advantageous to have a method that would artificially increase the effective cross-sectional area.

It is easy to increase the transverse amplitude of a particle by applying an electric or magnetic dipole field at some point in the ring, that oscillates near the natural betatron oscillation frequency. However, this is only a beginning, because in order to achieve a true increase in the effective area it is important that the motion of different particles be incoherent. Furthermore, some method must be devised to regulate the maximum amplitude of the particles, so as not to lose them.

Incoherent Motion

When any external force is applied to a group of particles, all of these particles must experience the same force; however, the response of different particles to the force may vary. For example, if there is a spread in betatron oscillation frequency of the particles, then the motion of different particles will get out of phase and become incoherent. A convenient method of producing a spread in betatron oscillation frequency is to introduce nonlinear magnetic fields in the ring lattice that produce a dependence of the frequency upon particle amplitude. The amount of nonlinear field necessary is often so large that it is not possible to inject particles with necessarily large injection amplitudes in its presence. Since the enlarged beam is needed only for collisions, this problem can be solved by first injecting the particles of the two beams in a non-interacting configuration with the nonlinear fields off, and turning them on only when the beams are to be enlarged prior to bringing them into collision.

Maximum Amplitude Control

The introduction of nonlinear fields also may be used to solve the second problem of controlling the maximum oscillation amplitude. All that is needed is to find the amount of nonlinearity so that at the desired amplitude the particle's betatron oscillation frequency is shifted far enough away from the exciting frequency to stop any further growth in amplitude. This brings up the interesting point that if a noise source, which has all frequencies present, is used for beam excitation, driving forces are present for all oscillation frequencies. While this method is quite successful when used to control the amplitudes of a single beam, it has grave difficulties when two beams are brought into interaction. As the beams are brought into interaction the amount of nonlinear field present increases tremendously, causing the cross section of the beams to decrease below the beam-beam limit with catastrophic results.

Another method of controlling the beam amplitude is by using the natural radiation damping. As the amplitude increases the radiation damping becomes more effective and at a certain amplitude there is a balance between this damping and the growth that is produced by the driving system. In this scheme the nonlinearities are used only to change coherent into incoherent motion. After the beam has received a transverse kick the motion will remain coherent for a certain period of time before the nonlinear forces have had a chance to change this motion into incoherent motion. If there is a mechanism that produces a damping of this coherent motion which[2] is faster than the radiation damping, then it is possible that the equilibrium amplitude will not depend upon the radiation damping rate, but will depend upon this coherent damping rate and decoherence time. This decoherence time is, of course, a function of the nonlinearity present and, thus, as the beams are brought into collision the decoherence time will decrease and the beam cross section will increase. One must be very clever or fortunate to have this final cross section the proper value for achieving the maximum luminosity.

Conclusion

It appears that the effective cross section of non-colliding beams can be enlarged in a controllable manner. However, at the present time the enlargement of cross sections of colliding beams has met with only meager success. This paper has pointed out some of the possible difficulties in the cross-section enlargement of colliding beams, but at the present moment it is not clear which, if any, of these difficulties is the real culprit.

References

1. See the paper in this panel discussion by F. Amman, Beam-Beam Limits.
2. V. L. Auslender et al., Investigation of Self-Excitation and a Fast Damping of Coherent Transverse Oscillations in VEPP-2 Storage Ring, Proc. International Symposium on Electron and Positron Storage Rings, Saclay (1966).