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REDUCTION OF BEAM-BEAM SYNCHROBETATRON RESONANCES USING COMPENSATING INTERACTION REGIONS*

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INTRODUCTION

The next generation of high luminosity circular electron-positron colliders requires many intense bunches in each beam, of order 200 to 1100. The interbunch spacing dictates that two separated rings are necessary. The ensuing problem is how to design the interaction regions so that the two beams can be made to collide and separate using physically realizable magnets, providing low detector backgrounds, having a practical vacuum system design, and obeying the constrains of the beam-beam interaction.[1,2] One of the solutions involves the use of a finite crossing angle between the trajectories of the two beams at the interaction point (IP). The problem with a crossing angle is the well-known problem of synchro-betatron resonances driven by the beam-beam force.[3]

A solution to the synchro-betatron problem is to make the beams effectively collide head-on by adding a tilt to each bunch at the IP, a so-called crab crossing. There are several methods to produce these tilted bunches.[4,5] However, all of these solutions involve placing RF cavities near the interaction region where either the betatron or dispersion functions are large. These crab cavities in turn generate additional design problems. Some of the problems are: (1) a significantly larger impedance of the ring vacuum system, (2) the large cavity voltages (of order 10 MV), (3) the rotation of both beams, and (4) the control and stability of these cavities.

An alternative solution discussed here has two interaction regions physically adjacent to each other where the beams collide at a finite crossing angle without tilted bunches. To ameliorate the synchro-betatron resonances, there is a specially chosen betatron phase advance between the two IRs so that the coupling effects from the beam-beam forces cancel. The consequence of this arrangement is that the interaction region design is now straightforward.

COMPENSATING INTERACTION REGIONS

A schematic layout of the interaction region is shown in Fig. 1. The beams cross each interaction region at a horizontal angle of ϕ for a total crossing angle of 2ϕ. As a result of the beam-beam force of a single collision, the head of each bunch is deflected in the opposite direction from that of the tail. The second

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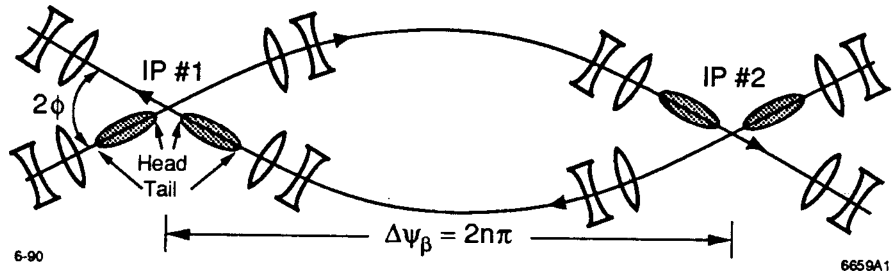

Fig. 1: Layout of compensating interaction regions.

interaction region is placed at a betatron phase advance of exactly $2n\pi$ from the first IP, with n an integer. Furthermore, the crossing angle is arranged to change sign between IPs. With this placement, the deflection angles of the head and the tail resulting from the first interaction region are, to first order, exactly cancelled by that of the second. The position offsets are also zero. Thus, the design goal is satisfied.

The horizontal incoherent beam-beam effects add linearly from the two collisions because of the integer phase separation. This addition will cause the horizontal beam-beam tune shifts to add directly from the two collisions and will somewhat reduce the maximum horizontal tune shift observed in either IP. This should not strongly affect the maximum luminosity since the beam-beam limit is most often determined by the limiting vertical tune shift (for flat beams). The linear addition of the vertical tune shifts from-the two interaction regions can be broken by adjusting the vertical phase advance between interaction regions so it is not $2n\pi$ but has a sizable fractional part, e.g., $2n\pi$ + 0.19. The design of an interaction region satisfying these two phase advance constraints should be straight forward. Some horizontal bending of the trajectories between the two IPs is needed to provide the proper geometry, requiring a dispersion matched lattice to be made.

The basic reason this scheme is worth investigation is that the direct coupling of the longitudinal position and the beam-beam force of the core of the beam is eliminated. The resonant condition is then removed. Unfortunately, a particle which is executing both a synchrotron oscillation and a betatron oscillation will see some coupling due to the nonlinear nature of the beam-beam force. Therefore, nonlinear effects influencing the sparse tails of the beams may likely appear upon detailed simulations. A detailed simulation of the beam tails will be conducted soon to investigate the strength of these possible nonlinear effects and how important they are.

In this design with compensating IPs, each individual bunch will collide with two opposing bunches thus interacting through the beam-beam force to all other bunches. This situation requires either that the intensity of all the bunches be the same to a small tolerance or that the collider operates just below the bunch intensity where the tune shift saturates and the vertical beam size starts to increase. This second scenario is the most advantageous and can likely be achieved by actively controlling the vertical-horizontal coupling with magnets throughout the course of a physics run as the currents decay.

The design of the interaction region for compensating IPs is easier than either a crab-crossing IP or a head-on IP. The first advantage is that no crab cavities need be planned for. Secondly, there are no bending magnets within the IP, significantly reducing the synchrotron radiation background problem. In this new scheme, the two IPs should be sufficiently close to each other so that radiation mixing of phase space is minimized. However, the added complexities are: (1) the phase advances must be carefully planned, (2) the bending needed between the IPs must be designed to provide for dispersion matching, and (3) the trajectories for the two beams between IPs need to have the same path length.

CONCLUSIONS

The concept of mutually compensating IPs to reduce the effects of synchrobetatron resonances associated with the beam-beam effect appears sufficiently interesting to pursue further. With success, the interaction region design will be simplified significantly. A detailed beam-beam simulation of this proposed concept is needed next to study possible nonlinear effects. A realistic IP layout and design are also needed.

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