EXPERIMENTAL INSERTIONS FOR THE ISA*

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Abstract

The general design features of experimental insertions for the ISA storage accelerators are presented. Various insertions which satisfy the requirements for specific high energy particle experiments are discussed. Some consideration is given to a) the distribution of the insertions in the lattice; b) the separation of experimental areas from those used for injection and protective extraction; c) the subject of beam crossing; d) the implications of high β, high quadrupole gradient conditions required in the insertions; and e) general characteristics, including luminosity and beam momentum spread.

Review of Original Study

In a study[1] done in 1971 and 1972, a variety of experimental insertions for the ISA were proposed. Specifically, four types of insertions, all matched with respect to betatron and momentum dispersion functions,[2] were suggested, with their basic structure dictated by the following general considerations: 1) Certain classes of experiments,[3] and, in particular, weak interaction studies, demand an insertion design in which the overriding objective is high luminosity in the interaction region. An example of an experimental insertion designed for this purpose is shown in Fig. 1. 2) The insertion designed for small angle p-p elastic[4] scattering has a rather different set of constraints. Luminosity is not the primary concern. Here, the design centers around the objective of reducing the angular spread of the primary interacting beams and thus optimizing the required angular resolution, needed for the precise definition of the scattering angle. Our attempt to satisfy this requirement, among others, is shown in Fig. 2. 3) A third type of insertion attempts to reconcile, in a practical way, the conflicting objectives of high luminosity and a long free drift around the interaction point. We must, in effect, sacrifice luminosity in order to keep the β function in an acceptable range throughout the insertion. We will expand upon this point later on. An experiment to detect large angle elastic p-p scattering events[5] can, for example, be performed with such a set-up, whose characteristics can be seen in Fig. 3. 4) Finally, an insertion which can accommodate two separate experiments was devised. Actually the ability to perform two simultaneous experiments in this insertion is an extra dividend. The primary purpose here is to devise an insertion suitable for a class of experiments typified by the measurement of single particle inclusive spectra.[6] The two basic requirements are a sufficiently long distance within the experimental building to accommodate the detectors and an interaction region which has a short physical length. These are satisfied by having a large angle crossing near one end of the straight insertion. This frees the other end for another experiment, limited of course by the extent of background interference between the two experiments. Figure 4 shows a possible insertion design.

More recently, as a result of the ISA Summer Study[7] and continued work at BNL, we have introduced some modifications to the design features which were given in Ref. 1.

Single Function Insertions

A key change in our thinking about experimental insertions concerns the other functions which these insertions could serve. In the original study, as well as in the Summer Study, it was thought practical to combine the insertions with both the injection function and the need for fast protective extraction. Thus, the latter function was included in the long (300 m) insertions and, furthermore, an additional insertion design was attempted which would allow injection and some limited experimentation. However, recent developments have allowed us to completely separate injection and protective extraction from experimentation.

First, a simple, short matched insertion (matched with respect to betatron parameters as well as dispersion function) was designed to be used for fast protective extraction. It is, in effect, a modification of a basic lattice cell with three 10 m free lengths inserted in a symmetrical manner. Secondly, we were able to develop an insertion suitable for injection. The main point here is that in order to accommodate the energy stacking type of injection, essentially the method used for the CERN ISR[8], we required an insertion in which the injection point would have high X_p, low β_H. This was achieved.[9] It is perhaps worth emphasizing that separating the functions of insertions as we have done does not result in any significant increase in the length or cost of the accelerator. The insertion is quite long (150 m); however, with programmed quadrupoles,[10] its high field characteristics could be such that it is essentially five normal lattice cells with three 10 m free drifts. Taking these developments into consideration, a lattice can be constructed with the functions of experimentation, injection and protective extraction separated. The details of the lattice structure will be presented elsewhere. However, one possibility is shown in Fig. 5. It has two-fold periodicity and the interesting feature that the rings are, in some sections, not identical.

Having separated the functions of injection and protective extraction from experimentation, we have chosen to increase the number of "first-class" experimental insertions (i.e. those capable of providing a luminosity of the order of 10^{34} cm^{-2} sec^{-1}) from two, as described in Ref.(1), to four, as in Fig.(5). In particular, the lattice has been modified to include two "300" m insertions and two "200" m insertions, arranged so that the two-fold symmetry can, if desired, be maintained. The "300" m insertions have been treated thoroughly in the original study. The new types have the same basic structure and the design of a high luminosity "200" m insertion, similar to type I, shown in Fig.(1), has been achieved. The β values at the interaction point for this insertion are of the order of 1 m.

The idea of beam "by-passes" or parallel arrangement of interaction insertions received considerable attention in the Summer Study. Based for the most part on arguments related to costs, derived benefits and operational efficiency, we have decided not to include bypasses in detail in the first stage ISA design. A review of these considerations can be found in Ref.(11). However, we do not preclude the future addition of bypasses. Thus, we have provided some straight-section allowance in order that they may be incorporated at a later stage.

Beam Crossing

In the original experimental insertions,[1] the beams, initially separated vertically, were brought together into vertical collinearity. However, in order to limit the interaction length, as a result of the limiting beam-beam interaction, it was necessary that the beams be given a minimum crossing angle.[1] To avoid the requirement of an even number of crossings around the ring, which would be the case with vertical cross-

*Work performed under the auspices of the U.S. Atomic Energy Commission

ings, it was decided there to use horizontal crossings. However, there is a strong reason why vertical crossing might be desirable. It is based on the fact that with vertical crossing, the luminosity would then be independent of the vertical beam size. With horizontal crossing, the luminosity is inversely proportional to the vertical size. The point is that the vertical size is large for two reasons: First, because of phase space interchange in the beam transfer line between the AGS and the ISA, which was done in order to make the beam roughly circular in the main lattice, (note that a circular beam minimizes the aperture requirement in the circular ISA chamber) the vertical emittance is much larger than the horizontal emittance. And secondly, since the beams have an intrinsic vertical separation, they must be brought together by dipoles, thus inducing a vertical momentum dispersion function of the order of 0.25 m (since the two beams are separated by 0.5 m) in the interaction region. This last addition to the vertical beam size was neglected in the original study because the momentum spread was assumed to be sufficiently small so that the vertical size corresponding to a vertical X_p of 0.25 m was completely insignificant. However, due to the problems related to longitudinal stability (unstable conditions can be excited by the total ring coupling impedance) a much larger momentum spread at 200 GeV might be required. Thus, for example, if $\frac{\Delta P}{P} \approx 6 \times 10^{-3}$, we would obtain an increase in vertical beam size due to this effect of 0.15 mm, which may not be negligible.

In this context, it should be mentioned that a modification of the Type I insertion (see Fig.(1)) has been proposed.[9] It has the desirable property, among others, of allowing for both horizontal and vertical crossing. The change from horizontal to vertical crossing is accomplished by slight changes in current in the appropriate dipoles.

Implications of High β, High Gradient Conditions

An aspect of continuing study is connected with the need, in the experimental insertions, for strong lenses associated with high β values. These high β values are necessary in order that the focusing to small β values at the interaction point be accomplished in a reasonably large distance. (That is, since $\beta\,\beta_o \sim \ell^2$ with β_o small and ℓ reasonably large, then β must be large.) The implications of such conditions are many and formidable. We just mention a few. The introduction of "large" chromaticity ($\frac{p d\nu}{\nu dp} \sim -3$ to -4) necessitates the use of "large" chromaticity correcting sextupoles whose presence produces undesirable nonlinear effects. These problems have been looked into[12] and seem to be tractable. A second consequence of the high β conditions is that maximum misalignment tolerances for these quadrupoles become severe. In particular, the required tolerances are of the order of ~ 0.002 in. and could not be achieved by any reasonable surveying technique. Thus, some dipole steering will probably be required.[13] Finally, under injection conditions, the large gradient, high β state is not tolerable because of the added aperture requirements. The quadrupoles will therefore be programmed so that the β functions are moderate at injection. In order to provide the required conditions for experiments, the individual quadrupole excitation will be changed in a programmed manner so as to obtain finally the desired experimental conditions. The matching of betatron and dispersion functions will, of course, be maintained at all times. The total time for the process is not of crucial significance, since the injection conditions in the experimental insertions naturally provide acceptable beam characteristics at high field. Thus, the change can be performed after the beam has reached its final energy. Tracking will therefore be no problem. However, it should be emphasized that the tracking required for the injection insertion must be performed within the time of acceleration since here, the injection conditions, particularly the quadrupole strengths required for the doublets, cannot be sustained at high energy.[10] Note also that if the lattice ν-values are altered by this change, the normal lattice quadrupoles will have to be tied in with the programming scheme.

Summary

The ISA lattice structure is conceived around four experimental insertions, with a maximum symmetry of two. Each of these insertions is matched to the main lattice with respect to horizontal and vertical betatron functions and momentum dispersion function.

We have considered some of the aspects and implications related to the presence of large β functions within the high gradient focusing quadrupoles required in the experimental insertions.

The momentum spread of the beam cannot be reduced below a minimum set by longitudinal stability requirements: A value of $\frac{\Delta P}{P} \approx \pm\ 3 \times 10^{-3}$ at 200 GeV would appear to be acceptable.

The desired luminosity of the order of 10^{34} cm^{-2} sec^{-1} is attainable in either the "200" m or the "300" m insertion. The limit is set by the beam-beam interaction. In practice, we limit the luminosity by cutting off the interaction region. This is done by allowing the beams to cross at a specified, small angle. We have discussed the question of using horizontal or vertical crossing and have concluded that in the present set-up, vertical crossing is desirable. However, the magnet arrangement is designed so that both can be achieved.

With reference to the separation of the expermental lattice regions from those required for injection and fast protective extraction, we can report that due to recent developments, which we have gone into above, such a feature has been incorporated into the ring design.

Finally, we have shown some of the basic insertion designs and have indicated some of the types of experiments which appear to be feasible with them.

Acknowledgment

We would like to thank Dr. J. Sandweiss for valuable discussions.

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10. The programming of quadrupoles must take place within the time of acceleration of the beam from 30 GeV to 200 GeV. This is essential since the

injection conditions are achieved with very high gradient doublets. As the momentum is increased by almost a factor of 7, the doublet strengths required for matching cannot be obtained. Thus, there must be a gradual changeover to a singlet structure. This point is gone into in detail in Ref. (9).

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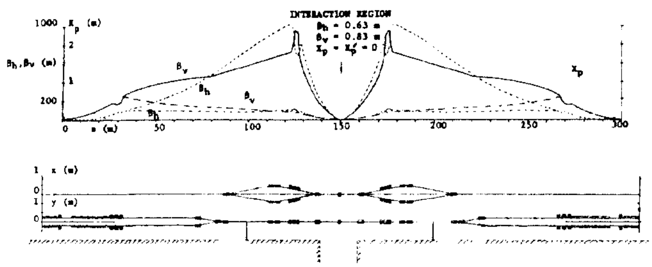

Fig. 1 High Luminosity Experimental Insertion. The lower β-values correspond to Start-Up Parameters. Within the insertion, the X_p functions (vertical and horizontal) essentially follow the orbit. See Ref.(2) for a discussion of this point. Quadrupole strengths and other parameters can be found in Ref.(1). Luminosities:
$L = 2.3 \times 10^{33}\ cm^{-2}\ sec^{-1}$ (Start-Up),
$L = 1.4 \times 10^{34}\ cm^{-2}\ sec^{-1}$ (high luminosity mode).

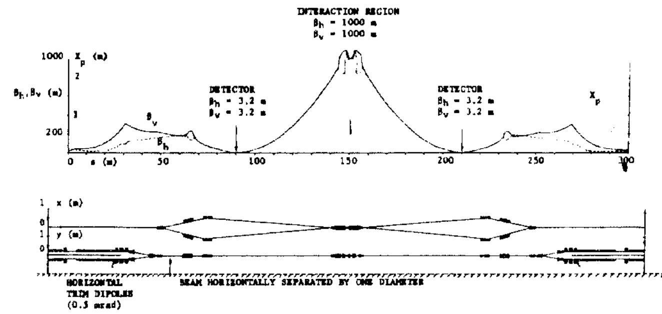

Fig. 2 Insertion for Small Angle Elastic Scattering. Luminosity, $L \approx 1.6 \times 10^{31}\ cm^{-2}\ sec^{-1}$.

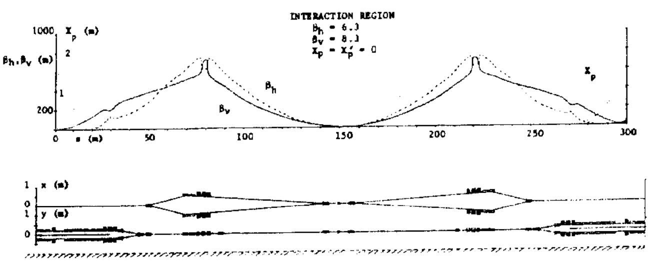

Fig. 3 Insertion for Large Angle Elastic Scattering. Luminosity, $L = 2.3 \times 10^{33}\ cm^{-2}\ sec^{-1}$.

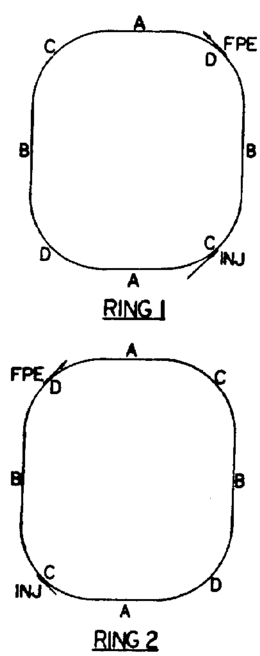

Fig. 5 Lattice Schematic. The rings are placed one above the other, Ring 2 below Ring 1.
A: 200 m Experimental Insertion
B: 300 m Experimental Insertion.
C: Quadrant containing Injection Insertion.
D: Quadrant containing Fast Protective Extraction Insertion.

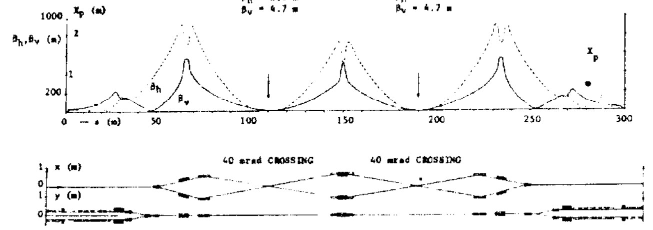

Fig. 4 Double Crossing Mode. Luminosity, $L = 4 \times 10^{31}\ cm^{-2}\ sec^{-1}$.