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ISA INJECTION

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ABSTRACT

The conceptual design of the ISA beam injection system is presented together with the relevant AGS-ISA beam transfer parameters. Steering onto the ISA injection orbit is done by means of a shutterless "split pole" vertical deflecting fast dipole. Consideration is given to the tolerable magnitude of the injection kicker stray field at the edge of the high density part of the beam stack. ISA aperture parameters are detailed and a maximum beam periphery profile ("dump profile") is defined within the aperture boundary of the superconducting ring magnet system.

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1. Introduction

A number of schemes have been studied¹ for injecting the AGS beam into the ISA. The simplest of these involves straightforward synchronous transfer between matched rf systems, taking nominally 11 bunches (out of a possible 12) from the AGS and distributing these during 4 AGS cycles in the circumference of the ISA. Its advantage would be that no debunching and rebunching of the beam is involved, however, its luminosity at 200 GeV would be too low.

An alternative method studied involves beam debunching in the AGS and rebunching to a single bunch with an approximately sawtooth rf waveform, with orbital fundamental frequency. This single bunch is transferred in box car fashion into ISA, stacking each single bunch as close as possible to the previously stacked ones.

A third method would be to transfer single AGS bunches, and by using rf manipulation with a number of suppressed rf "buckets" or, alternatively, single bunch path length perturbation, this bunch could be brought close azimuthally (about one tenth of their original spacing in the AGS) to previously stacked bunches in the ISA. Both of the latter schemes would result in such stacked currents that luminosities of nearly $10^{33} \text{ cm}^{-2} \text{ sec}^{-1}$ would be achievable with unbunched beams.

The fourth method is the proven injection scheme presently employed at the CERN ISR. It involves synchronous transfer of the AGS beam onto an injection orbit of the ISA, with subsequent rf acceleration with decreasing volts per turn amplitude into a so-called beam stack. The injection orbit and low energy end of the stack are sufficiently separated that the stray field of the repetitively pulsed injection kicker does not perturb the previously created debunched beam stack. After completion of the stacking process, the total stack is rebunched and accelerated to the desired beam-beam interaction energy.

A comparison has been made of these various beam stacking schemes,¹ the conclusion being that the last mode of beam stacking, i.e. the ISR energy stacking mode, with specific modifications, is adopted for the ISA beam stacking method.

2. Beam Preparation and Extraction in the AGS

To minimize aperture requirements in the ISA, AGS operation during injection will differ from present maximum intensity operation for the ongoing experimental program. The transverse phase space emittance at 30 GeV will be kept low by using only limited multiturn injection from the linac into the AGS.² This will result in lower than usual AGS final intensity (2.5×10^{12} p/p). The intensity in the ISA will be built up to the design value by injection of a large number (about 315) of AGS charges.

Further, in order to decrease the required rf voltage, for the ISA stacking system, it will be beneficial to reduce the momentum spread of the AGS beam, prior to ejection, by means of adiabatic debunching. This is done by reducing gradually the AGS rf voltage from 380 kV/turn to approximately 36 kV/turn, reshaping thereby the proton bunches, i.e. increasing their phase spread and, commensurately, decreasing their energy spread, in order to match the bunches to the empty buckets of the ISA injection orbit rf system.³

The parameters of the AGS, as ISA injector, are given in Table I.

Since it is essential to avoid unnecessary losses in the superconducting storage ring, special means will be employed both in the AGS, prior to beam extraction, and in the beam transfer channel, after beam extraction, to insure that the beam phase space parameters, as stated will be achieved. In the AGS this will be done by transverse phase space clean-up using one, or more, beam scraper targets.

Beam extraction will take place from the AGS H10 straight section location, as is presently being used for full intensity extraction for the 7-ft bubble chamber. The present full intensity fast extraction system makes use of a superposition of a number of fast current waveforms for the beam kicker (C15 kicker) to create an AGS ejection orbit. This mode of fast extraction was developed to permit

TABLE I. AGS Parameters, as ISA Injector

Linac injector	200 MeV, $I_L = 50$ mA
	$A_{t,80\%} = 3\pi \cdot 10^{-6}$ rad-m
	$(\Delta p/p)_{fw} = \pm 1.1 \cdot 10^{-3}$
AGS injection	limited multiturn (low efficiency, max. transverse density)
Beam parameters, after injection:	
N_{stacked}	$3.6 \cdot 10^{12}$ ppp (effect. 3 turns)
phase space, transverse	$4.5\pi \cdot 10^{-6} \times 13.5\pi \cdot 10^{-6}$ (rad-m) ²
$(\Delta E)_{fw}$, unbunched	± 0.40 MeV
$A_{2,l}^*$, per "future" single bunch	0.32 eV-sec
N_{captured} (12 bunches)	$2.5 \cdot 10^{12}$ ppp
Transition longitudinal dilution	≈ 1.1
Transverse phase space dilution, V.	≈ 2
Beam parameters at 28.5 BeV:	
phase space, transverse, V x H	$0.2\pi \cdot 10^{-6} \times 0.3\pi \cdot 10^{-6}$ (rad-m) ²
phase space, longitudinal	0.36 eV-sec
	$\delta E = \pm 18.2$ MeV
	$\delta \varphi = \pm 0.176$ ($\pm 10^\circ$ at 4.45 MHz)
	$(\Delta p/p)_{fw} = \pm 0.59 \cdot 10^{-3}$
Beam parameters, after adiabatic debunching	
V_{rf} 384 kV $\rightarrow$ 36 kV, and ejection:	
longitudinal	$(\Delta p/p)_{fw} = \pm 0.33 \cdot 10^{-3}$; $\delta \varphi = \pm 0.32$ ($\pm 18^\circ$ at 4.45 MHz)
transverse phase space, VxH	$0.25\pi \cdot 10^{-6} \times 0.4\pi \cdot 10^{-6}$ (rad-m) ²
extracted bunch train	11 bunches, $t_{bt} = 2.27$ μ sec
protons per bunch	$2.3 \cdot 10^{11}$ ppb
Repetition rate	1 c/1.3 sec minimum

also fractional fast beam extraction, simultaneous with resonant slow beam extraction. For full intensity ejection it involves a kicker amplitude variation of $\pm 12\%$.⁴ In order to reduce further the transverse phase space magnitude of the extracted beam it may be desirable to revert again to a constant amplitude ($\pm 1\%$) fast rise time ejection beam kicker, as was used previously for AGS fast beam extraction.⁵ With the reduced beam intensity and consequent reduced transverse phase space mode of operation for ISA injection, the existing AGS fast kicker unit (L10) will be adequate and is also satisfactorily located azimuthally for H10 extraction, if the existing kick polarity of this unit is reversed.⁶

3. Beam Transport From AGS to ISA

The beam transport between AGS and ISA takes, for a small part, advantage of the existing beam line to the neutrino target for the 7-ft bubble chamber. New construction would start at the existing 10° branching tunnel, upstream of the neutrino target. Nevertheless, since it is desirable to achieve a limited amount of beam clean-up in the already existing channel, the total beam transport between the 8° bend point in the existing line and the ISA injection point has been calculated. The results are shown in Fig. 1 and the required quadrupole parameters, expressed in kG ($\int G dl$) are, sequentially⁷:

Q8-51, Q9-44, Q10-51, Q11-68, Q12-66, Q13-113, Q14-49, Q15-78,
Q16 through Q20 53.5 kG
Q30-54, Q31-38, Q32-50, Q33-58, Q34-62.

A summary of the parameters of the principal transport elements is given in Table II.

As indicated also in Fig. 1, two separate 45 degree achromatic bend arrangements are required to direct the proton to either ISA insertion I, or insertion VII. Since the charging time per ring is approximately 15 min. each and, after storage ring commissioning this process will not occur more than once or twice per day, these 45° bend sequences will make use of 16 room temperature bending elements, with 2.3 cm vertical aperture.

Adjustable collimators will be incorporated, upstream of the 10° bend for limited transverse phase space clean-up, and near the center of the 45° achromatic bend for momentum distribution clean-up. Following the 45° bend a sequence of fixed collimators will be interspaced with the transport quadrupoles in order to complete the transverse phase space definition. Trim dipoles, adjacent here to each quadrupole element will be servo controlled by beam position monitors, to maintain optimum transmission during the injection sequence of approximately 315 AGS cycles in this, deliberately, limited aperture channel. The various elements including beam monitoring components are indicated in Fig. 2, where the general geographic arrangement of AGS-ISA beam transfer is shown.

TABLE II, Beam Transport AGS - ISA, Principal Components

Quadrupole magnets	35	2Q24	$\int G dl = 100 \text{ kG}$
	4	4Q26.5	100 kG
	1	8Q32	150 kG
	2	8Q24	100 kG
Dipole magnets	18	0.9D210	$B = 18 \text{ kG}$
	1	1.0D72	18 kG

(Note: element designation: first number, aperture (gap) in inches; last number, length in inches.)

4. ISA Injection

Rather than ISA beam injection into specially designed injection insertions it is advantageous to inject into a standard, so called, experimental insertion. In this fashion a higher lattice symmetry can be maintained. Moreover, as will be indicated below, the injection arrangement will not interfere with the experimental utilization capability of the insertion. As a consequence, an eight fold symmetric lattice structure evolved with the potential of seven experimental

Fig. 3
ISA Schematic
(8 equal insertions)

crossing domains. This is schematically shown in Fig. 3.

Inherent in the method of momentum stacking is the requirement that the injection kicker be located at a (near) maximum value of the local dispersion function in the lattice, consequently the kicker unit cannot be located in the insertion where $X_p = 0$ or approaches zero. Also, in order to avoid locating a 30 GeV injection line outside the ISA crossing beam lines, where it would interfere with experimental equipment, the injected beam is directed through the crossing point of the insertion. Avoiding also locating any injection septum magnets between the so called "20 m" quadrupole magnets in the insertion, the arrangement as shown for Insertion I and VII in Fig. 4 is arrived at.

A number of possible injection orbits using as a final element a horizontally deflecting beam kicker magnet have been calculated. Acceptable arrangements were arrived at with either the injection orbit traversing the stack or, alternatively, with a different end cell arrangement, an arrangement whereby this could be avoided. The dominant requirement is that the injection kicker be located at (or near) a maximum value of the lattice X_p function.

Contrary to the present ISR (CERN) design for the horizontal injection kicker, which makes use of a mechanically movable shutter to shield the stack from the stray field of the injection kicker, in the cases referred to here the use of a kicker without shutter but with eddy current shield field suppressors⁸ is assumed. This arrangement is shown in Fig. 5. Its great advantage would be that the injected bunched beam can be accelerated immediately into the stack, avoiding thereby the problems of dwell time (~ 0.2 sec) on the injection orbit of the high longitudinal phase space density, but low intensity, injected beam which would be susceptible to instability because of lack of Landau damping from nonlinearities.

In addition, the elimination of the shutter permits the addition of a lower density (low momentum) "tail" to the beam stack, during the stacking process only (see below) which alleviates the maximum impedance tolerance in the ring.⁹

With a 1.6 cm separation between the boundaries of the injected beam and the final beam stack, and the use of the stray field suppressor as indicated, the stray field perturbation averaged over the high density part only of the stack during the injection cycle would be ~ 1 to 1.5% of the kicker beam deflection, i.e. $\langle \theta \rangle \approx (5-10) \mu\text{rad}$ for a field rise and fall time of ≈ 100 nsec. Since the beam stack would be exposed to this perturbation up to approximately 315 times during stack formation it is of interest to determine the consequences of this and to ascertain the tolerable magnitude of the injection kicker stray field value. This has been done, here only the results of this study will be presented.

Because of loss of "coherence" between injection cycles the kicker stray field perturbation would be applied in a random manner to the orbiting particles. Considering only the dipole component of the perturbation, the random application of angular deflections (to an ensemble of particles) would be analogous to single particle rest gas Coulomb scattering. Using partly the existing theory^{10,11} of betatron amplitude growth associated with this, the transverse phase space growth due to the multiple exposure to the kicker stray field could be determined. The results may be expressed as follows:

A (one dimensional) Gaussian transverse beam distribution with $\sigma = \sigma_0$ will grow due to repetitive, but random, injection kicker stray field perturbations, into the distribution $\rho(x)$ given by

Fig. 5

Horizontal injection option using eddy current shield field suppressors

$$\rho(x) = \int_{-\infty}^{+\infty} \left[1/\sqrt{2\pi} \sigma_1 \exp -(x-x')^2/2\sigma_1^2 \right] \left[1/\sqrt{2\pi} \sigma_0 \exp -x'^2/2\sigma_0^2 \right] dx'$$

with $\sigma_0 = \frac{1}{2} \sqrt{E\beta}$ and $\sigma_1 = \sqrt{(t_i/t_o)(N/2)} \beta \langle \theta_s \rangle_N$

where N is the number of injection cycles, t_i injection kicker excitation time, t_o orbital time and $\langle \theta_s \rangle_N$ is the average angular deflection due to the kicker stray field. Carrying out this integration leads to a modified Gaussian distribution, $\rho(x)$, now with a standard deviation value of Σ given by

$$\Sigma = \sqrt{\sigma_0^2 + \sigma_1^2}.$$

Permitting a transverse phase space growth due to the repetitive kicker perturbation of 10% only $(\Sigma - \sigma_0)/\sigma_0 \leq 0.05$ results in

$$(\sigma_1/\sigma_0) \lesssim 0.3 \quad \text{or}$$

$$\langle \theta_s \rangle_N \lesssim 0.3 \frac{\sigma_0}{\beta} \sqrt{(t_o/t_i)(2/N)}$$

with $(t_o/t_i) \approx 3$, $N \approx 400$, $\beta \approx 40$ m, $\sigma_0 = 2 \cdot 10^{-3}$ m

$$\underline{\langle \theta_s \rangle_N \lesssim 1.8 \text{ } \mu\text{rad}}$$

or, using the inflection kicker parameter of $\theta_k = 0.5$ mrad, at $B = B_k$, it follows that

$$\langle \theta_k \rangle_N \leq 3.6 \cdot 10^{-3} B_k.$$

This value indicates that the ($\approx 1\%$) B_k magnitude associated with the horizontal kicker, without shutter, is not acceptable, and a greater separation between kicker (injection orbit) and stack would be required.

Actually, for the shutterless horizontal kicker, the stray field at the low momentum edge of the stack would be $\sim 2\%$ of B_k . This would result in non-negligible transverse phase space growth (horizontal)

during the latter part of stack formation. (Some limited growth would be acceptable, since horizontal scraping, at $X_p = 0$ locations, would be employed after every injection kick and that part of the azimuth where the stack tail would be diluted due to this, would, within seconds receive the newly injected beam.)

An alternate approach to beam stacking, without movable kicker stray field shutter, is by making use of a novel "split pole" pulsed magnet unit, which would deflect the beam vertically onto the injection orbit. This is illustrated in Fig. 6. Inherent in the orientation of field and magnetic poles relative to the essential free space through which the beam must be accelerated, the stray field at the stack location will be low. Mesh calculations for a static unit have been carried out and the results,¹² as indicated in Fig. 6, confirm this expectation. Prototype work is in progress to design a vertical injection kicker, approximately as shown, with field excitation as follows: rise time, not critical; flat top time, 3 μ sec; fall time, ≈ 7 μ sec. These parameters do not rule out the use of a laminated core instead of a ferrite core.

Since it is desirable to keep the opening in the pole narrow, this kicker unit will be located at a vertical $\beta_{\min}$ location, or maximum horizontal β value, consequently coinciding with a maximum X_p location, as required for injection. Therefore, the adoption of either a horizontal or vertical injection kicker as indicated here will not affect the free space required in either the end cell or X_p matching cell. For the present design the use of the vertical injection kicker will be assumed, because of its low stray field magnitude, with principal elements located as shown in Fig. 7. The component parameters are given in Table III.

5. Beam Stacking in the ISA

As indicated in Table I, 11 bunches would be synchronously transferred into the empty "matched" buckets of the ISA injection orbit rf system. The essential parameters of the "early" beam parameters in the ISA are

*These non-zero values are probably due to finite permeability of the iron.

Fig. 6

Vertical Injection Option Using a "Split Pole" Pulsed Dipole

Fig. 7

Injection Options

"Vertical Injection"

TABLE III, Injection Line Components

Element	IKV1	ISV1	ISV2	ILH1,2	ICH1
Length (m)	1	1	1	3	3
$\hat{B}$ (kG)	1	1.5	3	6.75	13.5
Excitation	-	$\frac{1}{2}\sin 0.1\text{msec}$	$\frac{1}{2}\sin 0.1\text{msec}$	<u>dc</u>	<u>dc</u>
$\hat{I}$ (kA)	~ 1	2.5	5	1.5	1.5
*Aperture (mm ²)	<u>>10h</u> <u>x20w</u>	<u>28h</u> <u>x20w</u>	<u>28h</u> <u>x20w</u>	<u>16h</u> <u>x>30w</u>	<u>16h</u> <u>x40w</u>
Septum (th, mm)	-	0.25, Al	0.25, Al	6, Fe	-
J_c (kA/cm ²)	-	25	50	1.5 (coil)	1.5 (coil)
Turns	2	1	1	6(2pc's)	12(4pc's)
Angle ₃₀ /unit	1	1.5	3	20	40
Deflector	V	V	V	H	-H
Units	1	1	1	2	1
Remarks	-	-	-	series **	

* Underlined dimension is "magnetic gap".

** $\Sigma R_{dc} \approx 25 \text{ m}\Omega$. PS: 1500 A, 50 V.

given in Table IV. Without going into the details of the dynamics of the beam acceleration into the stack, adiabatic debunching and, after stack formation, the rebunching process,³ here the basic parameters have been calculated with which the full beam momentum spread, immediately after the stack bunching process is completed, can be determined. This is also given in Table IV. The resultant maximum $(\Delta p/p)_{fw}$, bunched beam, value is 1.6% for a 10 A stacked beam.

Since the "poorer field domain" between stack and beam kicker would be used for a beam low momentum tail, in order to ameliorate the impedance requirements, only the stacking mode whereby the beam would be accelerated into the stack is applicable and the injection orbit would be a lower momentum orbit, nominally $p \approx - 1.011 p_0$, where p_0 is the central orbit in the vacuum chamber.

Also stated in Table IV is the "early" rate of acceleration, i.e. 4.6 BeV/min, for the stated parameters of the acceleration system. This can be increased shortly after injection, after some adiabatic damping has occurred to achieve a faster overall acceleration time. The rate of rise would be guided, however, such that $(\Delta p/p)_{fw} = 1.6\%$, which is the value after the rebunching process is completed, is a maximum value.

6. ISA Aperture

The ISA aperture is determined both by vacuum requirements and by the beam parameters and early beam manipulation as it occurs at and immediately after injection into the ISA. Here only the second part will be dealt with. The resultant aperture demand does match however, reasonably well with the vacuum system requirements which are guided towards a $\eta I \approx 30$ value.¹³

Using the parameters evaluated in the foregoing (see Table IV) the details of the aperture subdivision after stack formation and beam

TABLE IV. ISA Parameters at Injection

Injection, transverse	single turn, vertical stacking
longitudinal	bunched beam, synchronous transfer
Charge per injected turn	$2.5 \cdot 10^{12}$ protons (I/turn = 39.6 mA)
Beam parameters, on inj. orbit:	
transverse phase space	$0.4\pi \cdot 10^{-6} \times 0.4\pi \cdot 10^{-6} \text{ (rad-m)}^2$
longitudinal	$(\Delta p/p)_{fw} = \pm 0.33 \cdot 10^{-3}$ $6.4 \cdot 10^{11} \text{ p/(eV-sec)}$
bunch structure	11 bunches, $\nu_{rf} = 4.45 \text{ MHz}$, $h = 44$ (suppressed bucket operation)
Number of AGS cycles/stack	~ 315
Charging time/ring*	6.8 min. minimum
Debunched stack density	$3.2 \cdot 10^{11} \text{ p/(eV-sec)}$, $8.9 \cdot 10^{14} \text{ p}/\%(\Delta p/p)$, $15.1 \text{ A}/\%(\Delta p/p)$
Momentum spread, deb. beam	1% ($\sim 12.5\text{A}$) (stack = 0.7%, tail = 0.3%)**
Longitudinal phase space, "stack"	$1.95 \cdot 10^3 \text{ eV-sec}$
Beam rebunching, adiabatic	
rf parameters**	$\dot{V}_{rf,f} = 8.4 \text{ kV}$; $\varphi_s = 5^\circ$ ($N \approx 0.8$) $h = 2$; $(dV_{rf}/dt)_i \lesssim 10 \text{ kV/sec}$
"Early" rate of acceleration***	4.6 BeV/min.
Maximum $(\Delta p/p)_{fw}$, bunched beam	1.7% ($\sim 10 \text{ A}$)

* This value, and AGS rep. rate, will be determined by the minimum time required to debunch adiabatically the injected bunched beam into the stack.¹⁴

** Beam scraping of momentum tail just prior or during rebunching process.

*** (dE/dt) during cycle guided by $(\Delta p/p)_{fw} \leq 1.7\%$.

rebunching, are best expressed by the following relationship:

$$\begin{aligned} & (\text{Chamber aperture} - \text{dipole sagitta value})/2 \geq \\ & \sqrt{\beta/\hat{\beta}} \left[\sqrt{2} \sqrt{E \hat{\beta}} (10^{+3}) + \hat{C}O + c\hat{l}_{\text{beam-dump profile}} + c\hat{l}_{\text{dump profile-wall}} \right] \\ & + (1/2) (X_p/\hat{X}_p) [\hat{X}_p (1.7 \cdot 10^{-2}) \cdot 10^{+3}] \quad \text{where, sequentially;} \end{aligned}$$

- a) an instantaneous emittance enlargement of a factor of 2 is assumed after injection. Even though this will be eliminated by beam scraping and compensated for by the stacking process, the aperture allowance must be made.
- b) CO (closed orbit) errors. These errors have been evaluated in an earlier study for a similar superconducting ring device.^{15,16} Using appropriate scaling, the partially corrected closed orbit errors adopted for the ISA are: $\hat{C}O_H = 5.2$ mm, at $\beta = \hat{\beta}_H$ and $\hat{C}O_V = 3.0$ mm, at $\beta = \hat{\beta}_V$.
- c) Dump profile. The dump profile, an orbit amplitude function $F_d(\beta, X_p)$, has been adopted as a hypothetical maximum beam envelope, anywhere in the ISA, outside of which no "beam" would be allowed; and which defines the minimum acceptance of the protective dump extraction channel. An additional amplitude function $F_t(\beta, X_p)$ is required, satisfying: beam size $(\beta, X_p) < F_t(\beta, X_p) < F_d(\beta, X_p)$, and which, when exceeded, would trigger the protective extraction sequence. Because of inherent delays between detecting anomalous beam growth or anomalous orbit behavior and inherent delays in executing the protective extraction sequence, $F_t(\beta, X_p)$ must be smaller than $F_d(\beta, X_p)$.
- d) A value of 3 mm has been adopted for $c\hat{l}_{\text{beam-dump profile}}$ at a $\beta = \hat{\beta}$ value.
- e) Some extra beam-wall clearance is adopted to insure further that at no time the "beam" would impact with the cold wall and to provide for a minimum separation between the beam and its electromagnetic wall images. A value of $c\hat{l}_{\text{dump profile-wall}}$ of 5 mm at $\beta = \hat{\beta}$ has been adopted.

- f) Momentum dispersion. This last term scales the momentum stack width with the local X_p value. In a regular lattice structure one could combine this second term with the first term in the aperture expression since X_p is proportional with $\sqrt{\beta}$. In order to maintain applicability in the ISA momentum matching cells, and insertions where $X_p = 0$, it is given the present form. (For the vertical aperture the last term equals zero, since for the presently adopted horizontally oriented ISA structure $X_{p,V} = 0$ everywhere in the lattice.)
- g) Dipole sagitta. The magnitude of the dipole sagitta value is 6.5 mm (half amplitude).

Substituting values, it follows that the adopted value of 80 mm dipole aperture is just adequate for the horizontal aperture requirement and more than generously adequate vertically. The ISA aperture subdivision for the rebunched stack, at essentially injection energy, is shown in Fig. 8 for the "design" beam of 1.7% ($\Delta p/p$) and $A_H = A_V = 0.4 \pi 10^{-6}$ rad-m.

For a completely corrected machine, i.e. $\hat{C}0 \leq 1$ mm the maximum stack width could be 2.2% ($\Delta p/p$).

The dump profile follows readily by using part of the aperture relationship given above, again substituting numerical values, as:

$$F(\beta, X_p)_{dp} = \begin{cases} a_{dp} = (2.2 \sqrt{\beta} + 8.5 X_p) 10^{-3} \\ b_{dp} = (1.8 \sqrt{\beta}) 10^{-3} \end{cases}.$$

Further, since smaller aperture quadrupole magnets in the experimental insertions are desirable in order to arrive at more favorable crossing domain geometries, it may also serve to state, for first order guidance, the aperture requirement anywhere in the ISA, $F(\beta, X_p)_A$, as follows:

Fig. 8

ISA aperture subdivision for the bunched, injection energy, stack

at $\beta_x = 40 \text{ m}, \beta_y = 8 \text{ m}, X_p = 1.7 \text{ m}$
with $A_H = A_V = 0.4 \pi 10^{-6} \text{ rad-m}$

dump profile; $F(\beta, X_p)_{dp}$ given by (see text)

$$a_{dp} = (2.2 \sqrt{\beta} + 8.5 X_p) 10^{-3}$$

$$b_{dp} = (1.8 \sqrt{\beta}) 10^{-3}$$

$$F(\beta, X_p)_A \equiv \begin{cases} a_A = (2.9 \sqrt{\beta} + 8.5 X_p) 10^{-3} \\ b_A = (2.6 \sqrt{\beta}) 10^{-3} \end{cases} .$$

(For the "20 m" quadrupoles in the insertions, this would mean a full aperture of 70 mm for the standard insertion.)

Having established the definition of the dump profile, it is relevant now to check if within this amplitude function, beam injection and stack formation can take place, since, a priori, the same criteria related to protective beam dumping and minimum aperture requirements apply during the stacking process. Inherently, the only critical locations are at $\beta = \beta_H$ and $X_p \approx \hat{X}_p$; or, at the injection kicker location. The details of the ISA aperture subdivision during beam stacking, at this location, are shown in Fig. 9. It is evident, that no significant allowance exist for horizontal closed orbit errors during the stacking process, since the clearance between the design beam without errors and the dump profile here is 5.5 mm whereas the corresponding minimum clearance between the beam with errors and the dump profile adopted above is 4 mm. Consequently, the full stack momentum spread (unbunched beam) of 0.7% for the design beam will only be possible with a fully corrected machine ($\Delta O_H \lesssim 1.5$ mm). An alternative, a somewhat more hazardous approach, is to accept a larger amplitude dump profile during the injection and stacking process only and to reduce this to the above defined $F(\beta, X_p)_{dp}$ after the unbunched full stack has been centered. The details of the "beam" profiles are given in Fig. 10.

It is evident that the magnitude of the local dispersion function is dominant in determining the overall beam size. This is further illustrated in Fig. 11 where the horizontal beam size of the design beam and its location in the ISA aperture is plotted versus X_p (assuming a fixed β_x value). Using these data and taking into account the minimum separation between injected beam and the "high" density edge of the stack (16 mm) because of kicker stray field considerations, it follows that the injection kicker would need to be located at an X_p value of

Fig. 9

ISA aperture subdivision during beam stacking at the injection
kicker location

at $\beta_x = 40 \text{ m}$; $\beta_y = 8 \text{ m}$; $X_p = 1.7 \text{ m}$

with $A_H = A_V = 0.4 \pi 10^{-6} \text{ rad-m}$

Note: Prior to stack rebunching, the beam would be centered by field adjustment. Simultaneous with rebunching the beam would be scraped to the 0.7% high density stack only.

Fig. 10
ISA "Beam" Profiles

Fig. 11

≥ 1.7 m and that in the lattice dipoles an X_p value of 1.7 m should not be exceeded. These, for a regular lattice structure, almost contradicting requirements, are satisfied with the present ISA lattice design and injection arrangement.

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