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BEAM TRANSFER FROM THE AGS TO ISABELLE*

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Introduction and Summary

The ISABELLE design current is built up by repetitive transfer of charge from the AGS.[1] To do this, a momentum stacking method similar to the one used at the ISR has been chosen. The AGS beam bunches are synchronously transferred from the AGS into waiting rf buckets on the injection orbit at the ISA, and then slowly accelerated into the previously established debunched beam stack. This process is repeated until all the available momentum aperture in the ISA is filled up, whereupon the beam stack is rebunched and accelerated to the desired operating energy.

ISABELLE is located to the north of the AGS in sucy a way that an existing beam extraction system and part of an existing experimental beam transport tunnel can be used. The AGS extraction system is being redesigned to assure precise fast extraction of the required number of AGS bunches. The extracted beam is directed toward one of the ISA straight sections ("6 o'clock") and then bent toward the outer arcs of the two ISABELLE rings (see Fig. 1). The ISA injection system deposits the beam on the proper orbit in the ISA vacuum chamber. In the following, each of these three systems is described in turn. The synchronization of the AGS and the ISA and the accuracy requirements for the beam transfer process are discussed in the last section.

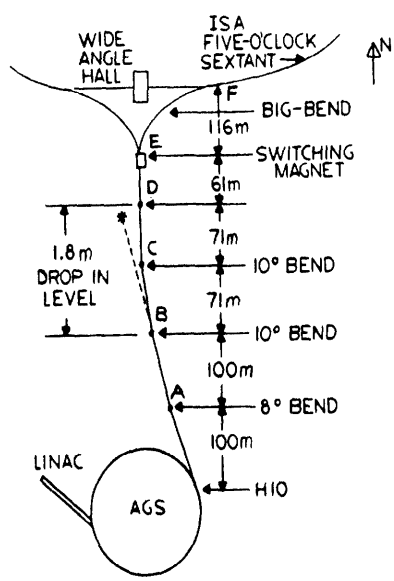

Fig. 1. Schematic layout of the AGS-ISA beam transfer geometry.

The injection line described here supercedes the earlier design published in the new 1978 ISABELLE Proposal.[1]

AGS and ISA Parameters

The AGS rf system operates at the 12th harmonic of the revolution frequency and it will be synchronized with the ISA stacking rf system which will accept bunches from the AGS at the same frequency. The circumference of the ISA ring is 4.75 times that of the AGS, thus the stacking system has harmonic number h = 57. It is proposed to extract 11 AGS bunches at a time (the 12th being knocked out prior to AGS acceleration) five times in succession to fill 55 of the 57 waiting ISA buckets. These 55 bunches are accelerated toward the momentum stack. This process requires several hundred AGS pulses to achieve the design current of 8 A (6×10^{14} protons) in each ring.[1]

The parameters of the AGS, when used as an ISA injector, are summarized in Table I. It is thought that the high beam brightness in transverse phase space is best obtained by running the AGS at relatively low intensity.

Table I. AGS Parameters

Energy	29.4 GeV
Intensity/Pulse	2.7×10^{12}
Momentum Spread	$\pm 0.5 \times 10^{-3}$
Vertical Emittance	$0.5\pi \times 10^{-6}$ rad-m
Horizontal Emittance	$0.5\pi \times 10^{-6}$ rad-m
Longitudinal Emittance	1.06 eV sec/bunch

Figure 2 summarizes the utilization of the ISA aperture (88 mm) at a point in the lattice where the momentum dispersion is at a maximum. The width of the full beam stack corresponds to a momentum spread of 1% full width.

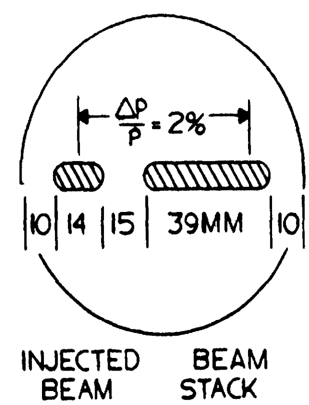

Fig. 2. Aperture utilization at the injection kicker.

Extraction From the AGS

The configuration of the proposed new AGS extraction system is outlined in Fig. 3. Before extraction a local 3/2 wavelength orbit deformation will bring the circulating proton beam into the aperture of a C-type fast kicker magnet (KM) located at straight section H5. The same bump will also align the beam as close as possible to the ejector septum (EM) located at H10. At extraction the kicker magnet will be powered to kick the beam into the aperture of the EM, which in turn deflects the beam out of the AGS. At the straight section H13 the separation of the external beam and the circulating beam is about 43 cm and the AGS magnet fringe field is negligible. Therefore, it is convenient to consider this location as the exit point from the AGS. An existing extension of this line, incorporating a 4^o bend and a superconducting 8^o bending magnet, direct the beam out of the AGS tunnel toward the North. The only new components in this system to be built in the future are the fast kicker KM at H5 straight section, and the local orbit bump. All other components and facilities already exist.

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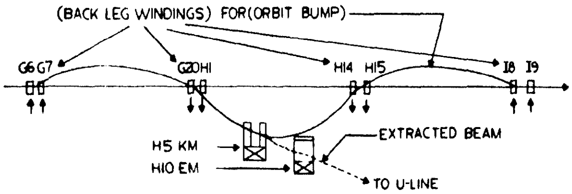

Fig. 3. The sketch of the proposed AGS new fast extraction orbits and components.

To provide clean single turn extraction the fast kicker will rise to full field in 150 nsec, i.e. less than the bunch to bunch separation of 225 nsec. The fast kicker deflection angle will be 1.2 mrad at 29.4 GeV energy, and the flat top of the kicker will be constant to within approximately ± 1%.

The theoretical emittance parameters of the extracted beam at the extraction point H13 are summarized in Table II.

Table II. Parameters at H13 Fast Extracted Beam

		Horizontal	Vertical
Admittance		$2\pi \times 10^{-6}$ rad-m	$2\pi \times 10^{-6}$ rad-m
Twiss Param.	β	31.1 m	7.47 m
	α	-3.362	1.244
Dispersion		2.96 m	-

The large admittance value makes allowance for full intensity AGS operation. The momentum dispersion is not zero at the extraction point,[2] but it is desirable to cancel the dispersion in the long straight portions of the subsequent beam transfer channel. Between the 4^o and the 8^o bend in this early part of the transport line there are five quadrupoles which are adjusted in such a way that the beam is well confined to pass safely through the superconducting magnet aperture, and is achromatic at its exit.

Beam Transfer AGS-ISA

In this section we discuss the beam transfer proper between the exit of the 8^o bend near the AGS and the special injection magnet system at the ISA. The beam is dispersion-free at the beginning of this line and by the time it reaches the ISA injection point, it must be matched in all aspects to the parameters of the ISA lattice. The geometry of the transport line is illustrated in Fig. 1. In the horizontal plane the beam has to be deflected twice; first to aim toward the ISA straight section center (2 x 10^o bend) and again towards the two injection points (81.5^o bend). In the vertical plane it is necessary to overcome an elevation difference of 1.8 m.

The injection geometry described differs from the earlier published plans in that only one straight section (rather than two) is used and the injection line is not seen at all by the users of the experimental hall. To accomplish this the ISA rings were rotated 30^o compared to the 1978[1] design proposal.

For each 10^o horizontal bend, we use four 3 m-long dipoles with field strength ~ 1.4 T. For the vertical pitching, we use two small dipole magnets. Each of them is 1.5 m long and capable of bending 12.7 mrad. The vertical drop starts at the same position as the first 10^o horizontal bend. In order to make the two 10^o horizontal bends achromatic, the phase advance between them is made to be exactly 180^o and for the same reason the phase advance between two vertical bends is exactly 360^o.

This is achieved by placing eight quadrupoles from points B to D in a FODO pattern (see Fig. 1). Each quadrupole is 0.7 m long with field gradient G = ± 9.5 T/m. Thus in the space between B and D, there are four FODO cells with phase advance per cell 90^o and cell length 35.5 m. Beyond point D the beam is again dispersion free and the straight space between D and E of 60 m is used for matching into the big-bend.

At the beginning of the big-bend is a switching dipole which is capable of switching the incoming beam either into the right arc or the left arc of the big-bend. From E to F the total length of the big-bend is 174.4 m. The total angle of bend is 81.5^o and the average radius of curvature is 105 m.

This part of the transfer is achieved by eight FODO cells too. The lattice structure of a unit cell is illustrated in Fig. 4. Again, the phase advance per cell is 90^o with quadrupole of length 0.8 m and excitation of G = ± 20 T/m. The cell length is 18.5 m and between quadrupoles there are bending magnets of 6 m long with 1.7 T excitation. As shown in Fig. 4, the maximum betatron function in the cell is 30 m in both planes and the maximum momentum dispersion function is 2.3 m. If we split the dipole into two pieces, the maximum sagitta in 3 m is 1 cm.

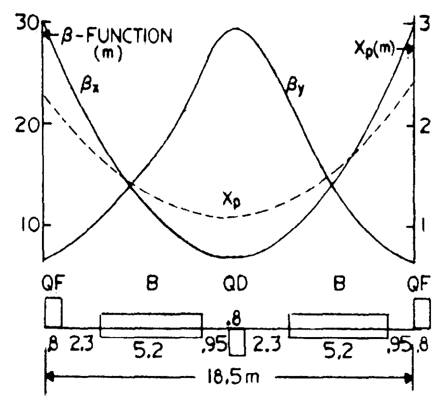

Fig. 4. Unit cell structure of the big-bend.

The final cell upstream of the first thin septum magnet for injection is slightly modified in order to match up the betatron function of the ISA lattice. To the first order approximation, we only have to omit the bending in the last cell to match the momentum dispersion function; however, in actual design there are two small dipoles for guaranteeing the exact dispersion match. Two meters upstream of the first septum magnet (Fig. 5), the dispersion function is zero. Here a small steering magnet is introduced to direct the off-momentum injected beam into the correct orbit in the ISA.

For the consideration of physical aperture of the magnets, we assume that the emittances in both horizontal and vertical planes are 2 π μm-rad at 30 GeV/c and intensity 10^{13} ppp. The momentum acceptance of the transfer line is assumed to be $\Delta p/p$ = ± .3% from the AGS to point D and ± 1% from D to the ISA. Thus the big-bend section can accommodate the entire acceptance of the ISA. This reserves flexibility for later developments. The resultant maximum aperture needed for the dipole magnets from A to D is 3 cm (V) x 10 cm (H) and that from E to ISA is 3 cm (V) x 12 cm (H).

ISA Injection

The beam is inserted into the outer arcs of the ISA utilizing the free spaces between the quadrupoles Q5-Q7 in the dispersion matching section between the straight section and the regular ISA bending lattice. Figure 5 illustrates the method. The beam approaches the ISA horizontally, about 2.5 cm above the median plane, and is deposited above the injection closed orbit by means of the horizontal septum S and the horizontal Lambertson septum LS upstream of the lattice quadrupole Q6. A vertical trim septum T and the partial aperture vertical fast kicker K bring the beam to a vertical landing on the injection orbit near Q7. Only the injection orbit is covered by the field region of the kicker. The injected beam is accelerated out of the kicker aperture into the stack through an open pole in the magnet.

Figure 5 illustrates the situation depicted in Fig. 2 when the momentum offset of the injection orbit is $\Delta p/p = -1\%$ and the stack is at higher momentum. If it should be desirable to inject at high momentum and decelerate into the stack, one may move the kicker over the centerline and readjust the injected beam trajectory horizontally by means of the Lambertson septum LS and a horizontal trimming dipole (not shown) located between the septum S and the last transfer line quadrupole Q. The aperture of all injection magnets (other than the kicker) are large enough to accept the full ± 1% momentum acceptance of the ISA.

The essential parameters of the injection magnets are summarized in Table III.

Table III. Injection Magnet Parameters

	θ (mrad)	B (T)
Kicker K	1.6	0.08
Trim Septum	~ 0.4	.08
Lambertson Septum LS	20	.67
Septum S	~50	1.3

The septum magnets will be pulsed with a pulse duration of approximately 10^{-3} seconds. The fast kicker will have a risetime to full amplitudes of ~ 150 nsec to permit successive insertion of five pulse trains from the AGS with the bunch to bunch separation of 225 nsec.

Tolerance Considerations

The necessity of avoiding beam dilution due to coherent motion imposes quite stringent tolerances on various parameters of the injection and beam stacking cycle. For example, in the transverse space an error of 1% in the injection kicker angle will introduce coherent motion amounting to a dilution of the vertical emittance area ($\varepsilon = 0.5 \times 10^{-6}$ rad-m) by about 20% (at the kicker $\beta_v = 14$ m). There are many sources of error of this kind in the beam transfer line and a discussion of all of them is not appropriate here. It is necessary to take two precautions: We allow for a "target zone" on the injection orbit and in the injection beam equipment which accommodates twice the theoretical beam size and we plan to install a transverse feedback mechanism in the ISA to damp these error oscillations down.

In longitudinal phase space it is important that all bunches be properly centered in their buckets before the stacking cycle begins: Energy error $\delta E/E$ and phase error $\delta\varphi$ have to satisfy $((\delta E/E)/(\Delta E/E))^2 + (\delta\varphi/\Delta\varphi)^2 \leq 25 \times 10^{-4}$ if the reduction in density, thus in total current in the circulating beam, due to these errors is to be kept below 10%. Given the amplitudes of the deviations in relative energy and in phase in the nominal bunch of $\Delta E/E$ ($\approx 5 \times 10^{-4}$) and $\Delta\varphi$ (≈ 0.6 rad), it follows that the central energy of individual bunches has to be correct to within $\pm 1.8 \times 10^{-5}$ and the phase to within ± 21 mrad for a dilution factor of 10%. Note that the loss in luminosity goes as the square of the loss in beam current: The two empty buckets mentioned before and a dilution factor of 10% together reduce the luminosity by 26% from what it might be.

Synchronization of the AGS rf frequency to that of the ISA will use a phase locked loop. It is expected that the phase error $\delta\varphi$ can be kept below the $\pm 1.2^{\circ}$ tolerance mentioned above. Control of the AGS magnetic field on the ejection flat top will be by means of a closed loop incorporating an integrated $\dot{B}$ signal and voltage to frequency converter. A reproducibility of $\leq 10^{-4}$ in B is the design goal. Any remaining dipole oscillations in the ISA buckets will be controlled by a feedback loop. Matching of the bunches to the buckets in the ISA will be performed in the AGS prior to extraction. Errors will be corrected by damping coherent quadrupole bunch oscillations in the ISA. Precise control of the AGS bunch area will be necessary in addition to intensity control so that the optimum longitudinal density for the ISA can be obtained. A study of various methods of programmed dilution acting prior to reaching the transition energy is planned. A range of $\approx .5$ to 1.5 eV sec/bunch will be the initial design goal.

References

1. ISABELLE Design Proposal, BNL 50718 (1978).
2. W.T. Weng, BNL, Internal Report, AGS DIV 78-2 (1978).

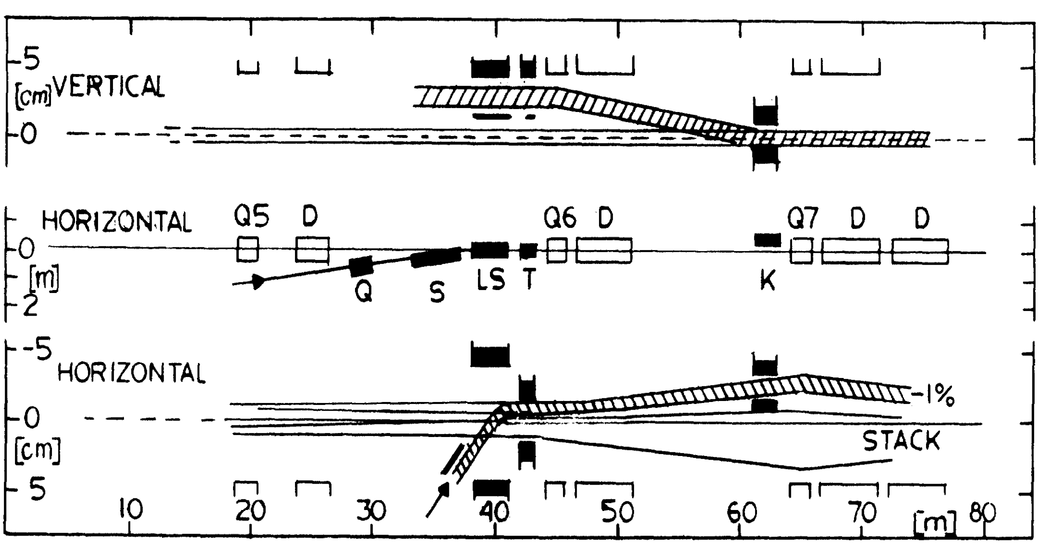

Fig. 5. Layout of the ISA injection trajectories, beam envelopes, and components.