BROOKHAVEN NATIONAL LABORATORY
Associated Universities, Inc.
Upton, New York

ACCELERATOR DEPARTMENT
Informal Report

VERTICAL BEAM STACKING IN ISABELLE

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December 10, 1971

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CRISP 71-52
ISABELLE PROJECT

INTERSECTING STORAGE ACCELERATOR NOTES

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The beam emerging from the AGS has phase space half amplitude areas of $0.8\pi (\mu\text{rad-m})^2$ vertically and $3.0\pi (\mu\text{rad-m})^2$ horizontally. Transverse phase space interchange in the transport line must be employed in order to rotate the smaller phase space area into the horizontal plane. With the stacking scheme described in CRISP 71-39 the full horizontal aperture can be filled by simply continuing the stacking process. As horizontal orbit errors are reduced, more intense beam stacks can be assembled. Figure 1 shows the proposed 50 mm aperture modified by the sagitta resulting from straight magnets assembled along a circle. The shaded area represents the area occupied by a single turn of beam at the beta values indicated. The unshaded areas shown are those resulting from the vertical stacking procedure to be described.

If the vertical extent of the beam is no greater than the shaded areas of Fig. 1, unused vertical space will remain.

The following is a set of principles around which the method is generated:

1. No mechanically moving parts in the vacuum system. This is done for simplicity and reliability.
2. All partial aperture vertical kickers are to be switched slowly (i.e., milliseconds). This requirement results from the need to laminate structure for faster switching and the system configuration (see Fig. 2) of these kickers is too thin to easily hold these laminations. Ferrite could be used, but the maximum field that could be employed would be greatly reduced making the kicker excessively long.
3. Fast (i.e., nanoseconds) full aperture, ferrite kickers can be employed in match sets so as not to stir up betatron motion in beams already circulating. This principle will be examined.

The proposed arrangement of apparatus is shown in the lower sketch of Fig. 3. The horizontal kickers #1 and #2 form a set which deflects the beam into vertical kicker #1. Similarly, horizontal kickers #3 and #4 deflect beam into vertical kicker #2.

The sequence of events are as follows:

1. With the beam stack shown in the top of Fig. 1 already circulating in ISABELLE, horizontal kickers #3 and #4 are energized to place the equilibrium orbit for injection momentum into vertical kicker #2. The main stack which possesses a higher momentum will be displaced adjacent to the vertical kicker (see section bottom of Fig. 2). The vertical kicker has been energized to move this equilibrium orbit vertically to match the center of the beam exiting the inflector. Thus the beam exiting the inflector will pass through horizontal kicker #3, into vertical kicker #3, then on into horizontal kicker #4 and emerge properly centered on its equilibrium orbit. The horizontal kicker set is turned OFF after the beam has passed. This beam will stably circulate in ISABELLE occupying the shaded areas shown in Fig. 1.
2. When the AGS has cycled again and is ready to deliver a second beam charge, the injection system is switched to a second set of conditions. The beam is deflected into both vertical kickers. Vertical kicker #1 kicks the previously injected beam into the position shown in the top of Fig. 3 (shaded area). Vertical kicker #2 causes the vertical equilibrium for this injection momentum to pass tangent to the inflector septum. Thus this equilibrium orbit is centered between the previously injected beam and the second AGS charge which is now exiting from the inflector. The center of charge of the two beams is on the equilibrium orbit and on the next pass with the horizontal kicker off the total beam will occupy the area shown at the left hand rectangle in Fig. 1 (top and bottom).

Note: During the second cycle of the AGS the beam in ISABELLE is held by a small rf system (see CRISP 71-39) so that it will not spread azimuthally.

3. Two additional AGS charges are injected and vertically stacked in the other half of the circumference and the four charges are accelerated into the main stack as described in CRISP 71-39.

The vertical extent of the beam is a tight fit in the vertical aperture. In fact the corners are chipped by the horizontal sagitta of the magnet array. There is no reserve for magnet alignment errors. Some of the second charge will therefore be lost. The amount will depend on the accuracy of the vertical alignment. Vertical alignment is easier to control than horizontal alignment. As alignment improves and beam tuning skills develop, more beam will be captured.

Since the horizontal kickers are full aperture kickers, they kick the assembled main beam stack. If the kickers that form the $\lambda/2$ horizontal sets are not matched or if the separation is not exactly a half wave length of horizontal betatron motion, a residual horizontal betatron motion will be included in the main beam stack. Matching the amplitude and electrical wave shape of the kicks is an engineering problem and with sufficient effort they can be matched to better than 1%. The $\lambda/2$ separation of the kickers that form a set must be carefully engineered in the magnet lattice of this region. A small quadrupole adjustment can provide vernier control. Other small full aperture horizontal kickers can be provided for further control of the residual betatron motion of the main stack. These can be operator or computer directed. Finally, fast electronics can be used to electronic damp this coherent motion. Such damping must occur in a few revolutions otherwise coherence will be lost due to small differences in horizontal v for particles of different momentum in the main stack.

The residual betatron motion induced by the raw process (without the electronic or computer refinements described above) can be estimated for this typical case.

The basic parameters are:

Kick amplitude (horizontal β min)	= 6.5 mm
Wave shape match (2 sets)	= 2%
Fraction of circumference occupied	= 8%
Number of kicks	= 30

Residual amplitude at a β min point is therefore the product of these quantities which is 0.3 mm. At a horizontal β max point the residual amplitude becomes 0.8 mm. These are acceptable values.

The vertical kickers are partial aperture devices and do not act on the main stack, therefore, the tight requirement described above does not apply.

The vertical kickers must be located at a horizontal β minimum. The inflector must be located at a vertical β minimum. If these locations are slightly off the desired vertical $\lambda/4$ separation, a small error in phase space will occur due to the additional phase rotation, but this coefficient is a cosine function of the error thus permitting some angular error without large amplitude error.

This vertical stacking method has been described in conjunction with horizontal momentum stacking described in CRISP 71-39. It can also be employed in conjunction with the Blewett-Courant "boxcar" stacking scheme. In this case each rf bucket is loaded with two vertically stacked AGS charges instead of only one. The only difference is in the switching times required. In the "boxcar" scheme 50 to 70 nsec of time exists between adjacent beam bunches whereas with the momentum stacking, 500 nsec exists between AGS charges. This will require 7 to 10 times more voltage on the horizontal kicker magnet and may alter the choice of ferrite material. The magnitude of the kicks required and hence the voltage required are dependent on the magnet lattice.

The vertical kicker has a iron septum which is assumed to be solid for this analysis. If the septum is 1 mm thick and has a half height of 15 mm, the maximum magnetic field that can be supported in the gap is 1000 gauss (assume 15 kG iron saturation). If the gap height is 17.5 mm the ampere-turns required to excite this field is 1.4×10^3 . The kick amplitude of these vertical kickers are altered between cycles of the AGS which may require 1.5 to 2 seconds. Thermal consideration of the kicker coils may shorten the switching time requirement to the order of tens of milliseconds. This is compatible with the choice of solid iron for the septum. The remainder of the core may be laminated.

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Fig 1

Fig 3