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

ACCELERATOR DEPARTMENT
Informal Report

MASTER

AN ALTERNATE BEAM STACKING AND
RF PARAMETERS FOR ISABELLE

J.G. Cottingham

November 9, 1971

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Accelerator Department
BROOKHAVEN NATIONAL LABORATORY
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CRISP 71-39
ISABELLE PROJECT

INTERSECTING STORAGE ACCELERATOR NOTES

AN ALTERNATE BEAM STACKING AND RF PARAMETERS FOR ISABELLE

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Introduction

Let us consider the following stacking procedures:

1. Reduce the AGS beam momentum spread in the AGS by adiabatic reducing the rf accelerating voltage. The momentum spread will reduce as the beam spreads in azimuthal extent.
2. Using the beam kicker and thin septum now under development, a single turn beam is extracted from the AGS and injected into ISABELLE. This ribbon of beam will occupy less than half of the circumference of the storage ring (10/24).
3. This beam is held in ISABELLE by an rf bucket fitted to the phase space shape of the beam delivered by the AGS.
4. Beam from the next AGS cycle is injected into the remaining circumferential space and capture in the previously empty rf buckets.
5. With this small rf system the beam is slowly accelerated to the stacking momentum. This process is repeated to form the final stack in a manner identical to that employed in the ISR at CERN.
6. A final rf system adiabatically captures the total stack and accelerates it to final energy.

Numerical Analysis

Step 1.

Figure 1 shows the energy damping that results from reducing the rf accelerating voltage adiabatically. (Reduced 30% per radian of small signal synchrotron frequency.) Note: The starting phase space ellipse is about twice the starting condition chosen by E.D. Courant in CRISP 71-5.

At 430 milliseconds the momentum spread has reduced to ± 165 ppm. The starting ellipse assumed in CRISP 71-5 would reduce to ± 80 ppm under the same conditions.

Step 2.

The "thin septum" is 0.015 in. thick if only the magnetic part exists and is very small if the electrostatic part exists. A beam with a momentum spread of ± 165 ppm will occupy 0.022 in. of radial space. The sum (0.037 in.) is the total kick required to extract this beam. The "beam kicker" has a slewing rate of 2.8 in. per microsecond maximum. Thus, 0.0132 microseconds is required to sweep this beam through the septum. This is about $\frac{1}{2}\%$ of a revolution.

Steps 3, 4 and 5.

Figure 1 shows the synchrotron phase space shape of the beam in the AGS after certain adiabatic debunching (namely, the curve labeled 430 msec). The beam shape described is nicely contained (except for small edges) in an rf bucket in ISABELLE generated by the following rf system:

$h = 29$

freq. = 4.45 MHz

voltage = 87.9 volt peak to peak per revolution

stable phase point - zero

The beam from one revolution from the AGS would occupy 12 of the 29 available rf bucket. The next AGS cycle will fill 12 more buckets with beam. The rf accelerating voltage could then be adiabatically increased to a few hundred volts and the beam accelerated by frequency change to move the beam to the region of the vacuum desired for the final stack. This process is identical with that presently employed at CERN.

The change in frequency required for the stacking rf system is approximately given by:

$$\frac{\Delta f}{f} = \frac{\Delta R}{R} = \frac{.0254}{220.06} \approx 1 \times 10^{-4}$$

(this approximation ignores changes in β).

A fixed tuned rf cavity with modest Q (500 or less) will accommodate this frequency change. Power delivered to beam is only a few hundred watts.

Since this rf system is small, further design details will be left until later.

Figure 2 is a plot of rf bucket total width vs the ratio of V/h and is repeated for several values of v . For $v = 17.3$ the equation is

$$\frac{\Delta p}{p} = 1.89 \times 10^{-4} \sqrt{V/h} ,$$

where V is crest voltage and h the harmonic number.

Similarly, Fig. 3 displays the relationship of the synchrotron frequency to the product Vh .

$$f_{\text{syn}} = 0.0172 \sqrt{V/h} \text{ for space } v = 17.3 .$$

Step 6.

The bucket width of the final rf accelerating system depends on the momentum spread in the final stack. The momentum spread in the final stack depends on assumed conditions in the AGS. The following Table outlines possibilities:

AGS Beam Intensity	Total Momentum Spread ($\Delta p/p$)	
	Momentum Spread in AGS	
	$\pm 80 \text{ ppm}$	$\pm 165 \text{ ppm}$
1×10^{13}	0.0048	0.0124
2×10^{13}	0.0024	0.0067

The above make no allowances for jitter and electronic precision.

The following Table relates harmonic numbers (h), momentum spread ($\Delta p/p$), rf crest voltage (V), synchrotron and rf frequencies (f_{syn} , f_{rf}).
(Table based on $v = 17.3$ and $\theta_0 = 0$.)

h	f_{rf}	$\Delta p/p = 0.015$		$\Delta p/p = 0.02$		$\Delta p/p = 0.025$		$\Delta p/p = 0.03$	
		V	$f_{\text{(syn)}}$	V	$f_{\text{(syn)}}$	V	$f_{\text{(syn)}}$	V	$f_{\text{(syn)}}$
4	618 kHz	26.0 kV	5.5 Hz	46.2 kV	7.31 Hz	72.2 kV	9.1 Hz	104 kV	10.96 Hz
3	464	19.5	4.11	34.6	5.48	54.1	6.85	78	8.22
2	309	13.0	2.74	23.1	3.65	36.1	4.57	52	5.48
1	154	6.5	1.37	11.5	1.82	18.0	2.28	26	2.74

The energy gain per turn required to reach 200 BeV in 100 seconds is 11 kV: A crest voltage at least twice this value is required ($\theta_o = 30^\circ$). The largest bucket ($\Delta p/p$) created by this voltage is desirable. This gives a unique design. ($h = 1$, $V = 26$ kV, $\Delta p/p = 3\%$, $f_{(rf)} = 154$ kHz, $f_{syn} = 2.74$ Hz.)

Cavity Design

If beam bunching occurs before acceleration starts, i.e., on a magnetic flat top, the stable phase angle is zero. The current presented by the beam will look reactive to the cavity and will act to detune it. The amount of detuning is given by

$$\Delta g = \frac{I_{beam} f_o}{2I_{cir}} ,$$

where I_{cir} is the reactive circulating current in the tank circuit of the cavity.

The bandwidth of the cavity is given by

$$\Delta f = \frac{f_o}{Q} ,$$

r , defined as the ratio of detune to bandwidth

$$r = \frac{\Delta g}{\Delta f} = \frac{I_{beam} Q}{2I_{cir}}$$

$$C = \frac{1}{2\pi f_o X_c} \text{ where } X_c = \frac{V}{I_{cir}}$$

therefore,

$$C = \frac{I_{cir}}{2\pi f_o V} = \frac{1}{2\pi f_o} \cdot \frac{I_{beam} Q}{2r V}$$

$$P = \frac{\frac{1}{2}CV^2 2\pi f_o}{Q} = \frac{I_{beam} V}{4r} .$$

Example

$h = 1$, $f_o = 154$ kHz, $V = 26$ kV peak. Let us choose $Q = 30$, $r = \frac{1}{2}$, number of gaps = 2.

The magnitude of the first Fourier coefficient of the beam current will depend on the form of the bunch. This coefficient is less than one for all bunch shape except those bunched in narrow bunches. Since this cannot exist, a Fourier coefficient of unit is conservative.

-5-

Therefore, $I_{\text{beam}} = 6 \times 10^{14} \times 1.6 \times 10^{-19} \times 154 \times 10^{+3} = 15 \text{ amps.}$

$$I_{\text{cir}} = \frac{I_{\text{beam}} Q}{r} = 900 \text{ amps}$$

$$C = 35700 \text{ pF}$$

$$L = 29.84 \text{ } \mu\text{H}$$

$$J = \frac{1}{2} CV^2 = 3.02 \text{ joules}$$

$$P = 97 \text{ kilowatts .}$$

Cavity must be ferrite loaded since an air core cavity would be very large. Let us assume two rectangular cores with an air gap and assume all the energy to be stored in the air gap

$$\text{air gap height} = \ell = \frac{4\pi I}{B}$$

if we assume B to be 1000 gauss maximum then $\ell = 0.28 \text{ cm.}$

$$\text{energy stored} = J = \frac{B^2 A \ell}{8\pi}$$

where A is cross-sectional area of ferrite. Therefore, $A = 1343 \text{ cm}^2$, which is typically two cores each $22 \times 30 \text{ cm}$ in cross-sectional dimension.

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r.f. Bucket width $(\frac{\Delta p}{p})$
vs

r.f. crest voltage and
harmonic number

V = crest r.f. Voltage
 h = harmonic number
 p = momentum

CASE $v=15$

$$\frac{\Delta p}{p} = 1.8756 \times 10^{-4}$$

$v=17.3$

Fig 2

Synchrotron freq.
v.s.
r.f. crest voltage
and harmonic number

Synchrotron freq.
v.s.
r.f. crest voltage
and harmonic number

2

Fig. 3

$V \times h$

10^7