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ISABELLE PROJECT

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INTERSECTING STORAGE ACCELERATOR NOTES

MASTER

BEAM BUNCHING IN THE AGS THROUGH THE USE
OF PULSE EXCITED ACCELERATING CAVITIES

J.G. Cottingham

June 9, 1972

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BEAM BUNCHING IN THE AGS THROUGH THE USE
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The beam in the AGS is accelerated in twelve bunches. These twelve bunches must be formed into a single bunch to be acceptable for transfer to ISABELLE. Dr. E.D. Courant and others have described (CRISP 71-5) schemes to accomplish this end. The first step in these schemes is to debunch the AGS beam so as to reduce its momentum spread to a very small value. Beams with small momentum spreads are subject to collective instabilities. Dr. M.Q. Barton has pointed out that beam induced voltages are not negligible and may present control problems.

In contrast this beam bunching method moves the twelve beam bunches together in time without large reduction in the momentum spread of an individual bunch. The steps in this process are:

Step 1. Adiabatically reduce the rf accelerating voltage from 400 kV to 10 kV. This reduces the momentum spread of the AGS beam by only a factor of two.

Step 2. Turn on and capture the beam with the circuit shown in Fig. 1 which is a pulse excited resonant cavity tuned to 35.6 MHz (96th harmonic). Two identical cavities are required to generate a crest voltage of 6.4 kV. The minimum voltage required to contain the phase space region populated by the AGS beam after Step 1 above, is 3.76 kV. The excess voltage is necessary to cover phasing error and beam acceleration described in the following steps. Figure 2 shows the shapes of various electrical buckets relative to the beam populated region.

Step 3. The time interval between pulses is decreased in a carefully programmed manner. A voltage amplitude control system is necessary to keep

the crest voltage amplitude constant as this time interval is varied. This system can operate on the screen voltage as grid impulse width. Waveform distortion will result as one impulse moves over the ring of the previous impulse. Figure 3 shows in detail the waveforms that result in the worst case. This waveform series starts with an impulse every second rings, waveform #1, and moves to waveform #6 which receives an impulse each ring. Waveforms #7 and #8 result from impulses even more closely spaced (30% for waveform #8) with the amplitude increased to preserve the ratio of voltage to frequency. Waveform #8 is the drive limited case of the tube system studied (2 each 4CX15000A per cavity).

Step 4. At this time the beam containing an electrical bucket is adjacent in time as shown in Fig. 4. The existing sine wave rf system can now be re-energized at 2.59 MHz ($h=7$) with 4 kV crest voltage. This produces the electrical bucket also shown in Fig. 4. The rf voltage is then raised adiabatically compressing the total time width of the beam bunch by a factor of 2.5. A voltage rise to approximately 60 kV is required which is well inside the 350 kV ability of the present rf system at this frequency. The beam bunch is now 103 nanoseconds in width and has a $\Delta p/p$ of $\pm 2.12 \times 10^{-3}$. This compares with 102 nanoseconds and $\pm 2.46 \times 10^{-3}$ $\Delta p/p$ for previously described methods (CRISP 72-5, Feb. 8, 1972, p. 6).

Cavity Design

The new pulse driven cavity must develop the prescribed voltage in the presence of beam loading. Therefore, its resonant circulating current must be larger than the peak instantaneous beam current which is

$$I_b(\text{peak}) = I (\text{beam average}) \times \text{bunching factor}.$$

$$I_b = \frac{2 \times 10^{13} \times 1.6 \times 10^{-19}}{2.7 \times 10^{-6}} \times \frac{360}{20} = 21.3 \text{ amps}.$$

Let us choose a circulating current of 50 amps which results in a beam loaded slope change of the voltage waveform of 40%. The gap capacity is given by

$$C = \frac{i(\text{cir})}{\frac{dV}{dt}} = \frac{i(\text{cir})}{\omega V_{\max}} = 70 \text{ pF}$$

for $V_{\max} = 3.2 \text{ kV}$ (note, two gaps are required to develop the necessary 6.4 kV total voltage).

This design is built around two each Machlett 4CX15000A for each gap (4 tubes). This tube has an output capacity of 26 pf per tube. This leaves 18pF for the gap insulator and other stray capacity. To resonante with this capacity a structure 1 meter long having a characteristic impedance of 85 ohms is required.

The Q of this resonant structure must be reduced in order to prevent rapid phase changes in the voltage waveform as the pulse period passes through periods integrally related to the resonant period. A Q of 10 is used in this example and the computer study of waveforms, although this is not a sharply determined parameter. A 15 kW load is required to load the cavity to this Q.

Grid Drive

The drive pulse width should be equal to half the resonant period or 14 nanoseconds. The rise time must be of the order of 2 nanoseconds. This can be developed by a lump constant distributed amplifier employing four each type 7213 tetrode per 4CX15000A. (Sixteen each 7213 are required for the total system.) The anode distributed line has a characteristic impedance of 100 ohms. The output from this line is transformer coupled to a 50 ohm transmission line which drives the grid of the 4CX15000A directly. The anode line constants are $L = 0.2 \mu\text{H}$ and $C = 20 \text{ pF}$.

The grid lump constant line has a characteristic impedance of 17.5 ohms ($L = 0.035 \mu\text{H}$, $C = 115 \text{ pF}$). Only a 40 volt swing is required which can be developed by solid state circuitry (2N5994).

Time Bunching Process

Step 1 - Adiabatic Reduction of Rf Accelerating Voltage to 10 kV Level

This process can occur in 54 msec using a decay rate of 30% per radian of phase oscillation frequency.

Step 2 - Bunch Position Shifting

To move one bunch relative to another acceleration must occur. Only a limited voltage is available in the pulse induced bucket for this purpose (see Fig. 2). To be conservative let us limit the voltage available for acceleration to 1.5 kV which is a stable phase angle of 15 degrees. The shortest time to accomplish the desired total beam bunch motion occurs when the bunch is accelerated uniformly for half the distance then de-accelerated uniformly for the remainder.

$$\text{the acceleration, } a = \frac{dv}{dt} = \frac{d(\beta c)}{dt}$$

where: v = positional velocity
 c = velocity of light
 β = particle velocity/ c

$$\beta^2 = 1 - \left(\frac{E_o}{E}\right)^2$$

$$\frac{\partial \beta}{\partial E} = \frac{E_o^2}{\beta E^3}$$

$$\frac{\partial E}{\partial t} = V_a \times \text{number of turns per unit time}$$

$$= \frac{V_a}{\text{revolution period}} = \frac{V_a}{2.7 \times 10^{-6}}$$

where V_a = voltage available for acceleration.

$$\text{Therefore, } a = c \cdot \frac{d\beta}{dE} \cdot \frac{dE}{dt} = \frac{c E_o^2 V_a}{\beta E^3 2.7 \times 10^{-6}} = .4975 \text{ meters/sec}^2$$

$$\text{for } V_a = 1.5 \times 10^3 \text{ volts}$$

$$E_o = .9382 \text{ BeV}$$

$$E = 30.9382 \text{ BeV}$$

$$\text{the time to complete half the process, } t = \sqrt{\frac{2s}{a}},$$

$$\text{where } s = \frac{\text{circumference at AGS}}{4} = 201.78 \text{ meters}$$

$$t = .285 \text{ seconds or } 2t = .57 \text{ seconds for the total process.}$$

Step 3 - Adiabatically Compressing the Final Bunch

This process requires 76 msec running a 30% increase in voltage per radian of phase oscillation frequency.

The total time required for the whole process is 700 msec. This could be shortened by increasing the pulse induced voltage, if desired.

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Fig. 1

Fig. 2