October 23, 1963

BUNCHING FOR HIGH-INTENSITY LINACS*

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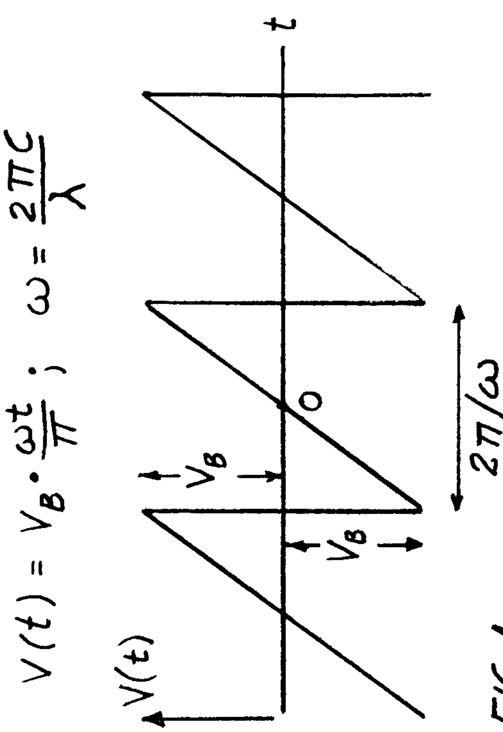
There are two equally important features to be achieved by a bunching system for high-intensity linacs: (1) high capture efficiency; (2) concentration of particles near the synchronous point in $(\Delta\varphi) - (\Delta\gamma)$ space. If the ion source can produce as much as 100 mA, it would be, in principle, possible to get a peak beam current of 20 mA without any buncher. However, it is essential that one keep the beam tightly bunched in the lower-frequency section (drift tube section) so that one can avoid undesirable beam loss at high energies when the frequency is increased by a factor of 4 or 5. Also, if the injected beam occupies a large area in the longitudinal phase space, "effective" transverse acceptance of the first tank would be reduced as indicated earlier by Swenson.

In order to get a very tight bunch with no long tails, a saw-tooth buncher operated at the linac frequency is the ideal solution. Figure 1 shows the applied buncher voltage as a function of time. Two cases of the perfect saw-tooth function are plotted

* Numerical calculations of this work have been done by M. Lockerd.



$V(t) = V_B \cdot \frac{\omega t}{\pi}$; $\omega = \frac{2\pi C}{\lambda}$
V(t)
V_B
V_B
O
t
$2\pi/\omega$

FIG.1

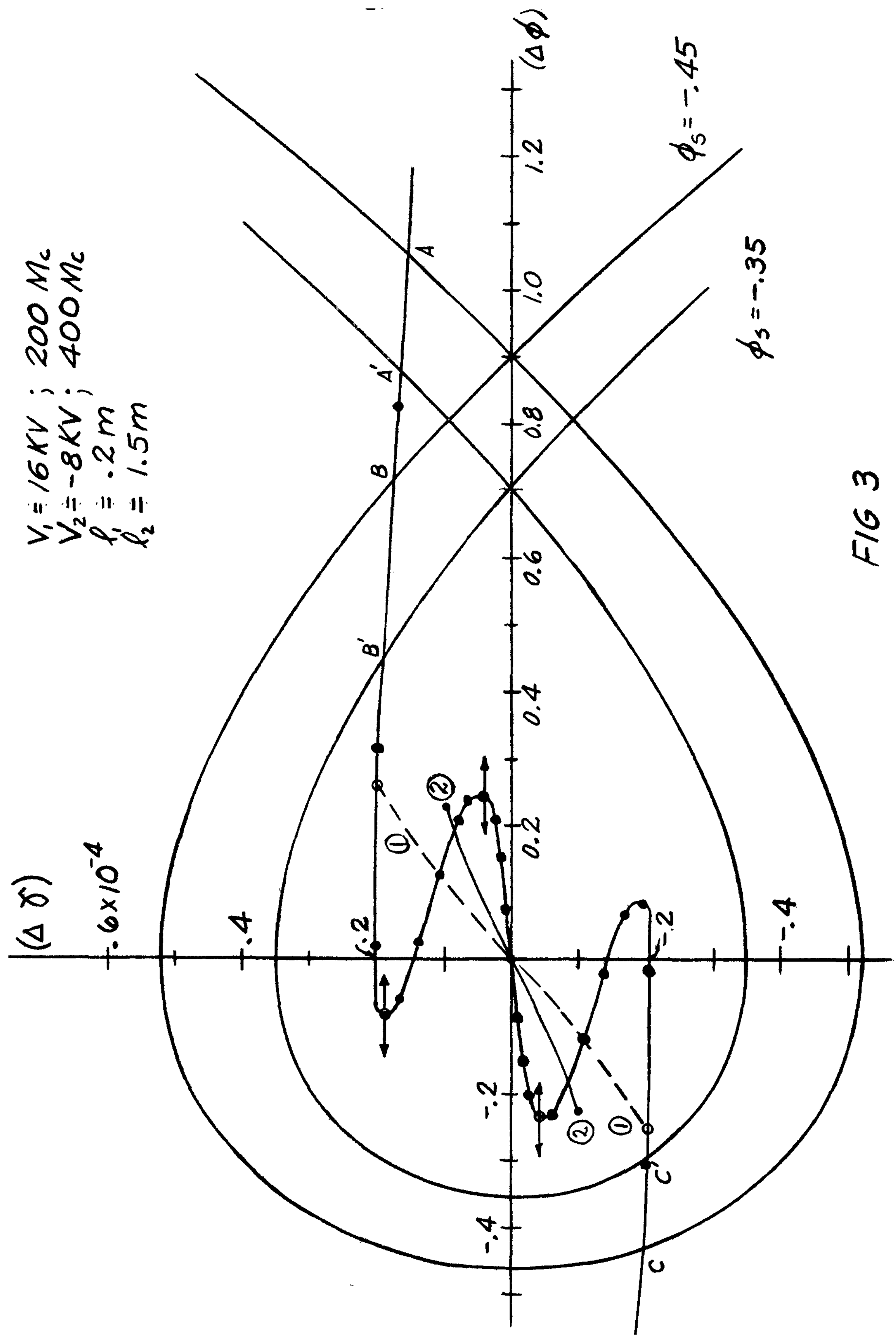
ℓ_1
ℓ_2
$V_1 SIN(\omega t)$
$V_2 SIN(2\omega t)$
FIRST LINAC GAP

FIG. 2

on the fish diagrams of Fig. 3 for 751 keV injected protons: (1) V_B = 18.8 kV (buncher voltage), drift space = 2.25 m and λ_o = 1.5 m, this is the dashed line segment marked "1"; (2) V_b = 9.4 kV, drift space = 4.5 m and λ_o = 1.5 m, this is the solid line segment, "2." Fluctuations of ± .05%~ ± .10% in the injector voltage could shift these bunches by (1) $\pm 3.4^o \sim \pm 6.8^o$ and (2) $\pm 6.8^o \sim \pm 13.5^o$, respectively.

As has been pointed out by Beringer and others, it does not seem to be impossible to build a perfect saw-tooth buncher. However, a bunching scheme (Fig. 2) which used two bunchers, one at the linac frequency of 200 Mc/sec and the other at 400 Mc/sec, has been studied as a possible substitute for the ideal system. In Fig. 3, a typical bunch from such a system is plotted together with "fish" diagram for φ_s = -0.45 and φ_s = -0.35. Energy gain is assumed to be 1.21 MeV/m for both cases, and capture efficiency would be somewhat smaller than indicated here because of the distribution of particles in the transverse phase space.

It is important to lose the undesirable tail part (A to B or A' to B' and near C or C') as quickly as possible (energy less than ~10 MeV). From this standpoint, the first short tank should be regarded as an integral part of the bunching system. A smaller values of φ_s (compared to the rest of the linac) might be preferable in this tank so that the resulting beam would have a smaller phase spread.



$V_1 = 16KV$; 200 Mc
$V_2 = -8KV$; 400 Mc
$\ell_1 = .2m$
$\ell_2 = 1.5m$
(Δδ)
.6x10^-4
.4
.2
-.2
-.4
(Δφ)
0.2
0.4
0.6
0.8
1.0
1.2
$\phi_s = -.45$
$\phi_s = -.35$
A
A'
B
B'
C
C'
①
②

FIG 3

PERRY: What sort of handle do you have on getting the beam into the middle region of the stability diagram?

OHNUMA: We have a computer program which not only calculates but plots the fish diagram and the beam shape. We change several parameters (drifting distances, buncher voltages, etc.) and try to get a reasonable combination. The drifting distance is always kept less than 2 m and the buncher voltage less than 30 kV.

VAN STEENBERGEN: I just wonder how closely one can choose the separatrix. We found at Brookhaven that actually we get optimum performance not when we have a complete agreement with the theoretical result but when the S-shape is smaller, as compared to the acceptance width. I think the separatrix is not as well-defined as one gets from computations.

OHNUMA: In order to find the true capture efficiency, we have to trace each particle through the machine. But we know definitely that if a particle is beyond the point A of Fig. 3, it will be lost very quickly, unless, of course, the particle is right on the origin of the transverse phase space. What I want to emphasize here is that the theoretical capture efficiency relative to the static fish diagram is not a very good measure of what we would get at the end of a linac.

GLUCKSTERN: One often hears the suggestion of operating a section of linac at $\varphi_s \simeq -90^{\circ}$ and gradually squeezing the "fish" size as the phase oscillation damps in order to get total capture. Have people really looked into this numerically to make some estimates as to whether it's useful?

OHNUMA: I think that would work all right if you don't have to change the rf frequency. But for our purpose, what is most important is a very small final phase spread. Maybe you can capture more particles, but I am afraid we would lose many particles at higher energies in the iris section because of the frequency change.