

HIGH CHARGE PICOSECOND PULSES WITH A DOUBLE GAP SUBHARMONIC BUNCHER*

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Summary

A new improved bunching system was designed in 1976 and installed in 1981 in the Argonne Electron Linac¹ to replace the one installed in 1972.² In the new bunching system, a spiral loaded double gap 12th subharmonic buncher is replacing the previous single gap 6th subharmonic buncher and a one wavelength fundamental frequency traveling wave prebuncher has replaced the previous two wavelength prebuncher.

Individual pulses of picosecond (25 to 36) duration and up to 40 nCoulomb in charge, with $\Delta E/E < \pm 0.5\%$ at FWHM over the energy range of 4 to 22 MeV, and a repetition rate from one to 1000 psec are available to the experimenter on a routine basis.

The design and the microwave properties of the cavity are discussed along with the general design of the injector and the results achieved.

Injector

The new ANL injector (Fig. 1) was designed to increase the available charge of the single picosecond pulse from 8 nC to 16 nC. With our pulser an increase in the gun pulse intensity would require also a wider pulse than the sixth subharmonic prebuncher could bunch without producing satellite pulses. The obvious solution would be to use a higher subharmonic prebuncher capable of bunching a wider pulse, but since no additional drift distance was available, a much higher modulating voltage or a multigap prebuncher was also required.

On the basis of computer studies of the bunching action in a system of multiple gaps, various methods were examined in order to find the optimum solution. Two 12th subharmonic prebunchers independently powered and phased or a combination of 12th and 4th or 18th and 6th subharmonic bunchers to generate a ramp function modulating voltage were examined and found to be very satisfactory. The two independent subharmonic prebunchers used in the SLAC injector produced excellent results.⁴

Influenced by the resonators of the ANL ATLAS project, the case of two equivalent gaps excited in the 12th subharmonic frequency and separated by one-half wavelength $1/2 \beta \lambda$ appeared to be an acceptable plan to provide a single RF cycle of high charge into an L-band accelerator (1300 MHz). This scheme would also have the advantage of the automatic phasing and signal balancing. Some phase adjustment between the gap is possible by a slight change in the gun voltage.

The Gaussian-shaped gun pulse available is shown in Fig. 2. A disc-model space charge trajectory program³ was modified to accommodate discs of variable charge corresponding to the shape of the gun pulse. A typical run is shown in Fig. 3 where it appears that 17.4 nC of the injected pulse (25.3 nC) can be compressed into one RF cycle at the fundamental frequency. At no time have we tried higher charges in our calculations. The results surprised us.

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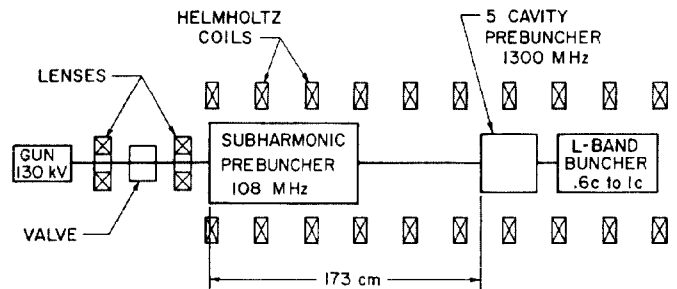


Fig. 1. ANL Injector

Extending the trajectory calculations into the fundamental traveling wave prebuncher of 2λ length, it became evident that the best bunch was formed in the middle of the prebuncher. For that reason the 2 wavelength (10 cavities) traveling wave prebuncher was replaced by a five cavity unit (λ) and the distance between it and the .6 C tapered buncher was reduced to the minimum possible. The distance between the two gaps is 82 cm and the drift distance between the first gap and the fundamental 5 cavity prebuncher is 173 cm.

Double Gap Cavity

Either gap of such a resonator may be represented by its capacitive reactance, $X = j/\omega C$, and the remainder of the cavity by a lossless transmission line, (of characteristic impedance Z_0) (Fig. 4) terminated by a capacitive reactance for which the input impedance (reactance) is

$$\frac{Z_i}{Z_0} = j \frac{-\frac{1}{\omega C Z_0} + \tan \beta L}{1 + \frac{1}{\omega C Z_0} \tan \beta L} \quad (1)$$

so that, for equal gaps, the resonant condition is

$$\tan \beta L = \frac{2(\omega C Z_0)}{(\omega C Z_0)^2 - 1} \quad (2)$$

However, the specified gun voltage (V_0) determines the normalized beam velocity (v/c) so that to arrive at the second gap one-half cycle later (at the subharmonic frequency) will require a drift distance (L).

$$L = \frac{v}{c} c \frac{1}{2f} = \frac{\sqrt{\gamma_0^2 - 1}}{\gamma_0} \frac{\lambda}{2} \quad (3)$$

where $v/c = \sqrt{\gamma_0^2 - 1}/\gamma_0$, $\gamma_0 = 1 + (eV_0/m_p c^2)$.

Noting that

$$\frac{R_0}{Q_0} = \frac{1}{\omega C} \quad (4)$$

and from eq (2), the resonant condition, it follows that

$$\tan\left(\frac{\pi \sqrt{\gamma_0^2 - 1}}{\gamma_0}\right) = \frac{2 \frac{R_0}{Q_0 Z_0}}{\left(\frac{R_0}{Q_0 Z_0}\right)^2 - 1} \quad (5)$$

from which it is clear that the normalized R_0/Q_0 of the

gap is set by the gun voltage and cannot be adjusted arbitrarily for drive power economy.

An alternate analysis is that the cavity consists of two quarter-wave cavities back-to-back, and that, therefore, the resonant condition is given by

$$\frac{R_o}{Q_o Z_o} = \tan\left(\frac{2\pi z}{\lambda}\right) \quad (6)$$

where $R_o/Q_o = 1/wC$ is descriptive of one gap, and $L = 2z$ in the double-gap cavity. It can be seen that eqs (2) and (6) constitute an identity.

For the intended gap voltage (V_g) the required drive power is given by

$$V_g^2 = 4R_L P \quad (7)$$

or, for an input coupling β

$$V_g^2 = \frac{16\beta P R_o}{(1+\beta)^3} \quad (8)$$

In the proposed application ($\beta = 1$)

$$V_g^2 = 2P R_o$$

The unloaded Q of this type of cavity may be estimated,

$$Q_o = \frac{1}{\delta} \frac{\text{VOLUME}}{\text{SURFACE}} = \frac{1}{\delta} \frac{L(b-a)}{L+(b-a)} \quad (9)$$

where the skin depth (δ) for copper is $\delta = 6.60/\sqrt{f}$ cm, or from Terman's rule where b is in centimeters.⁴

$$Q_o = 0.0839 b/\sqrt{f} \quad (10)$$

But, in either case the estimation is of the order of twice too high for the reason that the skin depth is computed from the bulk resistivity of the metal for an ideal surface whereas the machining finish is a significant factor.

In the design thus far it is evident that the gun voltage and subharmonic frequency have determined the principal description of the cavity; very little can be accomplished with the characteristic impedance ($Z_o = 60 \ln b/a$). The possibility of capacitively loading the gap by means of flanges is undesirable, since in the cut-off region of the gap the axial field varies radially (at mid-gap)

$$E_z(n) = E_z(n=a) \frac{I_o(\gamma r)}{I_o(\gamma a)} \quad \gamma = \frac{2\pi}{\lambda(\sqrt{v/c})} \quad (11)$$

Acceptability of the gap spacing depends upon the possibility of multipactoring. This condition is

$$\left(\frac{d}{\lambda/2}\right)^2 = \frac{eV(2n+1)}{m\omega C^2 \pi} \quad (12)$$

for the n -th order multipactoring.

In the design the floating drift tube must of course be supported. The support structure used is the well-known, noninductive, 360° radial spiral. With these coils spaced at 120° apart at the velocity of light if the cavity resonated as a periodic structure the oscillation would be indistinguishable from the intended mode.

The final design is shown in Fig. 4. The cavity dimensions were:

| | |
|--------------------|----------|
| cavity dia, 2b | 24.77 cm |
| drift tube dia, 2a | 5.72 cm |
| cavity length, L | 87.63 cm |
| gap length, g | 3.81 cm |

The cavity resonates at 108.33 mcs with a 200 kcs tuning range. The electrical properties are:

$$R_o/Q_o = 55 \text{ ohms (each gap)}$$

$$Q_o = 2000$$

Thus, the required power input for a gap voltage of 30 KV is about 4 KW. The very low Q is thought to result from the provision that the end plates be removable (unbrazed joints) for inspection and possible repair in the case of beam impingement or arcing. The theoretically achievable Q is in fact not wanted; the off-resonance shunt impedance being

$$R = \frac{R_L}{1+(2Q_L \delta f/f)^2}$$

the gap voltage will vary strongly with the frequency modulation in the drive power.

The center conductor inside diameter is, of course set by the estimated beam diameter; in this design concentric tubing was used to construct the drift tube thereby providing water cooling, the water being led in (and out) through the spiral supports.

Results and Discussion

After an initial conditioning of a few hours the subharmonic prebuncher broke through the multipactoring threshold and came up to power. It has been operating ever since with no problem at all with peak powers varying from 4 KW to 8 KW depending on the charge of the pulse to be bunched.

Charges up to 40 nC have been achieved, but the gun pulser must be very sharp otherwise a small satellite pulse follows the main pulse for 30 to 40 nC. Single pulses up to 30 nC are achieved routinely with very little time required for tuning.

The pulse width measured as in Ref. 3 was found to be ≈ 25 psecs at FWHM from 3 nC to 25 nC the only difference being that at the higher charges the base of the pulse became broader. Beyond 25 nC the pulse width increased and at 40 nC was 37.5 picoseconds (Fig. 7) with a long base of ≈ 200 psecs. The shape of the pulse can be changed by tuning, but such an endeavor is not easy at present until a streak camera is installed to monitor and optimize the pulse width.

The energy spread for all charges up to 40 nC is $\Delta E/E < \pm 0.5\%$ at FWHM but as it can be seen in Fig. 6 the base of the energy distribution plot is broader with a lot more particles at lower energies than the pulses with less charge. This, of course, correlates with the very broad base of the pulse Fig. 7 that extends almost 90°.

The emittance measured as in Ref. 3 was found for 90% of the current to be:

| | |
|---------------|------------|
| 40 n Coulombs | 15.7 mm mr |
| 30 n Coulombs | 11.8 mm mr |
| 20 n Coulombs | 9.84 mm mr |
| 10 n Coulombs | 7.87 mm mr |

In general, we believe that with a better pulser the characteristics of the beam with various charges would improve, but it is also apparent that beam characteristics start deteriorating significantly beyond the value of 25 to 30 nC/pulse due to the space charge forces.

The system of two independently powered and phased prebunchers because of its flexibility is probably the best solution to the problem of achieving single pulses of high charge.

Acknowledgements

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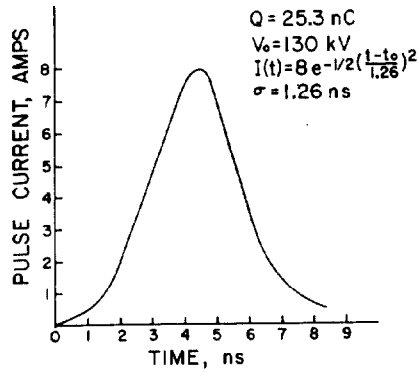


Fig. 2. Gun Pulse

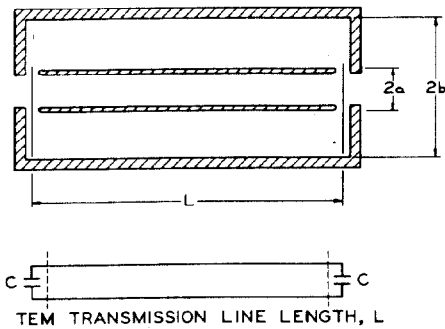


Fig. 4.

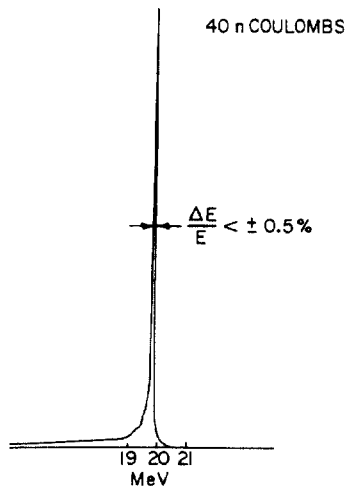


Fig. 6. Energy Spectrum

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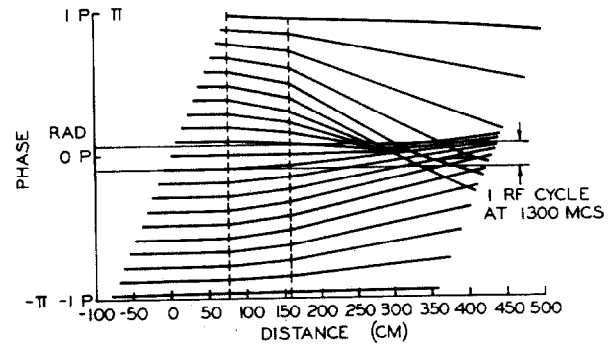


Fig. 3.

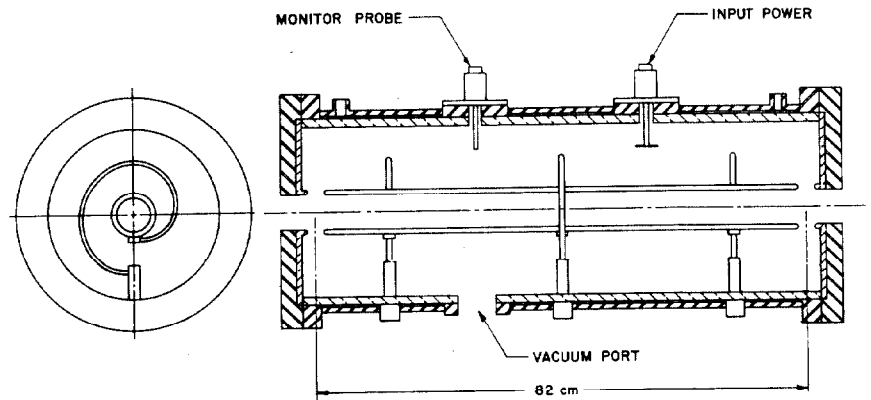


Fig. 5. Double Gap Cavity (108 MHz).

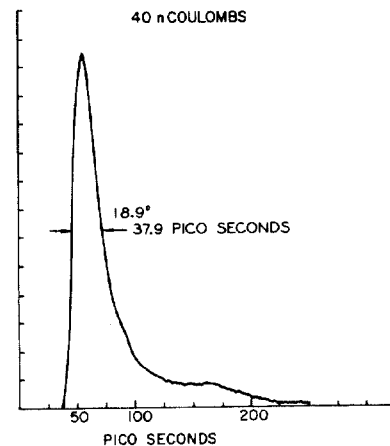


Fig. 7. Pulse Shape.