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THE NRL AUTOACCELERATOR CONCEPT

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A technique for the collective acceleration of an intense electron beam to very high energies is presented. A long pulse electron beam (800 ns) with a linear current rise is used to load a set of N cavities with magnetic field energy. At a time T the beam current is dropped and the stored energy in the cavities is transferred to a small portion of the following beam. Very efficient energy transfer is possible in this system, and the possibility of generating beams with energy in excess of 1 GEV exists. Verification of the acceleration mechanism in one and two cavity systems is presented.

The autoacceleration process is a collective acceleration mechanism that redistributes the energy within an electron beam such that the majority of the electrons transfer their energy to only a small portion of the beam. The NRL approach to this concept is depicted in Figure 1.

An LC generator is connected to a foiless diode which produces an annular electron beam with voltage and current waveforms shown in Figure 1.

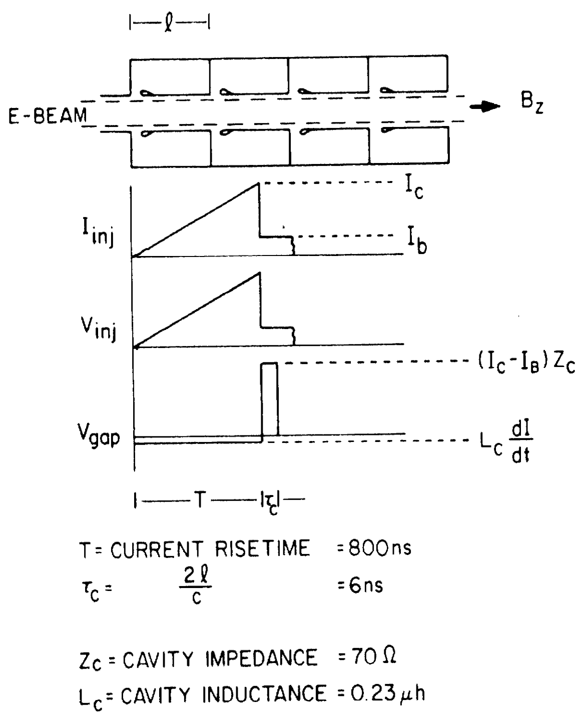


Figure 1. The NRL Autoaccelerator concept. From top to bottom the figures are: Cavity structure; Injected current I_{inj}; Injected voltage V_{inj}; Voltage developed across each cavity gap V_{gap} showing the retarding voltage due to $L\, dI_{inj}/dt$ during the current rise (T) and the accelerating voltage due to the current drop.

This beam propagates along a strong guide field (B_z > 10 kg) in a drift tube which is coupled to coaxial cavities via short accelerating gaps. The background gas pressure is low enough (<0.1) to inhibit the magnetic neutralization of the beam, thus the return current is forced to flow along the drift tube wall and around the cavity. In this way the cavity is "loaded" with magnetic field energy during the current risetime. When the current falls at time T, a TEM wave is launched in the cavity. The cavity acts as a transmission line with characteristic impedance Z_c, coupled to the beam via the accelerating gap. For a wave transit time to the end of the cavity and back to the gap, an accelerating voltage is present across the gap equal to $V_g = Z_c\,(I_c - I_b\,(t))$ where I_c is the peak beam current and I_b is the beam current flowing at time t. Note that since it is the current fall that generates the gap voltage, the same group of electrons are accelerated by each gap, i.e., there is automatic synchronization of the beam with the accelerating potential of each gap. The total beam energy after traversing N cavities is

$$E_{beam} = q(V_{inj} + n\, Z_c\, (I_c - I_b(t))) \qquad (1)$$

The present beam generator is capable of producing a beam with peak voltage and current of 1.5 MV and 50 KA respectively. The cavities used in our experiment have an impedance of 70 ohms giving a maximum acceleration per gap of 3.5 MV. In order to reduce RF and microwave oscillations in the cavities, carbon resistor chains have been installed which reduce the effective cavity impedance to 6- ohms.

In a two cavity system a maximum beam energy of 3 MeV has been observed using x-ray and Faraday cup measurements. The predicted cavity operation has also been confirmed using electric and magnetic probes located at various positions in the cavity.

As stated previously, carbon resistor chains were installed along the cavity center conductor in order to reduce the RF and microwave oscillations in the cavity during the beam risetime.

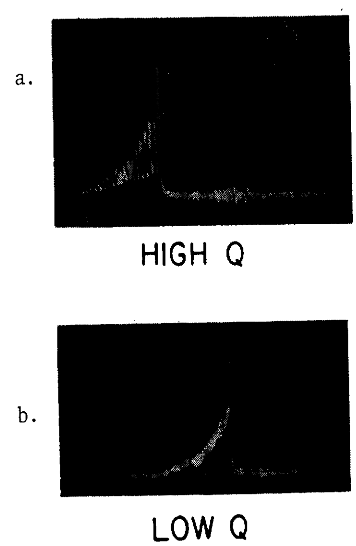


Figure 2. Bremstrahlung X-Ray intensity for two shots (100 ns per division).

a. Two cavities without resistors installed (note the oscillation at the first cavity harmonic in the x-ray intensity).

b. Two cavities with carbon resistor chains installed to lower cavity Q (note the absence of coherent oscillations on the x-ray intensity).

Without these resistors, noise on the beam excites the cavity at its resonant harmonics causing a large energy modulation of the beam as shown in Fig. 2a. Insertion of the resistors drops the oscillations to an acceptable level as shown in Fig. 2b. Fig. 2b also shows the characteristis x-ray pulse during the acceleration phase of the beam. The bremstrahlung x-ray intensity from the beam striking the drift tube wall or a carbon target is used as a diagnostic to measure the beam energy and current. The x-ray intensity is found using a scintillator-photodiode combination looking along the drift tube axis. It has been shown[6] that the intensity is proportional to $I_b E_b^{2.8}$. Using this relation, the intensity at maximum acceleration relative to the intensity at the peak current can be expressed as

$$X_r = \alpha^{3.8} \left[1+n \frac{Z_c}{Z_0} \left(\frac{1}{\alpha} - 1\right)\right]^{2.8} \qquad (2)$$

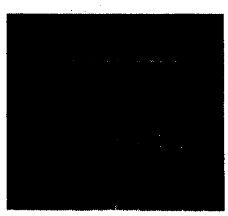
where $\alpha = I_c/I_b$ (t), n is the number of cavities, and $Z_0 = V_c/I_c$. It is assumed that all of the beam current is accelerated by the gap and that the diode impedance remains constant during the current fall. The experimental value of X_r agrees well with the value determined from equation 2 using the experimental value of $\alpha(t)$. These results also agree with Faraday cup measurements done on the accelerated electron beam.

Operation of a two cavity system has shown a significant deterioration of the current falltime at the second gap at current levels above 14 KA. This is attributed to current emission across the gap during the current falltime.

a.

2 CAVITIES

b.



SINGLE CAVITY

Figure 3. Comparison of single and double cavity operation (5 ns/division). The upper and lower traces are integrated magnetic probe signals at the first and second gaps respectively.

a. Two cavity operation.

b. Single cavity operation is obtained by shorting the first gap with brass shimstock in order to keep all other parameters the same.

Figure 3 shows a comparison of single and double cavity operation where single cavity operation was obtained by shorting the first gap with a tube of brass shimstock. Note the improvement in the falltime at the second gap when the first gap is shortened. Electrostatic probe measurements in the gap of the second cavity have indicated the presence of energetic electrons at the gap during the risetime. It is likely that these electrons are generating plasma on the gap which allows significant electron emission during the acceleration phase. We believe that by increasing the beam gamma during the charging phase we may be able to substantially reduce the energetic electron current striking the gap, and thereby operate at higher current levels. This approach is being pursued at the present time.

In conclusion, the autoacceleration mechanism has been confirmed experimentally using one and two cavity systems. The beam energy has been increased by a factor of 15 in a two cavity system from 200 Kev at the diode to 3 MeV after acceleration. Microwave and RF oscillations in the cavities have been reduced by lowering the cavity Q with carbon resistor chains. Consistant operation of a two cavity system at current levels up to 14 KA has been demonstrated.

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