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MEQALAC RF ACCELERATING STRUCTURE*

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Introduction

A prototype MEQALAC capable of replacing the Cockcroft Walton pre-injector at BNL is being fabricated.[1] Ten milliamperes of H^- beam supplied from a source sitting at a potential of -40 kilovolt is to be accelerated to 750 keV. This energy gain is provided by a 200 Megahertz accelerating system rather than the normal dc acceleration. Substantial size and cost reduction would be realized by such a system over conventional pre-accelerator systems.

Experiment

Four beamlets are guided through an electrostatic quadrupole transport system to the first accelerator cavity. A buncher shown in Figure 1 will eventually be used. The two gap buncher will provide 1 kilovolt/gap with an excitation power of 100 watts. This buncher has a Q of 400 which is adequately low to minimize the effect of frequency drift.

Two 200 MHz RF systems were available. The first system capable of 5 kilowatts peak RF, is easily transportable. The second system can provide up to 200 kW of pulsed RF but is located at the AGS linac. So that most of the early work could be done in the MEQALAC group lab, the accelerator was split into two sections. The first will accelerate the beam to 124 keV and the second cavity, using approximately 100 kilowatts of rf power, will bring the beam to the final energy of 750 keV. See Figure 2.

To a great extent the type of accelerating structure was dictated by the requirements of the electrostatic quadrupoles. The quadrupole array had to be hung by a single set of skewers so that alignment may be maintained in the 4 beam channels. The bore hole diameter of each channel is 3 millimeters. Quadrupole plates are accurately mounted to a boron nitrate insulator through which the skewers pass. Boron nitride was used for ease of fabrication. In an operating system, ceramics would be more appropriate. See Figure 3.

Cavity Design Theory

The cutoff frequency of a rectangular waveguide operating in the TE_{10} mode can be reduced by a post at the center of the guide (ridged waveguide). Refer to Figure 4. Further reduction can be achieved by extending plates from the post to the region outside the cavity thus providing additional capacity to the ground wall. The electric field in the capacitive gap will extend from the plate to the ground plane. By suitable choice of the longitudinal length of the plate (and ground planes) a $\beta\lambda/2$ structure is formed. At cutoff there is only two field components namely longitudinal magnetic field, Hz, and transverse electric field, Ey, in the cavity. The cutoff frequency of a single cell can be approximated by the transverse dimensions. The capacitive reactance of the gap must equal the inductive reactance of the side walls. The inductance is equivalent to that formed by a shorted parallel plate transmission line (see Figure 5). Because of symmetry only half the transverse circuit needs to be solved.

$$Z_o \tan \frac{2\pi W}{\lambda} = \frac{2}{\omega C}$$

where

W = width of par. plate line

C = total gap capacity

Z_o = characteristic impedance

λ = free space wavelength

ℓ = cell length

$$Z_o = 377 \frac{\varepsilon}{C'}$$

d = cavity height

where

C' = cap/unit length of parallel plate tx. line

$$C' = \frac{\ell x 10^{-12}}{4.45d}$$

and

$$\tan \frac{2\pi W}{\lambda} \simeq \frac{2\pi W}{\lambda}$$

$$Z_o \tan \frac{2\pi W}{\lambda} = \frac{377\varepsilon}{\ell x 10^{-12}} (4.45d) \left(\frac{2\pi W}{\lambda}\right. = \frac{k_1 dW}{\ell\lambda}$$

$$\frac{2}{\omega C} = \frac{k_2 \lambda}{C}$$

$$\therefore \frac{dW}{\ell\lambda} k_3 \frac{\lambda}{C}$$

where k_1, k_2, k_3 = constants. Or

$$\frac{C}{\ell} = \frac{k_3 \lambda^2}{dW} \tag{1}$$

From equation (1) it can be concluded that for a fixed cavity height, d, and width, 2W, by setting the capacity per cell length constant an electromagnetic wave will propagate down the cavity. As Beta increases the cell length, ℓ, increases and thus capacitive loading must increase. This is achieved by simple increasing the width of the extension plates (drift tubes) with Beta.

End Terminations

The previous section established the transverse dimensions for a TE_{10} type of modal propagation in the longitudinal direction. Figure 6A shows the longitudinal phase velocity, v_p, as a function of frequency. At cutoff v_p is ∞ and so is guide wavelength. As frequency increases the v_p goes down. In a standard waveguide the v_p would approach c, the velocity of light ($\lambda_g = \lambda_o$). Because of the capacitive loading in the accelerating cavity the v_p becomes less than c as frequency increases. Thus the guide wavelength is less the λ_o and the cavity appears as a slow wave structure. By placing end walls on the cavity a longitudinal resonance is established. Figure 6B shows the equivalent transmission line circuit for this longitudinal resonance. If the resultant resonant frequency is too high the cavity will appear as a slow

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wave structure and a voltage standing wave will appears. Since $\lambda_g < \lambda_o$ this could be quite serious since the voltage in the middle gap would be much larger than the end gaps. Noting however that the end walls appear as a shunt inductance, a shunt capacitance mounted to the center post can be used to tune the end wall impedance. This shunt C forces the resonant frequency toward cutoff ($\lambda_g >> \lambda_o$). As suspected the value of capacitance is equal to the C/ℓ of the structure. In this manner the magnetic field turns the corner and closes upon itself. In this manner a TE_{100} type mode is established at the cutoff frequency determined by the transverse dimensions. Only Hz and Ey fields are present.

TABLE 1

Cavity number	1	2
Frequency (MHz)	201.25	201.25
Structure type	βλ/2	βλ/2
H^- entrance energy (keV)	40	124
H^- exit energy (keV)	124	750
Length (cm)	13	50
Width x height (cm)	10x6	19x8
No. of gaps	10	18
Peak RF gap volts (kV)	12.7	50.7
Gap length (mm)	1	4
RF power required (kW)	4.1	115
Q	970	1000
Shunt impedance (MΩ/M)	13.2	6.7
Field flatness (%)	±4	±2

Cavity One

(a) Quadrupoles

Pockets are made in the extension plate which will be referred to as hot drift stores (Figure 7). Quadrupole assembly hung from the top scewers are placed in these pockets. The wiring for these quads come up from the bottom of the cavity. In addition pockets are made in the ground drift tube for similar quadrupoles. The wiring comes from a bus mounted on top of the cavity. The anticipated quadrupole voltages is ±4.5 kilovolts. This means the vacuum gap between the quad plate and opposite quad tip has a dc voltage gradient in excess of 3 mV/M. Various dielectric configurations have been tried to ease the stress in the dielectric - especially at metal-dielectric boundaries.

(b) RF Cavity

The peak RF gap voltage is 12.7 kV which provides an energy gain of approximately 9 kV/gap when operating at a stable phase angle of 45°. Each gap is 1 mm; transit time factor ranges from .88 to .96. The bore hole diameter has more influence on these numbers than the g/L ratio. The length of the 9 cells (10 gaps) is 9 cm.

The unloaded Q of the structure is 950 necessitating approximately 4200 watts for design field.

The first cell capacitance dictates the overall capacity since it fixes the C/ℓ ratio in the entire structure. It is desirable to reduce this capacity since power goes up linearly with capacity for a given gap voltage. This capacity was dictated by the cross sectional area required for the quadrupole assembly. Since there are only 4 beamlets this area is quite large compared to the cross sectional area occupied by the beam. The area of the first gap capacitance is .6 x .9 in^2.

There is stray capacitance from the drift tubes to the metal skewers. This is approximated .5 μμf/cell. The overall capacity is 40 μμf.

A loop mounted on the side wall, couples rf power into the cavity via the longitudinal magnetic field. A similar loop provides a monitor signal for cavity field calibration. A 3/4 in^2 rotatable paddle enables the cavity frequency to be increased by 2 megahertz when rotated into the magnetic field. It has negligible effect on Q and field flatness.

The cavity is tuned by maximizing the end capacitor thus driving the resonant frequency toward cutoff. The capacitors are then reduced to obtain minimum capacity with acceptable field flatness. The field drop off was set at 9% in the two end gaps. This could have been set to less than 2%. Since the frequency would have fallen below 201.25 Megahertz necessitating rework to increase the cavity width the 9% drop off was deemed acceptable.

The cavity is installed in the vacuum chamber and system testing to establish accelerated beam are under way.

Cavity Two

The gap capacity of this cavity was purposely increased to reduce dimension since there is access power available for this cavity (200 kW). The cavity will require approximately 100 kilowatts of pulsed power to establish a peak gap voltage of 50 kilovolt. This will provide for an energy gain of 36 kilovolts/gap. Inall there will be 18 gaps. Each gap is 4 mm long.

An error was made in the construction of the RF testing model. The C/ℓ increased as the cell length increased. On tuning it was found that the field level ramped fairly linearly providing higher gap voltage (13%) on the end gap. The field varied approximately 2% over this linear ramp. This may be useful in future designs since the input gap energy gain is limited to a certain fractin of the input energy. The cavity length is 15" which is a 1/4 of the free space wavelength at the operating frequency. When the gap capacitance error is corrected it is expected that test results will verify that $\lambda_g > 4\lambda_o$.

There is some concern about RF radiation from the 4 mm gap into the vacuum system. Provision for shielding will be required.

Acknowledgements

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References

1. G.M. Gammel, et.al., "MEQALAC DEVELOPMENT AT BROOKHAVEN", these proceedings.

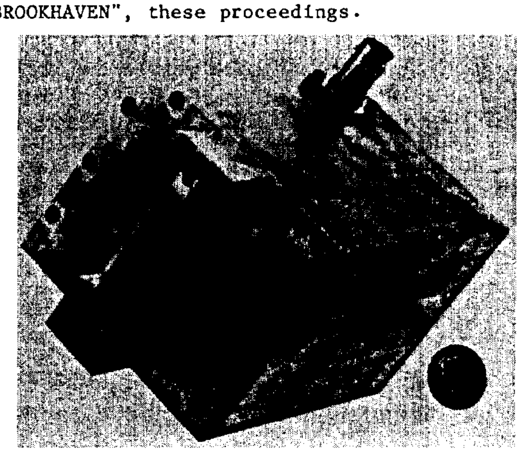

Figure 1. Buncher

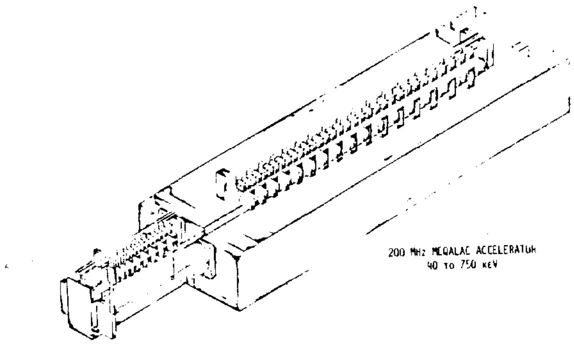

Figure 2.

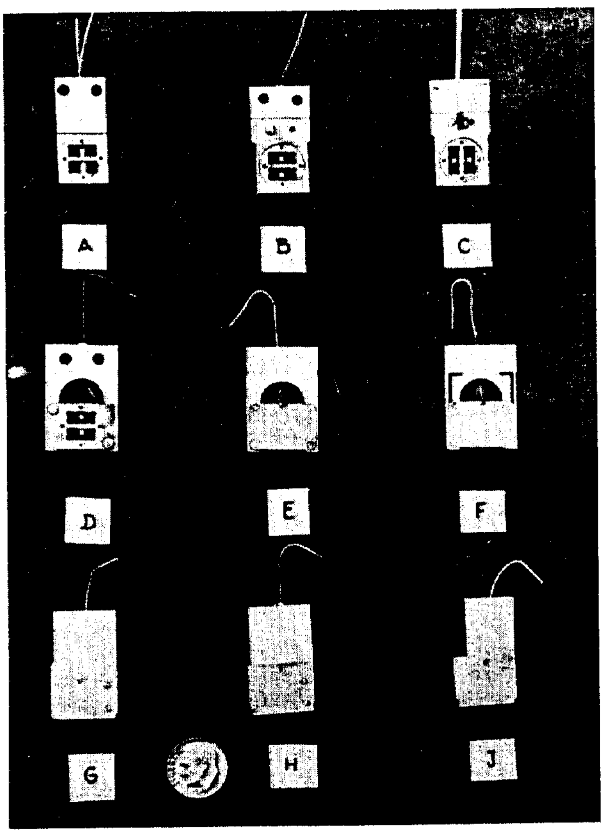

Figure 3. Prototype Quadrupoles

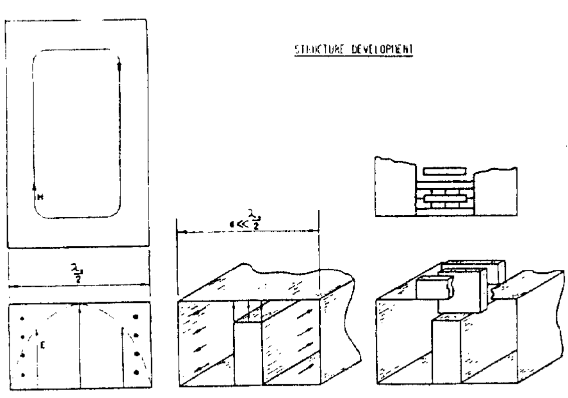

Figure 4.

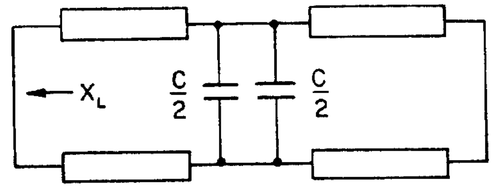

Figure 5. Transverse Equivalent Circuit

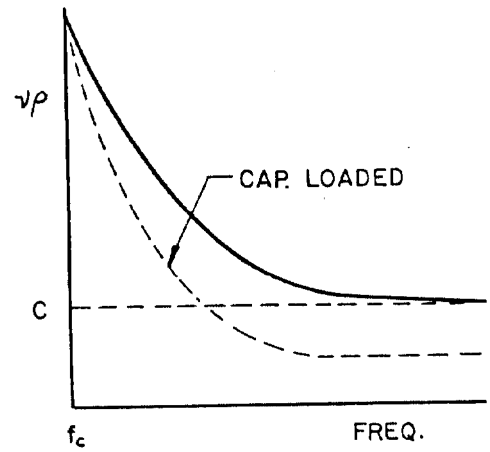

Figure 6A. Phase Velocity Versus Frequency

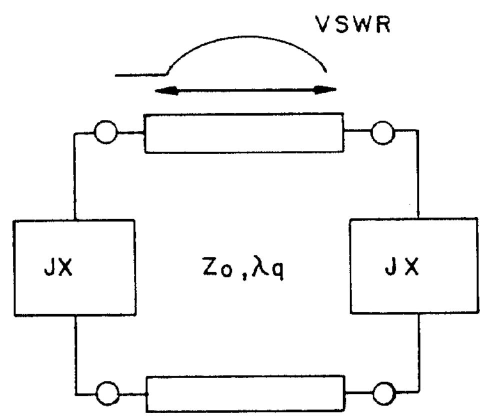

Figure 6B. Longitudinal Equivalent Circuit

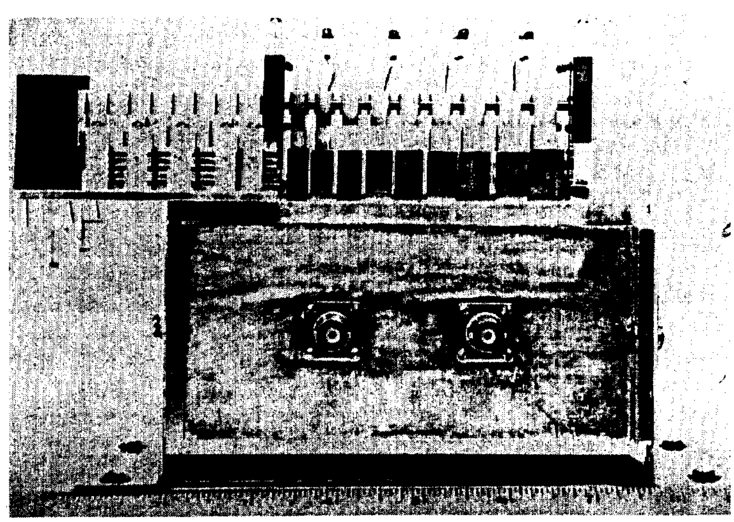

Figure 7. Cavity 1