MASTER

BUNCHER CAVITY FOR 750 keV PROTONS

J. T. Keane
April 10, 1978

ACCELERATOR DEPARTMENT
BROOKHAVEN NATIONAL LABORATORY
ASSOCIATED UNIVERSITIES, INC.
UPTON, NEW YORK 11973

under contract No. EY-76-C-02-0016 with the
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(Inertial Confinement Fusion
-TID 4500)

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Summary:

A 50 MHz bunching cavity was built and operated at BNL for studies into the effect of bunching on neutralization of a 750 keV proton beam. Since this cavity was intended for a short testing period, a low cost unit that could be assembled rapidly was desired. This cavity is described.

I. Rf Cavity

A length of 9" 50 ohm coaxial transmission line was obtained as well as a Dielectric Products vacuum window. This vacuum window conveniently fit into a vacuum box that was already installed in the 750 keV proton beam line.

(See Fig. 1).

By placing a sliding short on one end of the transmission line, a $\frac{1}{4}$ wavelength coaxial resonator was formed. See Fig. 2 for the equivalent circuit. At the voltage maximum (trans"E" field) point a drift tube was mounted. The center conductor was supported at one end by the shorting plane and at the other end by the vacuum window. The resonating section was run in air.

Low level rf testing was performed on the assembly minus the drift tube section. The position of the short was determined for a resonant frequency of approximately 50 MHz. This was facilitated by use of two small loops mounted on the outer conductor. One loop was powered by a signal generator. The power coupled to the other loop was measured with a HP vector voltmeter. By this method, the unloaded "Q" of the resonator was found to be 900.

The easiest way to couple power from the transmitter was with RG 19 flexible coaxial cable, which was on hand. Rather than look for an expensive input rf coupling system, the center conductor of the RG 19 was connected directly to the center conductor of the resonator. Fig. 3 shows the equivalent circuit. By placing the tap position at the appropriate point in the resonator, the input

was matched to the 50 ohm input line. (Adjust magnetic coupling for equivalent transformer match). This position was found by terminating the transmitter end of the RG 19 cable with 50 ohms and adjusting the tap position till the loaded Q of 450 was observed.

The position was found to be approximately 1" from the shorting plane. The length of the line for resonances was 45 inches.

II. Accelerating Section

A drift tube was fabricated by soldering together two four inch end caps stocked by the plumbing shop. (See Fig. 4). A $\frac{1}{4}$ " copper stem (3") was used to connect the drift tube to the vacuum side of the coaxial center conductor.

Aluminum side walls were used to section off the vacuum box. Mounting was done with screws and aluminum tape. (See Fig. 4). Half cells were secured to these side plates.

From Figs. 5 and 5A it is seen by adjusting the cell length a two-gap buncher operating in the $\beta\lambda/2$ mode has been formed.

III. Operation

The coaxial cavity was mounted on the vacuum box and powered by the transmitter. Cavity field was observed by a small pickup loop. Power level and frequency were adjusted till cavity field was observed. The shorting position and frequency was readjusted for minimum reflected power. Due to capacitive loading effects of the drift tube, the resonant frequency was reduced to 46 MHz, which was acceptable for our application.

It was found that there was only a certain power range over which the cavity would operate. If the power was too low multipactoring would occur and all the input power was reflected. When the power was too high, voltage breakdown would occur in the resonating section. This possibly was caused by arcing in

the drift tube. Biasing of the half drift tubes may have eliminated the multipactoring effect but since the operating range was sufficient for bunching at our viewing box no further work was done. The operating range was between 2 to 7 kW. Most of the bunching experiments were around a power level of 5 kW.

Using Eq. 4 of the appendix the value of field in the gap is approximated as follows:

$$I^2 = \frac{Q P_{avg}^4}{\pi Z_0}$$

where I = current at short ckt

$$Z_0 = 50\Omega$$

$$= \frac{(900)(5 \times 10^3)^4}{\pi 50} = 114.6 \times 10^6$$

$$P_{avg} = 5 \text{ kW}$$

$$I = 338.5 \text{ amps}$$

$$V_{rms} = (50)(338.5) = 16.9 \text{ kV}$$

$$V_{peak/gap} = 1.414(16.9 \text{ kV}) = 23.9 \text{ kV}$$

$$V_{peak} = 2 \times 23.9 \text{ kV} = 47.8 \text{ kV for 5 kW}$$

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The work of E. Meier and K. Riker and the members of the Brookhaven Heavy Ion Fusion Group was essential for the realization of a working system.

APPENDIX

Stored Energy in Coaxial Quarter Wavelength Resonator

The magnetic stored energy in a resonator is given as follows:

$$U_H = \int_V \frac{\mu}{2} H^2 dV \quad \text{where } \mu = \text{permeability of media (henries/meter)} \quad (1)$$

H = magnetic field intensity (amp/meter)

Using ampere's law to find the field in a coaxial guide operating in the TEM mode

$$\oint H \cdot d\ell = I$$

$$(H_\phi \cdot 2\pi r) = I$$

where I = current flow on inner conductor

r = radius

$$H_\phi = \frac{I_0}{2\pi r}$$

H_ϕ = only component of magnetic field intensity using cylindrical core

Since resonance is assumed, there will be a longitudinal dependence of current

$$H_\phi = \frac{I_0 \cos \beta z}{2\pi r}$$

where I_0 = current flow at short circuit plane (2)

β = phase constant of media (rad/meter)

z = length from short (meters)

Combining Eqs. (1) and (2) yields

$$U_H = \frac{\mu}{2} \int_{r_1}^{r_0} \int_0^{\lambda/4} \int_0^{2\pi} \frac{I_0^2 \cos^2 \beta z}{(2\pi)^2 r^2} r dr dz d\phi$$

where r_0 = outer conductor radius

r_i = inner conductor radius

λ = free space wavelength

$$\begin{aligned}
&= \frac{\mu I_0^2 (2\pi)}{2(2\pi)^2} \int_{r_i}^{r_o} \int_0^{\lambda/4} \frac{\cos^2 \beta z}{r} dr dz \\
&= \frac{\mu I_0^2}{2(2\pi)} \left(\frac{1}{2\beta} \right) \left[\sin \beta z \cos \beta z + \beta z \right] \bigg|_0^{\lambda/4} \int_{r_i}^{r_o} \frac{dr}{r} \\
&= \frac{\mu I_0^2}{4(2\pi)} \left(\frac{1}{\beta} \right) \left(\frac{\beta \lambda}{4} \right) \ln \left(\frac{r_o}{r_i} \right)
\end{aligned}$$

$$U_H = \frac{I_0^2 \mu \lambda}{2\pi(4^2)} \ln \frac{r_o}{r_i}$$

$$\text{but } \mu \lambda = \frac{\mu v}{f} = \frac{\mu}{\sqrt{\mu \epsilon} f} = \sqrt{\frac{\mu}{\epsilon}} \frac{1}{f} = \frac{376.7}{f} = \frac{2\pi(60)}{f}$$

where ϵ = permittivity of media

$\sqrt{\frac{\mu}{\epsilon}}$ = intrinsic impedance of air

v = velocity of light

$$U_H = \frac{I_0^2 (2\pi)}{(2\pi) 4^2 f} 60 \ln \left(\frac{r_o}{r_i} \right)$$

but $60 \ln \left(\frac{r_o}{r_i} \right) = Z_0$ characteristic impedance of coaxial line

$$U_H = \frac{I_0^2 Z_0}{16 f}$$

$$U_H = \frac{I_{rms}^2 Z_0}{8 f} \text{ where } I_{rms} = \text{RMS value of current} \quad (3)$$

It follows that the "Q" of the circuit is:

$$Q = \frac{2\pi f U_H}{P_{avg}} = \frac{\pi I_{rms}^2 Z_0}{4 P_{avg}}$$

$$I_{rms}^2 = \frac{4Q P_{avg}}{\pi Z_0} \quad (4)$$

Fig. 1 Coaxial Resonator Mounted on Vacuum Box Housing Drift Tube

EQUIVALENT CIRCUIT OF RESONATOR AND DRIFT TUBE

FIG. 2

EQUIVALENT INPUT CIRCUIT

FIG. 3

MATCHED EQUIV. CIRCUIT REFERRED TO INPUT

FIG. 3A

Fig. 4 Drift Tube Assembly

TOP VIEW OF VACUUM BOX
FIG. 5

FIG. 5A

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