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LOW BETA ACCELERATOR FOR XENON

J.T. Keane
April 3, 1978

ACCELERATOR DEPARTMENT
BROOKHAVEN NATIONAL LABORATORY, ASSOCIATED UNIVERSITIES, INC.
UNDER CONTRACT NO. EY-76-C-02-0016 WITH THE
UNITED STATES DEPARTMENT OF ENERGY

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Summary:

The xenon accelerating structures fabricated at BNL is described. Low level measurements yielded a Q value of 1600 and effective shunt impedance of 50 mega Ω /meter. For the 20 KW of rf available an energy gain of 400 keV appears attainable.

I. Description

A folded quarter wavelength resonant coaxial cavity has been built for accelerating xenon (See Fig. 1). This cavity having a length of 96" and an outer diameter of 17.5" is resonant at 16.5 MHz. An equivalent circuit of the resonator is shown in Fig. 1A as well as a section view in Fig. 1B. At the voltage maximum point in the line, 11 drift tubes are mounted $\beta\lambda/2$ apart (See Fig. 2). By alternately mounting the drift tubes to the wall and center conductor the phase of the electric field in successive accelerating gaps is displaced 180° . There is no quadrupole focusing in the drift tube.

Frequency was set by adjustment of a variable shorting plane. Rf input power is provided by a magnetically coupled loop located approximately an $1/8$ wavelength from the shorting plane. A vacuum window is incorporated in the $3\frac{1}{8}$ inch coaxial feed assembly, thus the complete rf resonator is under vacuum.

Flexibility is incorporated into the assembly in such a manner that different type drift tube structures may be easily inserted.

II. Measurement of Q and Matching of Loop

Two electric field couplers were mounted near the voltage maximum point in the coaxial line. Care was taken to assure probes did not effect the value of measured "Q". The test set-up is shown in Fig. 3. With use of the vector

voltmeter resonant frequency was set and the 3 db bandwidth (BW) was found.

The Q value was found to be 1600.

$$Q = \frac{f_{\text{resonance}}}{\text{BW}} = \frac{16.5 \times 10^6}{10.3 \times 10^3} = 1600$$

When the input loop coupling ratio is adjusted for a matched input from Fig. 4 and 4A, it is seen that the circuit resistance is halved and thus the Q is halved. By terminating the input loop with 50Ω and measuring Q (800) the loop coupling area was adjusted for an input match condition.

The Q measurements were rechecked by pulsing the rf drive and measuring the falltime of the cavity rf field. Q is related to falltime by:

$$Q = \pi f \Delta t \quad \text{where } \Delta t = \text{time field drops by } 1/e \text{ of initial value}$$

See figure 5.

III. Perturbation Measurements and R_0/Q_0

Using the set-up shown in Fig. 6 the cavity oscillated at its natural frequency. When a cylindrical perturbator was passed through drift tube gaps the frequency shift was noted. The inherent stability of this set-up enabled accurate measurement of much smaller frequency changes than possible with a fixed generator and its associated frequency shift. This allowed smaller perturbators to be used which lead to greater accuracy of measurement. After testing of various size and shape perturbators, a cylinder of approximately 3/16" diameter and 1/4" length yielded good results.

Using the equivalent circuit of Fig. 7 the value of R_0/Q_0 can be determined by noting the frequency change produced by a metal cylinder in an electric field.¹ Since the capacitance change due to the perturbator in the drift space is

$$\Delta C = - \frac{a}{4\pi} \frac{dS}{S^2} \quad \text{where } S' = \text{gap length}$$

a = cross sect

area of cylinder

$$\frac{R_o}{Q_o} = 120 S^2 \frac{d\lambda}{d\tau} \quad \text{where } d\lambda \text{ is change in wavelength}$$

S = .59" $d\tau$ is volume of cylinder

$$d\tau = \pi r^2 \ell = \pi (.0915")^2 (.263")$$

The maximum frequency change observed in each cell is shown in Fig. 8.

Using an average frequency change of 420 cycles the value of R_o/Q_o is

$$\frac{R_o}{Q_o} = \frac{120 (.59)^2 d\lambda}{\pi (.0915)^2 (.263)} \quad \text{where } d\lambda = \Delta f (.433 \times 10^{-4}) \text{ inches}$$

$$\frac{R_o}{Q_o} = 110.$$

The value of Q_o was found to be 1600

$$R_o = (110) (1600) = 176 \text{ k}\Omega$$

For 20 kW of available power the expected peak field/gap is

$$V_{rms}^2 = R_o P = 1.76 \times 10^5 \times 20 \times 10^3 = 35.2 \times 10^8$$

$$V_{rms} = 5.93 \times 10^4$$

$$V_{peak} = \underline{83.9 \text{ kV/gap.}}$$

$$\text{Total voltage} = 12 \text{ gap} \times 83.9 \frac{\text{kV}}{\text{gap}} = 1 \text{ megavolt.}$$

The design value for transit time (T.F.) factor is .75 and the stable phase angle (θ_s) envisioned is 45° . Thus a design energy gain of 400 keV for this accelerating cavity appears attainable with the 20 kilowatt RF power available.

The length of the accelerating structure is approximately 1/2 meter, thus the shunt impedance (including the effect of $\theta_s = 45^\circ$ & T.F. = .75) is

$$\frac{500 \text{ kV}}{1/2 \text{ m}} = \frac{1 \text{ MeV}}{\text{m}}$$

$$Z = \frac{(1 \text{ MeV})^2}{20 \text{ kW}} = 50 \frac{\text{M}\Omega}{\text{m}} (\theta_s = 45^\circ, \text{ T.F.} = .75)$$

IV. Field Distribution

From Fig. 8 it is seen that the maximum frequency shift in the cells ranged from 385 to 455 cycles, thus a 9% change in field can be expected

$$\frac{V_{\max}}{V_{\min}} = \left(\frac{455}{385} \right)^{1/2} = 1.09.$$

A drop off of field at the end cells is observed. One possible explanation for this effect is the lack of a stem and its associated inductance on the half drift tubes mounted on the cavity wall.

A typical perturbation plot through cells 6, 7 & 8 is given in Fig. 9.

Acknowledgment

The author wishes to recognize the efforts of P. Grand required for the mechanical design and construction of the Xenon Linac.

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.

¹ Ginzton, E.L., "Microwave Measurements," pp. 436-442, McGraw-Hill Book Company, Inc., New York, 1957

Fig. 1 Xenon Accelerator in Beamline

DRIFT TUBE ASSY.

FIG. 2

RESONANCE AND "Q" MEASUREMENTS

FIG. 3

COUPLER EQUIV. CIRCUIT

FIG. 4

EQUIV. CIRCUIT REFERRED TO SECONDARY
WHEN INPUT MATCHED AND TERMINATED
IN 50 OHMS.

FIG. 4A

RISE TIME

20 μ SEC/CM

FALL TIME

FIG. 5. "Q" MEASUREMENT BY FALL TIME

CLOSE LOOP PERTABATION MEASUREMENTS

FIG. 6

$$L = \frac{R_0}{\omega_0 Q_0} \quad C = \frac{Q_0}{\omega_0 R_0}$$

EQUIV. CIRCUIT REFERRED TO HIGH VOLTAGE POINT

FIG. 7

FIG. 8

FIG. 9

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