Reduced Length Design of 9.8 MHz RF Accelerating Cavity for the Positron Accumulator Ring (PAR) of the Advanced Photon Source (APS) *

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Abstract

A 9.8-MHz RF accelerating cavity is developed for the first harmonic system in the APS PAR [1] and an aluminum unit is tested. The design goal is 40 kV at the accelerating gap, Q-factor of $\sim 7,000$ for the accelerating mode, 1.2-m diameter, 1.6-m length with good mechanical strength and stability. The design employs no dielectric or ferrite loading for tuning. The cavity is a plunger-loaded reentrant coaxial structure; the end of the inner conductor facing the wall has a piston-shaped loading structure which consists of a circular disk and a cylinder. The RF characteristic of the cavity was investigated using the URMEL-T and MAFIA programs. Compared with a coaxial structure with lumped element capacitive loading, this design gives improved RF characteristics.

I. Introduction

Designing low-frequency tuned RF accelerating cavities for high power operation with a cavity length ℓ much less than a quarter wavelength is impossible without extra capacitive loading. One way to shorten cavity length is to use folded coaxial structures as shown in Figure 1. However, if the maximum radius of the cavity is specified, the characteristic impedance of the coaxial transmission line becomes lower as the number of folds increases. The reactance at the open end of a short-circuited coaxial line is $Z_{in} = jZ_o tan(\beta\ell)$. The characteristic impedance of the coaxial transmission line

$$Z_o = 60 \; ln\frac{r_2}{r_1}, \tag{1}$$

where r_2 and r_1 are the radii of the outer and inner conductors, respectively. With lower characteristic impedance of the transmission line, Z_o, Z_{in} does not increase appreciably until the total line length ℓ approaches $\lambda/4$.

By analogy of an equivalent $L-C$ resonant circuit, greater capacitance is needed near the accelerating gap and greater inductance is needed near the short-circuited end to reduce the cavity length. Eq. (1) suggests that using the outermost conductor for the low Z_o coaxial section and the innermost conductor for the high Z_o coaxial section is more efficient in getting a shorter cavity length for a specified cavity radius. A design of this cavity is shown in Figure 1. In Figure 2, a capacitive loaded, foreshortened $\lambda/4$ coaxial cavity is shown. In the following section, these two reduced length coaxial cavities are discussed and compared with equivalent transmission line circuit analysis. This design is found to be good for determining the cavity dimensions for a given fundamental mode frequency and voltage distribution. The URMEL-T and MAFIA codes were used in computer simulation of the cavities to find the frequencies, modal field patterns, and shunt impedances. The conductivity of copper was used in the simulation.

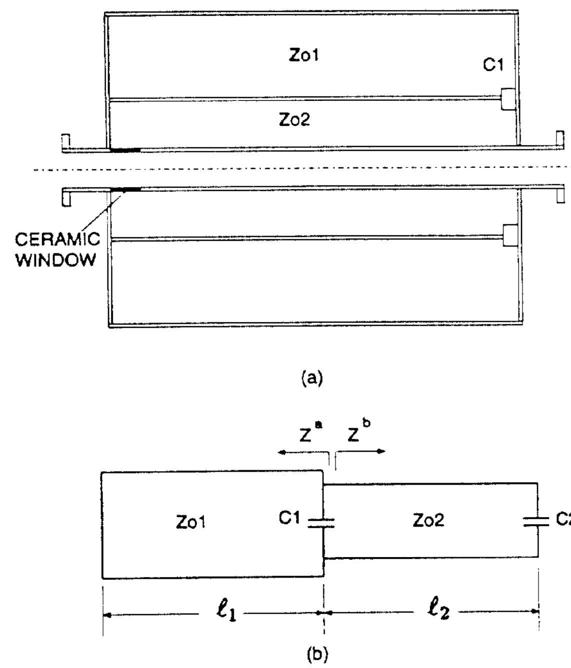

Figure 1
Folded coaxial cavity and equivalent circuit

II. Cavity Designs

A. Folded Coaxial Cavity

The folded coaxial cavity with lumped element capacitive loading is shown in Figure 1. Using the equivalent circuit, the loading capacitance C_1 is solved as

$$C_1 = \frac{Z^{b*} - Z_{o1} tan\beta\ell_1}{\omega Z_{o1} Z^{b*} tan\beta\ell_1}, \tag{2}$$

where Z^b is the impedance looking into coaxial line with Z_{o2} as shown in Figure 1 and * denotes the complex con-

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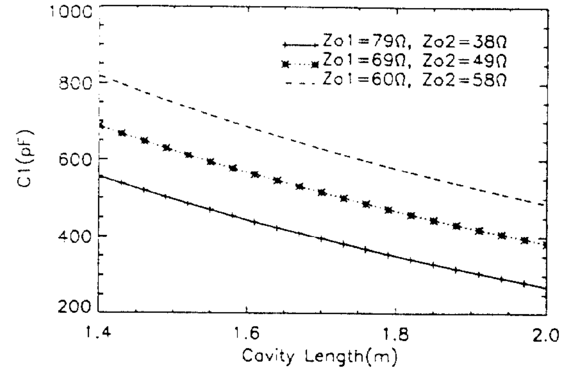

Figure 2
Loading capacitance in a folded coaxial cavity.
$f = 9.8\ MHz, r = 0.6\ m$.

Table 1
Computed modes for the 9.8-MHz folded coaxial cavity TM0-monopole modes, TM1-dipole modes, EE-end plates are electric wall. Voltage integrated at $R_o = 0.0\ m$ off-axis for monopole modes and at $R_o = 0.076\ m$ off-axis for dipole modes.

$MODE$	$FREQ$ (MHz)	Q	R_s $(M\Omega)$
TM0-EE- 1	9.82	12689	0.635
TM0-EE- 2	49.88	9372	1.010
TM1-EE- 1	76.04	10040	0.000
TM0-EE- 3	97.24	34276	0.007
TM0-EE- 4	140.46	15537	0.599
TM1-EE- 2	157.28	58638	
TM0-EE- 5	192.41	47295	0.005
TM1-EE- 3	228.76	61723	

jugate.

The loading capacitance C_1 with respect to the cavity length and the characteristic impedances Z_{o1} and Z_{o2} are shown in Figure 2 for the case of the 9.8-MHz cavity. The cavity has a length ℓ=1.6 m, a radius r_2=0.6 m, and a 13.0-cm accelerating gap length. These results show that lower Z_{o2} and higher Z_{o1} are required to lower the resonant frequency of the cavity for a fixed cavity length. The voltage across C_1 is > 90% of the gap voltage across C_2 [2]. The lower Z_{o2} requires smaller distance between the inner and the outer conductors, which is incompatible with high voltage operation. In order to increase the distance between the conductors, greater loading capacitance is required. The URMEL-T code was used with the constraints ℓ=1.6 m, r_2=0.6 m, 0.13 m of accelerating gap length, and 10.0 cm of conductor separation in the inner coaxial structure and permittivity of the anular dielectric ring was varied to simulate the ~500 pF of extra capacitive loading. Table 1 shows the properties of the monopole

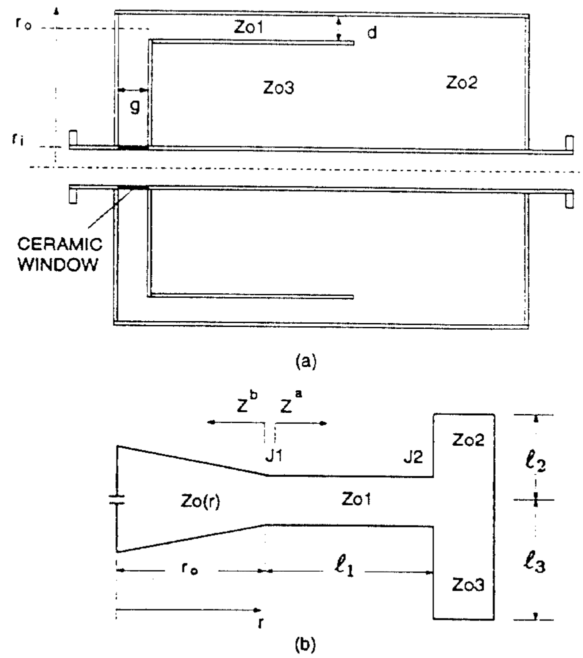

Figure 3
Loaded gap cavity and equivalent circuit

and the dipole modes of the folded coaxial cavity obtained from the computer simulations.

The inner coaxial structure must have a minimum of 10 cm of separation between conductors for high voltage operation [1, 2]. The capacitive loading may be realized by using one or more circular disks at the junction of the coaxial transmission line sections. A circular parallel plate capacitor with 50-cm radius will have a capacitance of about 500 pF if the spacing between the plates is 1.5 cm. However, this small spacing is not desirable for high-voltage application.

B. Loaded Gap Cavity

A coaxial cavity and its equivalent circuit are shown in Figures 3(a) and 3(b), respectively. This design uses a parallel plate radial transmission line across the accelerating gap for the low Z_o structure. This configuration is useful in lowering the resonant frequency for a fixed cavity size, since the coaxial line section near the short-circuit with Z_{o3} utilizes the beam pipe as the smaller radius of the center conductor, and the section closer to the gap with Z_{o1} utilizes the cavity outer wall as the outer conductor.

The input impedance seen in the direction of the short-circuited coaxial transmission line is Z^a, and at J_2 the two transmission line sections 1 and 2 are connected in series.

At a desired resonant frequency, $Z^a = Z^{b*}$ and the length of the high impedance transmission line section ℓ_2

is found to be

$$\ell_2 = \frac{1}{\beta} tan^{-1} \left(\frac{N_1 - N_2}{D} \right), \tag{3}$$

where

$$\begin{aligned} N_1 &= Z^{b*}(Z_{o1} - Z_{o3} tan\beta\ell_1 tan\beta\ell_3) \\ N_2 &= jZ_{o1}(Z_1 tan\beta\ell_1 + Z_3 tan\beta\ell_3) \\ D &= Z_{o2}(jZ_{o1} + Z^{b*} tan\beta\ell_1). \end{aligned}$$

and Z^{b*} is the input impedance of the radial transmission line at $r = r_o$ [2, 3].

In a computer simulation for 9.8 MHz, a 0.6-m outer radius and a 1.6-m total length were used. The accelerating gap length g and the conductor spacing d were chosen to be 13 cm and 9 cm, respectively. This gap length is sufficient for accelerating voltage. Figure 4 shows the length ℓ_2 versus the spacing d of the low impedance coaxial line with Z_{o3}.

The monopole and dipole modes found from the computer simulation are listed in Table 2.

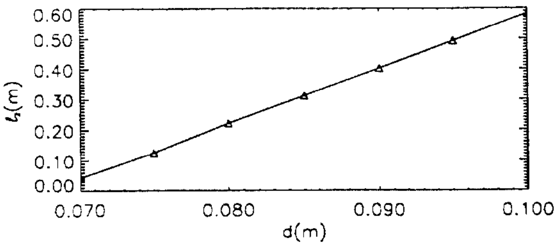

Figure 4
Transmission line length ℓ_2 vs. conductor spacing d of coaxial section with Z_{o1} for 9.8 MHz. ℓ_1=1.1 m, r=0.6 m, g=0.13 m.

Table 2
Computed modes for the 9.8-MHz loaded gap cavity TM0-monopole modes, TM1-dipole modes, EE-end plates are electric wall. Voltage integrated at R_o= 0.0m off axis for monopole modes and at R_o= 0.076m off axis for dipole modes.

MODE	*FREQ* (MHz)	Q	R_s $(M\Omega)$
TM0-EE- 1	9.82	10581	0.762
TM1-EE- 1	95.27	16225	0.004
TM0-EE- 2	97.07	22692	0.148
TM0-EE- 3	112.59	17871	0.332
TM1-EE- 2	158.80	20027	0.014
TM0-EE- 4	188.90	22431	0.690
TM1-EE- 3	193.48	68873	0.002
TM0-EE- 5	204.95	43563	0.012

Table 3
Measured frequencies and Q-factors of the 9.8-MHz loaded gap prototype cavity.

		Measured	
MODE	$f(MHz)$	$f(MHz)$	Q
TM0-EE- 1	9.82	9.85	5171
TM1-EE- 1	95.27	94.85	4806
TM0-EE- 2	97.07	99.22	3026
TM0-EE- 3	112.59	114.87	1625
TM1-EE- 2	158.80	156.18	5315
TM0-EE- 4	188.90	180.00	4745
TM1-EE- 3	193.48	195.06	4744
TM0-EE- 5	204.95	249.26	2297

III. Prototype Measurement

One loaded gap cavity has been built and tested. The cavity is made of aluminum with a copper center conductor. The shunt impedance and the Q-factor are 160kΩ and 4900, respectively, at the fundamental mode frequency of 9.8 MHz. Table 3 shows the measured frequencies and Q-factors. The measured frequencies agreed well with the simulation. The fact that the computed shunt impedance and Q-factor are greater than the measurement may be due to unwelded conductors. For the required accelerating voltage of 40 kV, the input power is ~5 kW.

IV. Conclusion

The loaded gap cavity is easier to implement and requires much less critical capacitance than the folded cavity. Comparing simulation results of the folded and the loaded gap structures for the fundamental mode, the loaded gap design has higher R/Q by ~ 40% and lower Q by ~ 15% than the folded structure. Comparing the simulation results for the above two cavities, it can be seen that the higher-order mode frequencies differ significantly and the monopole and dipole modes are ordered differently. The prototype loaded gap cavity has acceptable RF characteristics and required mechanical strength.

V. References

[1] M. Borland, "Update on the Argonne Positron Accumulator Ring," these proceedings.

[2] Y. W. Kang, R. L. Kustom, and J. F. Bridges, "Reduced length design of 9.8MHz APS/PAR cavity," APS Light Source Note LS-211, May 1992.

[3] Ramo, Whinery, and Van Duzer, Fields and Waves in Communication Electronics, John Wiley and Sons, New York, 1965.