MICROWAVE COLD TESTS OF PLANAR RF CAVITIES*

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Abstract

The RF cavities for a sheet-beam klystron [1] are designed for a strip electron beam interacting with the electromagnetic fields. The axial electric field for these cavities is constant over the width of the beam. The cavity design can be adapted as a basic cell structure for high-frequency, traveling-wave, planar accelerators. We report here rf measurement results on the field uniformity, isolation between cavities and other pertinent characteristics of the cavities at a scaled frequency of 11.4 GHz. Comparisons are made with MAFIA simulations.

INTRODUCTION

Recent interest in planar rf cavities has stemmed from two developments. First, it has been found that a sheet electron beam with a large aspect ratio can be used in a high power klystron to avoid many of the shortcomings of a conventional round beam klystron. A sheet beam klystron with a low perveance per square is capable of high rf conversion efficiency. Yu *et al* [1] have designed a 200-MW X band sheet beam klystron with an efficiency of over 65%, using a flat beam of dimensions 0.5 cm $\times$ 16 cm, at a beam current of 770 A and a beam voltage of 400 kV. The sheet beam klystron is particularly suited to operate at high frequencies (up to 100 GHz), because its output power scales linearly with wavelength, rather than quadratically as in the case of a round beam klystron. The sheet beam klystron cavities have a planar, barbell-like geometry providing a flat axial field in the region through which the beam traverses [2]. A schematic of a barbell cavity is shown in Figure 1.

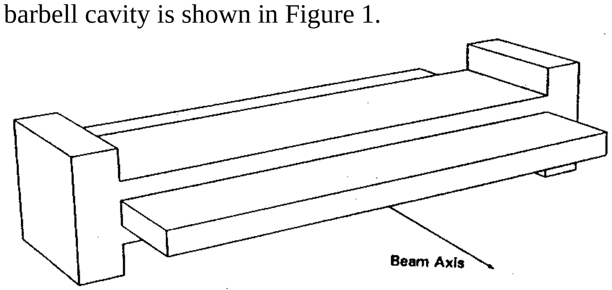

Figure 1 Schematic of a Planar Barbell Cavity

Another recent development for which planar cavities would be useful is high-frequency rf accelerators [3]. High gradient acceleration requires operation at high frequencies. At high frequencies (e.g. > 50 GHz), it is almost certain that the tolerance requirements of a cylindrical, disk-loaded structure of a conventional design cannot be met by traditional manufacturing techniques, i.e. precision machining and brazing. Modern microfabrication techniques [4] such as LIGA or wire EDM, on the other hand, are particularly suitable for planar structures. A planar traveling wave accelerating structure may consist of a series of barbell-like planar cavities, or variants thereof, connected by short rectangular beam pipes [5] as shown below.

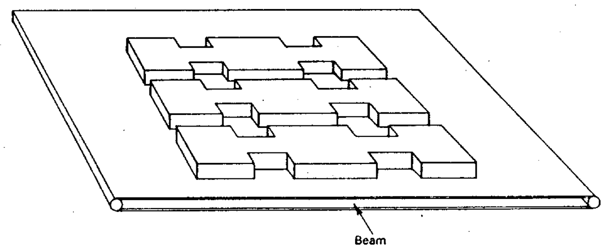

Figure 2 Schematic of a Planar Tugboat Traveling-Wave Structure (3 cells illustrated)

Planar accelerators and sheet beam klystrons using flat field cavities can in principle be mass produced with new microfabrication techniques.

DESIGN AND FABRICATION OF THE BARBELL CAVITY

Traditional cylindrical pillbox rf cavities have axial electric fields quite uniform near the axis in both magnitude and phase, at any given instant of time, along the transverse dimensions. This important feature has been exploited in many klystron and accelerator applications in which the electromagnetic field in the cavity interacts with a bunched beam of finite size. The accelerating fields should be constant in the region traversed by the beam as it goes through betatron motion in an external axial magnetic field.

The axial electric field (E_z) in a rectangular cavity of width L and height H assumes a profile of $\sin(m\pi x/L)\sin(n\pi y/H)$, where m and n = 1,2,3… Thus, rectangular cavities (including the so-called muffin tin [5]), unlike their cylindrical counterparts, have a sine-like accelerating field along the transverse direction of the cavity. For the lowest order mode, the field exhibits a maximum at the center and vanishes at the walls.

The barbell cavity features a constant axial electric field along the transverse direction near the beam axis. Flat field is important for acceleration of a flat beam, either in a klystron or in an accelerator. Even if a round beam is used in a planar structure, the field should be flat at least within the betatron radius. The design principle of a planar barbell cavity is that the resonant frequency of the central section of the cavity is at or near cutoff for rf

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propagation in the transverse direction, while the two ends of the cavity are below cutoff, thus producing a flat electric field in the central region of the cavity. Figure 3 shows a MAFIA axial field plot of the fundamental TM mode of our first X band barbell cavity.

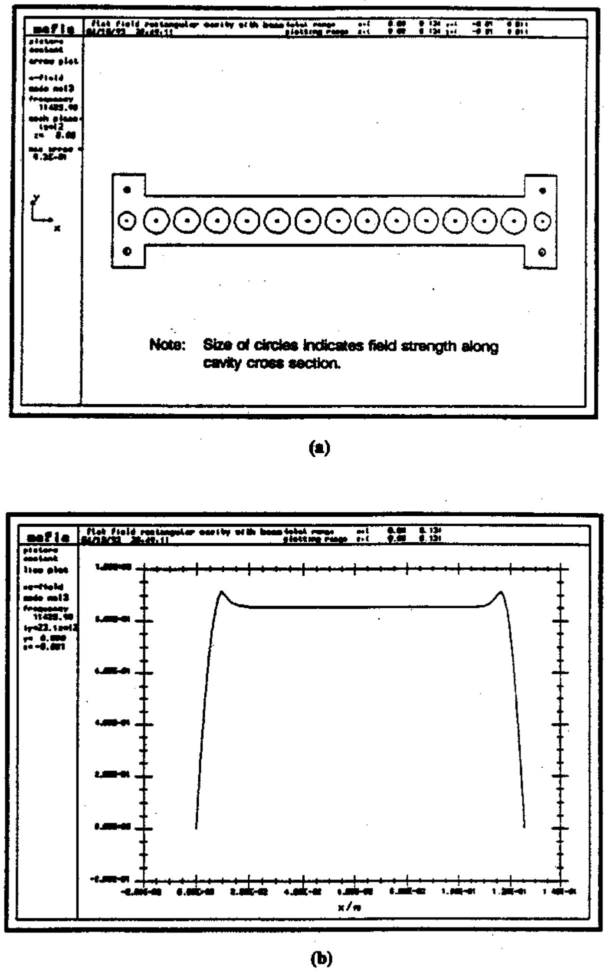

Figure 3 MAFIA Axial Electric Field Plots of a Barbell Cavity. a. Arrow plot b. Line plot

The flat surfaces defining the boundaries of the barbell cavity, or variants thereof such as the "Tugboat" and "H-block" cavities [6], can be etched using deep x-ray lithography techniques. Alternately, they can be cut with wire EDM techniques, and different layers of the structure can be bonded together using diffusion bonding techniques. These manufacturing techniques are particularly useful at high frequencies, at which the structures become increasingly miniaturized. At frequencies below 30 GHz, these structures can still be made with conventional machining and brazing techniques.

As a first experiment to demonstrate the rf properties of the planar flat-field structure and to verify the MAFIA simulations, we designed a barbell cavity at 11.4 GHz. The properties of the cavity are calculated with MAFIA. The electric field for the fundamental TM mode, shown in Figure 3, is constant over a wide aperture of 8.8 cm. The calculated Q of this mode is 6800. The frequencies of the higher order TM modes are listed in Table 1.

Table 1 Resonant Frequencies (MHz) of TM Modes of an X-Band Barbell Cavity

MAFIA	Measured
11420	11498
11491	11547
11695	11734
12026	12060
12474	12508
13026	13038
13669	13747

If two barbell cavities are connected by a rectangular beam pipe, it is possible to couple the fundamental TM mode of two adjacent cavities through a propagating TE mode in the beam pipe connecting them, provided there is any asymmetry due to fabrication imperfection, or if the beam is off axis.

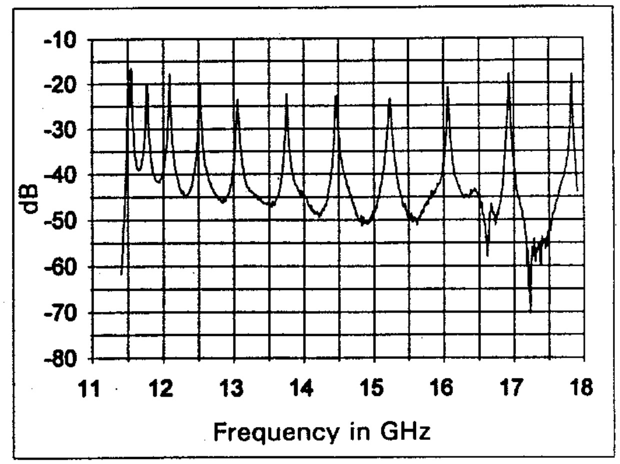

Figure 4 TM Modes frequency Spectrum of a Barbell Cavity as Measured with a HP8510C Network Analyzer

COLD TEST RESULTS

A structure consisting of two identical barbell cavities connected by a short beam pipe was fabricated by ANL using design drawings provided by DULY Research. We performed cold tests for these cavities on a HP8510C Network Analyzer. Test data were displayed and stored on a PC using LABVIEW4. To measure the frequencies of the cavity, a small current loop was inserted through a hole on the cavity end wall to excite the magnetic fields of the cavity modes. Depending on the orientation of the current loop with respect to the beam axis, TM or TE modes of the cavity would be excited. After properly calibrating the network analyzer for the frequency range of interest, we measured in a straightforward way the frequencies of the modes excited by the current loop. The measured and calculated resonant frequencies of the first few TM modes of the barbell cavity are shown in Table 1 and Figure 4. The Q of each mode was measured directly from the half width of the resonance. To measure the transmission through the beam pipe, a small current loop is inserted through a hole in a first cavity, and another loop is inserted through a small hole on the side wall of a second cavity, connected to the first by a beam pipe. The cold measurements confirmed the modal frequencies predicted by MAFIA, and the large coupling between the TM modes of the cavities.

In a cavity with a wide transverse dimension, spurious higher order TM modes may exist. However, if there is sufficient frequency separation between the fundamental and higher order modes, and if the Q values of the modes are high, then the existence of the higher order TM modes need not adversely affect the beam acceleration which occurs in the narrowband fundamental TM mode.

The cavities fabricated by ANL unfortunately were welded rather than brazed as specified in the drawings. The measured Q for the fundamental TM mode was 1100, compared with a calculated Q of about 6800. Because of the lower Qs resulting from fabrication imperfection, the separation between the fundamental mode and the first higher order TM mode was not as clean as it could be. Consequently, measurement of the electric field of the fundamental mode alone was difficult. A bead pull measurement confirmed that there was considerable mixing between the first two TM modes.

In order to improve the results, we have designed another cavity by shortening the transverse dimension by one-third, thus increasing the frequency separation between the fundamental and the first higher order TM modes from 60 MHz to 170 MHz. The calculated frequencies for the TM and TE modes of the shortened cavity are shown in Table 2. The new cavity has now been fabricated in a precision machine shop at Los Angeles and is being brazed together for final test. We expect that the larger modal separation, combined with higher Q values, should enable measurements to confirm the flat field predicted by MAFIA.

Table 2 TE and TM Modes of a Shortened Barbell Cavity

TM modes	TE modes
11439.3	5992.38
11608.5	7100.01
12058.7	8197.42
12733.8	8629.78
13713.1	9053.06
14829.8	10388.2
16077.0	11859.9
17407.8	11859.9
17844.9	12264.0

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REFERENCES

[1] D. Yu, J. Kim, P. Wilson, "Design of a High Power Sheet Beam Klystron", AIP Conference Proceedings 279, Advanced Accelerator Concepts Workshop, Port Jefferson, Long Island, NY, June 14-20, 1992. pp. 85-102.

[2] D. Yu, P. Wilson, "Sheet Beam Klystron Cavities", Proceedings of the 1993 Particle Accelerator Conference, Washington D.C., pp. 2681-2683, May, 1993.

[3] D. Yu *et al*, "Design and Microfabrication of Planar Accelerating Structures", Proc. of the 6th Adv. Accelerator Concepts Workshop, Lake Geneva, Wisconsin, June 12-18, 1994.

[4] P. Chou *et al*, "The Fabrication of Millimeter-Wavelength Accelerating Structures", SLAC-PUB-7339, November, 1996, presented at the 7th Workshop of Advanced Accelerator Concepts, Lake Tahoe, California, October 12-18, 1996.

[5] H. Henke, "Planar Structures for Electron Acceleration"; Proc. of 1995 Particle Accelerator Conf., p. 1750, Dallas, Texas, May 1995; D. Yu and H. Henke, patent pending.

[6] DULY SBIR Phase I Final Report, DE-FG03-96-ER82213, May, 1997.