APLE ACCELERATOR PROTOTYPE CAVITY FABRICATION AND LOW POWER TESTS*

A. M. Vetter, T. L. Buller, T. D. Hayward,
D. R. Smith, and V. S. Starkovich
Boeing Defense & Space Group
P.O. Box 3999, M/S 2T-50
Seattle, WA 98124-2499

Abstract

The first 5-cell, 433-MHz accelerator cavity [1] for the APLE free electron laser experiment at Boeing has been assembled and tuned. Low power RF measurements indicate that the critical electrical parameters (Q_o, f, and β) for the accelerator and TM_{110}-like modes are consistent with expectations based on measurements made on an 800-MHz model cavity. The cavity is being readied for its initial vacuum bakeout, during which the constituents of the residual gas will be monitored. First application of high power RF is scheduled for late summer of 1993.

I. INTRODUCTION

A 5-cell, 433-MHz accelerator cavity [1] has been developed for high average power FEL application. The cavity electrical design is derived from the familiar storage ring cavity exemplified in PEP [2] and PETRA. The cavity is a slot-coupled, π-mode standing wave structure, center fed through a waveguide coupler. Design and operational parameters are summarized in Table 1. The general layout of the cavity is shown in Fig. 1.

Table 1
APLE 5-Cell Accelerator Cavity Parameters

Accelerator Mode Frequency	433.33	MHz
Relative BW $(f_o-f_\pi)/f_\pi$	.02	
Q_o	27000.	
R/Q	337.	Ω/cell
Shunt Impedance (V^2/P_c)	45.	MΩ
Accelerating Voltage	1.1	MV
Average Beam Current	.23	A
External Coupling Coeff	3.	
Duty Factor	.25	
Thermal Dissipation	165.	kW
TM_{110} Band Q_L	< 10000.	
Operational Pressure	5×10^{-8}	Torr

II. MECHANICAL DESIGN

A. Basic Fabrication Concept

We have elected to fabricate the cavities using bright copper plated aluminum 6061 parts with O-ring sealed joints. Using this approach rather than brazing together OFHC copper parts, we expect to: reduce the weight of the structure by half, affording easier handling and support; enhance structure ruggedness; allow repair in case of damage dur-

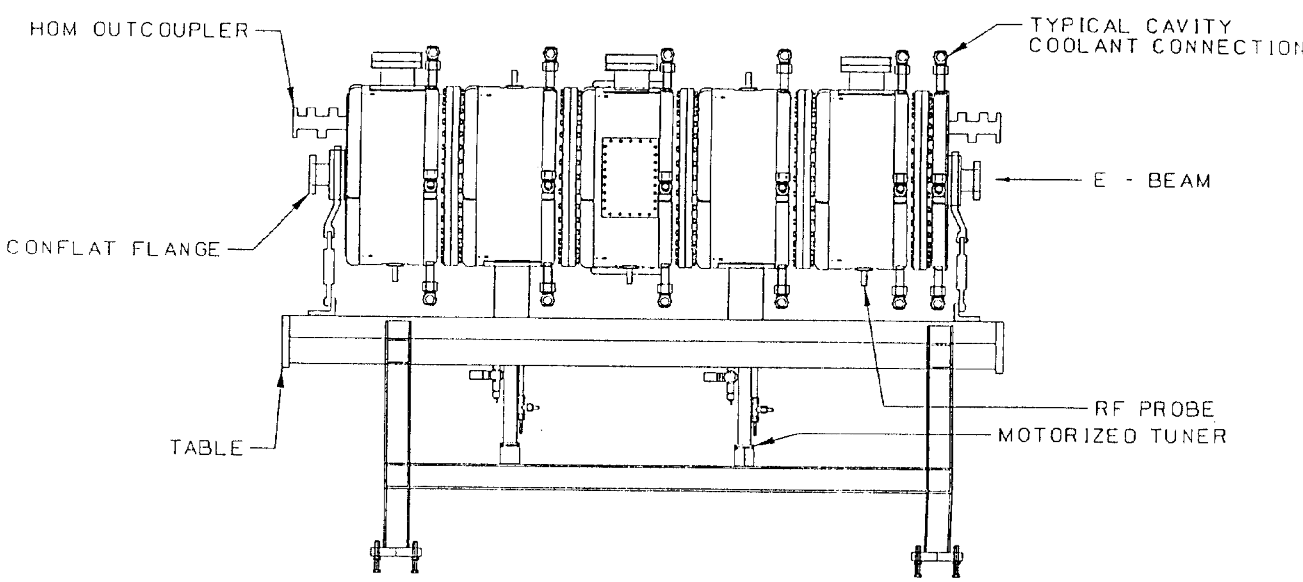

Figure 1. APLE 5-cell cavity layout.

*Work supported by USASDC/BMD contract DASG60-90-C-0106.

ing fabrication or operation; and avoid difficulties associated with brazing a very large copper structure.

The required processes are now well understood (a 95% yield rate is obtained in brazing and ~80% yield is obtained in plating), and the convenience of working with a lighter, stronger structure is appreciated daily.

B. Cell Design

In order to avoid having the equatorial joint between the two halves of a cell pass through the holes cut for tuners and external couplers, the joint has been moved longitudinally until the clamping bolt heads come up against the water manifold feeding the radial holes in the web. A mechanical unit cell is shown in Fig. 2. The external coupling aperture and tuner ports are shifted slightly relative to the center of the accelerating gap. An electrical cell therefore consists of one side of the web and associated shell of one mechanical unit, and the shallow side and web of the adjacent unit. The last cell is completed with an end cap which has a nose cone on one side only.

Both vacuum and RF seals are required at circumferential joints between cell parts. The RF joint is formed by a 6.5-mm section silver plated C-seal [3], vented to avoid virtual leaks. Behind the C-seal, a 7-mm section Viton O-ring seal forms the vacuum joint. These seals are clamped by 36 3/8-18 studs equally spaced around the circumference.

C. Cooling

The high average power application of the cavity dictates that cooling channels must be embedded in the nose cones. These are fed by holes drilled from the outer cooling manifold radially through the web to the nose cone channels. These web channels lead the water around the ends of the coupling slots, which are also sites of high thermal flux. Water returning from the nose cones is circulated through half of the (typically) 32 holes running the length of the shell of the cell, collected in a manifold, and returned through the other longitudinal holes to a collection manifold over the web.

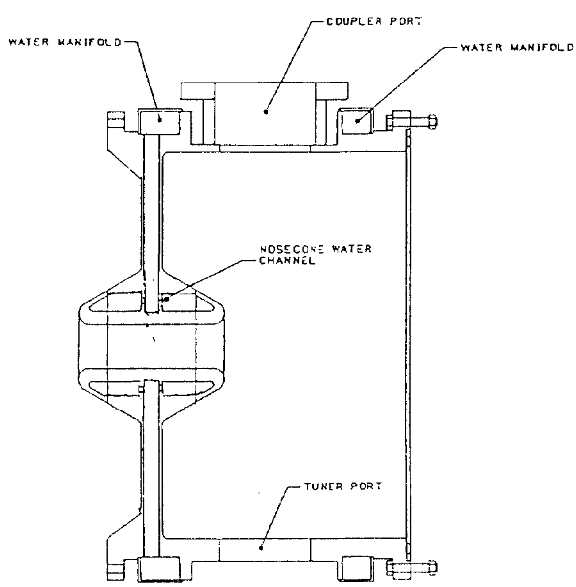

Figure 2. APLE cavity mechanical unit cell.

D. Accessories

Each cell is provided with a tuner and RF sample probe. Tuners in the end cells and center cell are not movable after initial adjustment for field flattening; tuners in the next-to-end cells are equipped with stepper motors. Tuner plungers are water cooled, and movable tuners have graphite RF dampers to spoil resonances behind the plungers, as in PEP and earlier Boeing cavities [4].

Each end cell is provided with a high order mode (HOM) outcoupler mounted in the end wall. The loop of this probe is oriented in the tangential plane, so that a minimum of 433-MHz power is coupled out. Following the loop is a high pass filter which prevents residual 433-MHz power from reaching the 10-W termination load.

The cavity is pumped through the waveguide coupler, which is fitted with a 10-cm cryopump. Provision is made for an optional titanium sublimation pump. The pumps are mounted on an H-plane miter bend, which isolates the RF window from direct line of sight of the coupling aperture.

After assembly and initial pump down, the evacuated cavity will be baked at 180° C for 24 hrs. We anticipate the base pressure will be 5×10^{-8} Torr after the bake.

III. FABRICATION

A. Brazing and Heat Treating

The cells, which ultimately differ slightly in inner diameter depending on their position within the cavity, were formed from identical 6061 aluminum forgings. The embedded nose cone cooling channels were machined in the forgings in an initial machine process during which the coolant holes were drilled in the web, the coolant manifold cut around the circumference, and the interior contours roughed out.

The exposed cooling channels in the nose cones were covered by annular rings which were vacuum brazed onto the forging. This braze step was initially conceived as a dip braze, but it was recognized that vacuum brazing would avoid problems with removing flux trapped in the cooling channels in the web. Initial attempts at vacuum brazing resulted in porous joints which leaked and often cracked during the subsequent heat treating. This was corrected by increasing the thickness of braze alloy, adding more getter to the vacuum chamber, and improving the clamping fixture.

Following the braze, the aluminum is very soft. T4 temper is recovered by reheating the part, followed by a glycol immersion quench and artificial aging. (A water spray quench was tried, but did not cool the part fast enough to recover temper.) The improved temper proved to be of value in subsequent machine operations during which the interior contour of the cell was taken to net dimensions, coupling slots were cut in the webs, longitudinal cooling and bolt holes drilled in the outer shell, and many minor features added. Beam pipe and HOM outcoupler flanges, water manifold covers, and the waveguide coupler box end were welded onto appropriate cells before turning the final inside contour.

The only remaining machine work at this juncture was the cutting of the O-ring grooves and mating surfaces on the major circumferential joints. This was deferred until after plating operations, which require much handling of the parts, in order to avoid damage to these critical sealing surfaces.

B. Plating

To prepare the 6061 aluminum parts for plating, the exterior surfaces were coated with plastisol and the surfaces to be plated chemically cleaned. The zincate bright copper plating process began with a zincate strike followed in turn by .5-mil electroless nickel plating, a cyanide copper strike, and finally 2.5 mil of bright copper plating.

For plating uniformity, special lead anodes were made to conform to the shape of the part. These anodes were enclosed in rayon fabric bags to prevent particles which form on the anode from falling onto the plating.

Several trials were required to determine the required thickness of the electroless nickel plating, which is consumed in the subsequent cyanide copper strike during which the pH must be carefully controlled. Considerable care is required at each step of the plating process.

After plating, assuming there were no obvious defects, the parts were baked for one hour at 100 Celsius. If no significant blisters or delaminations appeared, the parts were then baked for 24 hours at 200 Celsius. Any blisters greater than .1 inch across, or more than ten blisters of any size, or any blister on a nose cone resulted in rejection of the part, which must then be replated. Acceptable blisters were vented and pressed flat against the underlying aluminum. We also found occasional occurences of millimeter sized pits, which are acceptable if not located on the noses.

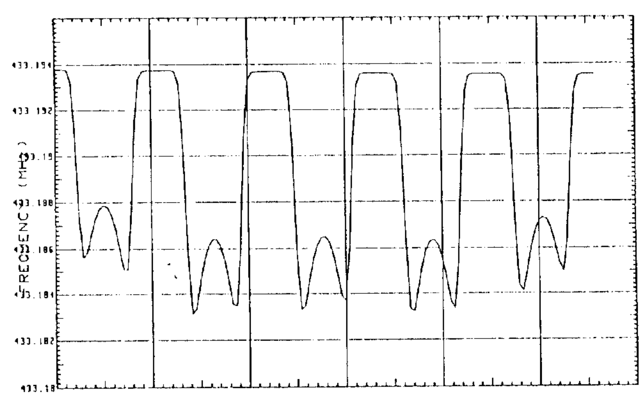

Figure 3. Field profile data. Downward deflection of trace is proportional to square of local field strength.

C. Final Assembly

Accepted plated parts were stripped of plastisol, and the O-ring grooves and mating surfaces turned. Interiors were scrubbed with ScotchBrite and wiped with acetone and isopropanol until clean. A final wipe with absolute ethanol preceded the stacking of the cells in vertical orientation. After the 180 clamping bolts were tightened, the cavity was tipped horizontal and placed on a transport cart for installation of accessories, leak checking, and various electrical measurements.

IV. LOW POWER ELECTRICAL MEASUREMENTS

The Q_o of the assembled cavity has been measured at 26,600, with an external coupling coefficient of 2.94. This is the Q expected for a brazed copper cavity with this geometry, so the RF quality of the plating and C-seal joints is evidently quite satisfactory.

The field profile (Fig. 3) shows the end cells about 5% below the mean field strength, and interior cells about 3% above. Sample probes are adjusted to deliver approximately 400 mW into 50 Ω with 1 MV/cell accelerating voltage.

TM_{110} band Q_L varies from 2000 to 9000, depending on the particular structure mode, with the HOM outcoupler adjusted for minimum accelerator mode loading. Relative to the main power coupler input, the outcoupler insertion loss exceeds 80 dB at 433 MHz.

Electrical measurements have consistently been predicted on the basis of previous measurements made on an 800-MHz aluminum model cavity, except that the end cell frequencies are unexpectedly high by a few hundred kHz. End cell diameters have been corrected on the follow-on three-cell cavities.

V. ACKNOWLEDGEMENTS

The authors extend special thanks to many people at the following companies: Lenape Forge, Inc. of West Chester, PA; Thompson Industries, Ltd. of Hawthorne, CA; Harbor Island Machine, Lukas Machine, Inc., and Industrial Plating of Seattle, WA; and AccSys Technology of Pleasanton, CA. Due to the efforts of these principal vendors, total flow time from ordering the forgings to completion of low power measurements on the first 5-cell cavity has been 14 months, with completion of the second 5-cell and two 3-cell cavities expected within five months.

VI. REFERENCES

[1] T. L. Buller, et al., "Design of the APLE Accelerator Cavity," Proc. 1992 Linear Accelerator Conf., Vol. 2, p. 689.

[2] M. A. Allen, et al., "RF System for the PEP Storage Ring," IEEE Trans. Nucl. Sci. NS-24, No. 3, 1780 (1977).

[3] B. Rusnak, et al., "Evaluation of RF Seals for Resonant Cavity Applications," Proc. 1990 Linear Accelerator Conf., p. 129.

[4] A. M. Vetter, et al., "High Power Tests of 433 MHz Single-Cell Accelerator Cavities and Associated Feed System," Proc. 1989 Particle Accelerator Conf., p. 183.