DESIGN OF THE APLE ACCELERATOR CAVITY*

T. L. Buller, T. D. Hayward, D. R. Smith,
V. S. Starkovich, and A. M. Vetter
Boeing Defense and Space Group
P.O. Box 3999, M/S 8Y-39
Seattle, WA 98124-2499

Abstact

A 433-MHz, 5-cell, slot coupled, standing wave cavity, operated in the pi-mode, has been designed for the Average Power Laser Experiment (APLE) at Boeing in Seattle. The cavity is designed to provide approximately 5 MeV acceleration for electron beams of roughly 200 mA (CW). The design parameters, results of low power RF measurements on model cavities, thermal analyses, and fabrication approach are described.

Introduction

The proposed APLE experiment at Boeing is an RF-driven FEL operating at 10.6 microns. The required performance parameters for the 5 cell standing wave structure are shown in table 1:

Table 1
Required Performance Parameters

Duty Factor	CW (100 %)
Accelerating voltage	$\geq$ 5 MV
Average beam current	230 mA
Klystron power (peak)	$\leq$ 2 MW at 433 MHz
Pulse length (FWHM)	60 ps
Pulse charge	8.5 nC
Reptition frequency	27.1 MHz
Maximum pressure	1 x 10^{-7} Torr

The 5 cell structures are driven in tandem by one 4 MW, 433.333 MHz klystron (25% duty factor). The power split is accomplished with a quadrature hybrid arrangement, with equal power reflected from the two cells combining into a water load. The two cavities are operated (n $\pm$ 1/4) x 360 degrees apart in phase (where n is an integer)and located (n $\pm$ 1/4) x free space wavelength apart. They are designed to be matched at the full beam loading. This relates to a cavity coupling coefficient of 3 (no-beam VSWR = 3 : 1). We now proceed to outline some of the more important details in the design of the structure.

Mechanical Design

The APLE accelerator cavities are formed from 3- and 5-cell configurations. A 5 cell structure is shown in figure 1. The cell structures are copper plated 6061 aluminum. Cells are bolted together and capped with an end plate to form the cavity. The separation plane is near one end of the cells so that it does not interfere with the ancillary equipment (RF waveguide coupling, slug tuners, and RF probes, that are mounted near the equatorial plane of the cells). The high current RF contact between the cells is made with a 6.5 mm section silver plated C-seal[1]. These seals are vented to eliminate virtual leaks, and the vacuum seal is made with a 7 mm section viton O-ring located outside of the C-seal.

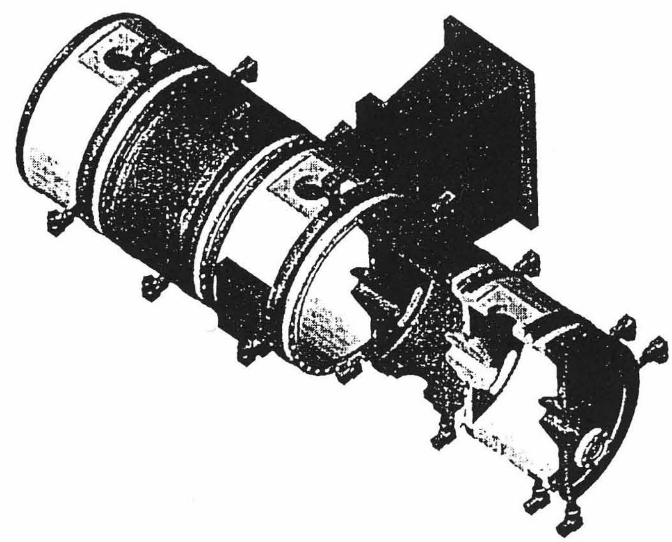

Figure 1

The cells which are slightly different, depending upon their position within a cavity, are all formed from a common aluminum forging. The only cooling water-to-vacuum interface occurs at the closure of the nose cone cooling passages. These interfaces are closed by aluminum vacuum brazes prior to final nose cone contour machining. External cooling manifolds and mounting flanges are TIG welded prior to final machining. After final machining, the RF surfaces are bright copper plated using the zincate process. The cells are vacuum baked at 200^0 C for 24 hours, to verify the quality of the plating and to drive off any moisture from the plating process. Next, the cells are assembled and the resonant frequency is measured. The compliance of the C-seals is 0.5 mm, which allows a final cut to be taken across the end of the cell. This is used to compensate the cell frequency for manufacturing tolerances in the machining and

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plating process. This frequency correction can be up to 200 kHz .

Each cavity is pumped by a 100 mm diameter cryo-pump mounted on the waveguide between the coupling iris and the vacuum window. In particular, this waveguide will be a H-plane mitre bend so the window is not visible from the electron beam path to reduce damage to the window ceramic from recombination radiation. This bend will have vacuum pumping ports built into the H-planes. Provisions are also made for the addition of a titanium sublimation pump. After assembly and initial pump down the evacuated cavities are baked at 180^0 C for 24 hours. After this, the anticipated base pressure is 5×10^{-8} Torr.

The advantages that we have found for the bolted copper plated aluminum structure compared to a brazed solid OFHC copper are: significantly reduced materials and manufacturing costs; one third the assembly/component weight, making handling, installation, support and alignment easier; a stronger less fragile assembly; and we anticipate that the bolted structure will facilitate inspection, repairs, and modifications.

Support and alignment of each cavity is very similar to that used on the PEP cavities. It is a three point kinematic support (hexapod) with negligible coupling between the alignment parameters. An offset alignment approach accommodates alignment checking and or monitoring.

Electrical Design

As can be seen from examining figure 1, the APLE structure is driven through a full (WR-1800) to half-height tapered coupling box on the center cell. This reduces the size of the coupling slot. The minimum thickness of the 'edges' of this aperture are kept large (~0.4") to keep the temperatures down at CW operation. A symmetrization well opposite the coupling slot serves to move the electrical field center back to the physical center of the cell.

The cells are of a re-entrant nose cone shape. The aperture is 2 inches. This keeps the shunt impedance high and has a negligible effect upon the wakefield effects. The cell to cell coupling is provided by 4 kidney shaped slots each subtending 30 degrees of arc. The slots are 90 degrees apart. Each cell is equipped with a cooled slug tuner and field sampling probe. The tuners have damping for beam driven tuner modes. The damping of higher order modes in the accelerator structure is done as described in references 2 and 3. Some of the electrical characteristics are listed in table 2. As the heat load in the structure increases, the five cells become lower in natural frequency. The active tuners in cells 2 and 4 are moved in, keeping the input VSWR a minimum. This raising of the resonant frequencies of the number 2 and 4 cell tends to deplete the field in them, leading to a field unflatness. The bandwidth of nearly 2 % keeps this to an insignificant amount, even if the field is initially flat when cold.

Table 2
Electrical Characteristics
Five Cell APLE Cavity

Shunt Impedance ($\equiv V^2/P_{diss}$)	>45 Mohm
Shunt Impedance (no coupling)	60 Mohm
Relative bandwidths	
accelerator mode	1.9 %
dipole mode	2.9 %
Input coupling parameter	3 : 1
Joulean losses (CW)	600 kW
Cell de-tuning (CW)	~ 300 kHz
Peak electric Field	0.7 Kilpatrick
Field unflatness (CW)	< ± 10 %
deQing (due to slots)	20 %

Cooling Design

The 5 cell structure must be cooled to remove the resistive losses in the cavity walls. Each cell is independently cooled using a series of manifolds and drilled passages designed to provide maximum cooling in the areas of highest heat concentration. The coolant travels axially through the outer cylinder of the cells, radially inward through the web, circulates around the nose-cone, then exits radially outward through the web and axially again through different drilled passages in the outer cylinder. The required performance parameters for 100 % duty operation for each cell are given in table 3:

Table 3
Cooling System Performance
per cell

Duty factor	100 %
Coolant	De-ionized water
Power Dissipation	120 kW
Average Wall Temperature	< 100^0 C
Frequency Detuning	<500 kHz
Thermal Stress	<0.5 yield strength
Coolant Flow	11 gpm

The performance parameters were verified by analysis using computer models. The MAFIA[4] and POWER[5] codes were used to produce a heat flux distribution within a cell. The heat flux distribution was then mapped into a 3D ANSYS[6] model to produce thermal, stress, and displacement profiles. These profiles were used to modify the initial design and ultimately produce the cooling system described above which is compatible with the manufacturing approach and meets the performance requirements.

Summary

In conclusion, the APLE accelerator cavity should meet or exceed the required performance for successful operation of the APLE high average power 10.6 micron oscillator.

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