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DESIGN OF MCTD PHOTOINJECTOR CAVITIES*

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Abstract

The Modular Component Technology Development (MCTD) accelerator is an 8 MeV electron linac designed to test high power components and electron scources for a proposed FEL. The injector is two 433 MHz rf cavities with a photocathode at one end of the first cavity. Cavity shapes are based on Lasertron theory [Jones & Peter, IEEE Trans. NS32(1985)1794.], cavities designed by John Fraser, and practical constraints. RF measurements were made on 1/3-scale cavities. Fabrication of the cavities is nearing completion.

Introduction

The Modular Component Technology Development (MCTD) program is a part of Boeing's Free Electron Laser (FEL) program. Its purpose is to develop and test components for an 8 MeV, 0.125 A (0.5 A @ 25% duty factor) linac. The components under development are a high voltage power supply (140 KV @ 60 A), a regulator for producing 10 ms pulses, a klystron with 4 MW peak power at 433.33 MHz, a photocathode electron source, three types of standing wave rf cavities, a chicane buncher, a high power beam dump, and beam diagnostics.

This paper concerns the first two rf cavities, which are called photoinjector cavities. (The MCTD accelerator has 6 other cavities of the PETRA-type.) The design of the photoinjector cavities is based on the 1300 MHz cavities designed and built at Los Alamos.[1] John Fraser, retired from Los Alamos, provided a starting point for our 433.33 MHz design.

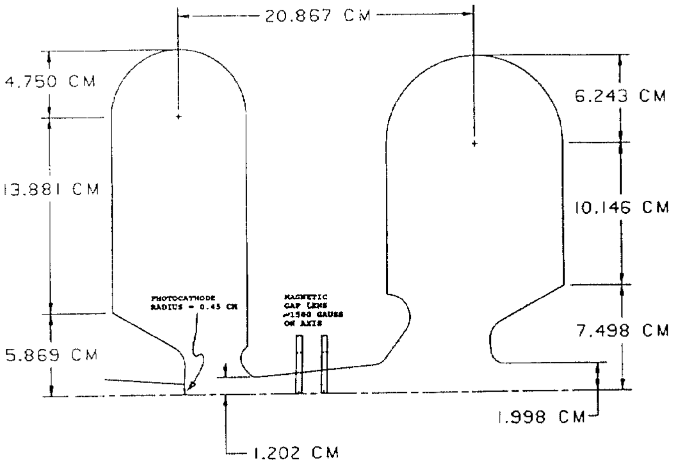

Fig. 1 Upper half MCTD Photoinjector Cavities f= 433.33 MHz; gap lens is two iron ring around the beam piped powered by an external magnetic circuit. Lengths are in centimeters.

Design Criteria

Figure 1 shows the shape of the photoinjector cavities. Only the upper cross section of these cylindrically symmetric cavities is shown. The shape of the first cavity near the beam axis is close to that proposed by Jones and Peter.[2] This shape should produce a transverse (r-axis) electric field component that changes linearly with radial distance (r-axis), thus minimizing the nonlinear growth of transverse beam emittance. (If the charge density in the bunch were linear in r, there would be no nonlinear emittance growth.) The shape of the second cavity starts from a reversal of the shape of the first cavity, modified because the electrons have higher average energy in the second cavity. The upper portions of the cavities simply provide the volume necessary for resonance of the accelerating mode at 433.33 MHz. The height of the cavity was limited by the diameter of prepurchased copper billets ($R \leq 25$ cm.) The final cavity dimensions were adjusted with the help of SUPERFISH.

The choice of distance between cavities depends on several interrelated factors. The maximum electric field gradient in the first cavity is limited to about 38.6 MV/m by removal of heat from the cavity walls (maximum of 250 kW at cw.) Because of planned future FEL application, all cavities must be designed for cw operation, even though MCTD operation is limited to 25% duty factor. With this gradient, the energy gain in the first cavity is less than 0.9 MeV as calculated by PARMELA. The MCTD electron bunches will contain about 10 nC, have a length of 60 ps and hence a peak current of 167 A. The diameter of the photocathode will be about 0.9 cm. At this low energy, space charge forces will cause substantial tranverse expansion of the bunch before it leaves the first cavity. The second cavity must be placed close to the first to raise the energy as quickly as possible. Relativistic effects will slow the apparent expansion of the beam. The distance is further restricted by a requirement of 90° rf phase difference between the cavities. In MCTD one 4 MW klystron will feed two pairs of cavities. This splitting fixes the phase between members of a pair. The transit time for 90° is 5.77 ns. If the particles were traveling at the speed of light, that would correspond to 17.31 cm. This spacing is barely adequate for the cooling water manifolds and a magnetic gap lens. The gap lens applies a radial impulse that counteracts the space charged-induced radial momentum acquired during passage through the first cavity. Without the lens the beam would strike the beam pipe at the end of the third cavity.

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*Work sponsored by U.S. Army Stratgic Defense Command under contract DASG60-87-C-0052.

CH2669-0/89/0000-0420$01.00©1989 IEEE

The Design

Figure 2 compares the "Lasertron" shape given by Eqs.(1) and the first two rows of Table 1 with the actual cavity shape for the first cavity. Figure 3 is the same comparison for the second cavity. In Eqs(1) z_0 is the axial position at which the axial electric field $E_z(r=0,z)$ vanishes. (See Figs. 2 and 3 for the choice of z_0.) E_0 is the value of the axial electric field at the origin. The choice of z_0 depends on the expected electron transit time through the cavity and is somewhat arbitrary. It was taken to be the "length of the cavity." The quantity μ is a free parameter. Jones and Peter have found that $\mu = 0.15$ produced the smallest beam emittance in their simulations. The quantity was chosen to give the beam pipe radius r_{min}. From we obtained E_0 by requiring arbitrarily that = 100. This process just chooses a particular equipotential surface (from the infinite set) to be the cavity surface.

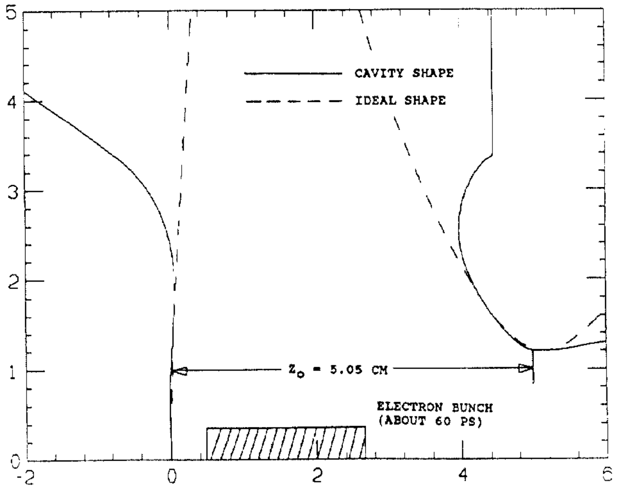

Fig. 2 Comparison of photocathode cavity shape with "Lasertron" cavity shape.

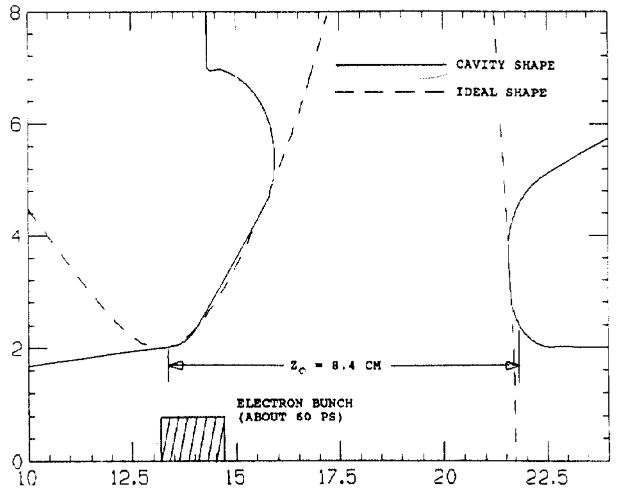

Fig. 3 Comparison of 2nd cavity shape with a reversed "Lasertron" cavity shape.

$$\rho^2 = 2[(\psi-\zeta)(1-2\mu)+\tfrac{1}{3}\zeta^3-\mu\zeta^2](\zeta-\mu) \qquad (1)$$
$$\zeta = z/z_0, \quad \rho = r/z_0, \quad \psi = -\phi/(E_0 z_0)$$

Table 1. Lasertron Parameters

Surface Element	z_0(cm)	E_0(V/M)	ψ	μ	r_{min}
Cavity 1 Cathode	5.05	----	0.00	.15	---
Cavity 1 Exit	5.05	19.80	77.27	.15	1.2
Cavity 2 Entrance	8.40	11.91	77.26	.15	2.0
Cavity 2 Exit	8.40	-----	0.00	.15	---

Other important cavity dimensions are given in Table 2.

Table 2. Cavity Dimensions

Dimensions (cm)	Cavity 1	Cavity 2
Length	5.05	8.4
Diameter	49.00	48.16
Radius of Dome	4.75	6.25
Throat Length	~3.95	~5.60
Entrance Diameter	0.9(Cathode)	4.00
Exit Diameter	2.4	4.00
Coupling Slot (z x O)	7.62x10.16	7.62x10.16
Vacuum Port (z x O)	≤7.6x10.2	≤7.6x10.2

Table 3. gives the electrical characteristics from the output of SUPERFISH and URMEL.

Table 3. Electrical Properties from SUPERFISH/URMEL

Quantity	Cavity 1	Cavity 2
Shunt Impedence(MΩ)	1.6	2.3
Quality Factor	22,822	26,646
Stored Energy(Joules)	0.0142	0.0622
Pwr. Dissipation(kW)	1.7075	6.3535
Max E-Field (MV/m)	3.189	5.045
Resonant Freq. (MHz)	436.1	432.95

The cavity shape was not adjusted to give the exact resonant frequency of 433.33 MHz since empirical corrections have to be made for the coupling slot, etc. The shunt impedence given by URMEL is based on the power definition $P = V^2/(2R_s)$.

Given the cavity fields from SUPERFISH, the beam dynamics were modeled using PARMELA; output is shown in Fig.4. The normalized transverse emittance, covering 90% of the electrons, at the end of the second cavity is 90.0 pi-mm-mrad, assuming zero emittance at the cathode. The emittance at the end of the accelerator however was only 36.6 pi-mm-mrad. The rapid transverse expansion of the beam produces an increased emittance after the first two cavities, which is reversed by the gap lens. The energy and energy spread at the end of the second cavity were 1.92 ± 0.08 MeV. The gap lens couldn't be modeled exactly, hence we expect the real emittance to be slightly larger.

We tried a cavity shape at the exit of the first cavity that more closely approximated the Lasertron shape. The PARMELA output was insensitive to this shape change.

Two-dimensional codes cannot give the final cavity dimensions because in practice one must cut in coupling slots, tuning ports, vacuum ports and ports for measuring rf power in the cavity, all of which change the resonant frequency. Port dimensions are given in Table 2. The short dimension of the slot is parallel to the z-axis. The vacuum port is cut-in 180^{o} from the coupling slot to reduce the asymmetry effects. The coupling slot is attached to half-height WR1800 waveguide by a tapered section. The rf enters the cavity in the TE10 mode.

Third-Scale Cavity Measurements

A series of rf measurments were made on a one-third scale aluminum model to determine the sensitivity of the resonant frequency to ports and change in cavity diameter. Figure 5 shows an engineering drawing for the cavities, which are made in two halves and brazed together. The rf measurements were made with the halves clamped together instead of brazed, for ease of machining between measurements. Therefore the measured Q was much lower than the calculated value. The measured R_s/Q value for the first cavity was 72 Ohms and 89 Ohms for the second cavity.

Full Scale Cavities

The inner surfaces of the cavities were roughed out leaving approximately 150 mils extra on the outer diameter and side walls. The nosecone area was cut to tolerance. A measurment of the resonant frequency was made. Approximately 50 mils were removed from the cavity wall and the frequency remeasured. Through a sequence of cuts and measurements, the cavity frequency was brought down to 436.0 MHz. After brazing and cutting of the ports, the frequencies are expected to be close to 433.0 MHz. The range of the motor-driven tuner plug should be about +1.0 MHz to -0.2 MHz, which will be adequate.

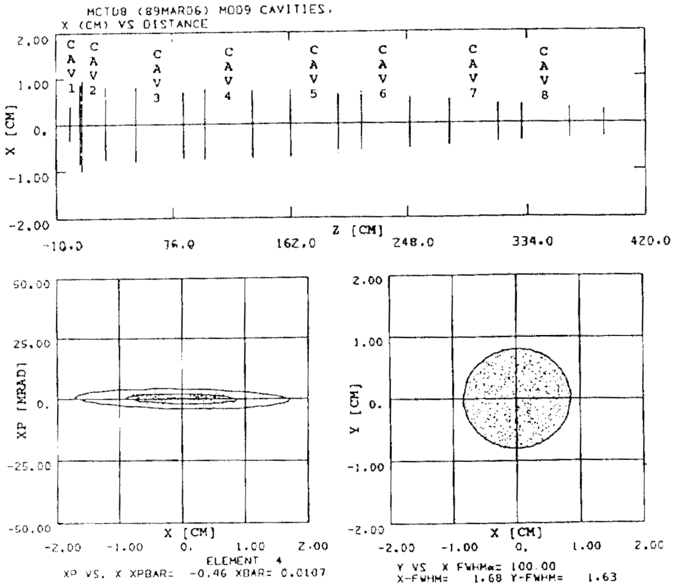

Fig.4 Output from PARMELA obtained using cavity fields from SUPERFISH. The top graph shows the bunch diameter as a function of distance down the beam line for the whole MCTD accelerator. Location of cavities is noted. The graph at lower left is the emittance plot at the entrance to the 3rd cavity (Element 4). The graph at lower right is the cross section of the beam at Element 4.

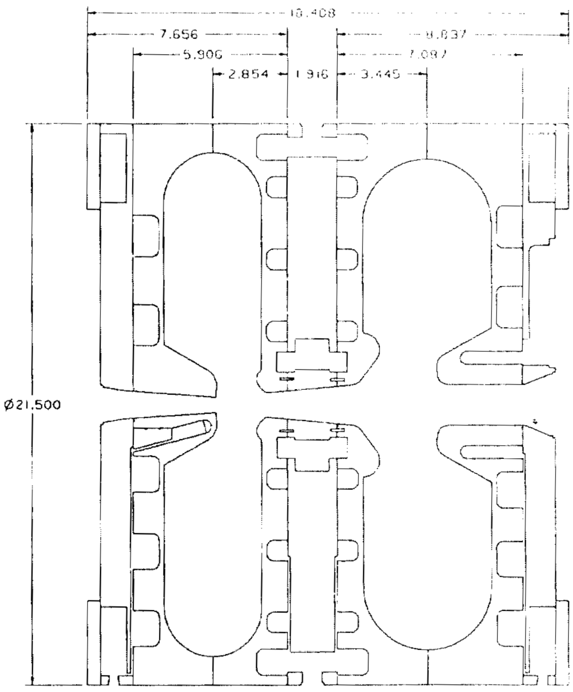

Fig.5 Engineering drawings of the first two MCTD cavities. Dimensions are in inches. Complicated pattern of lines between cavities indicate the spiral cooling channels.

References

[1] J.S. Fraser, R.L. Shefield, E.R. Gray, P.M. Giles, R.W. Springer and V.A. Loebs, "Photocathodes in AccelertorApplications," 1987 IEEE Particle Accelerator Conference, Washington D.C., p.1705.

[2] M.E. Jones and W.K. Peter, "Particle-in Cell Simulations of the Lasertron," IEEE Trans. on Nuc. Sci. NS-32(1985)1794.