HIGH-POWER TEST ON A CLOVERLEAF CAVITY*

J. R. Parker, J. D. Doss, R. W. Freyman, E. A. Knapp, and W. J. Shlaer
University of California, Los Alamos Scientific Laboratory,
Los Alamos, New Mexico

Abstract

A one-cell plus two half-cell cloverleaf cavity similar to those suitable for a proton linear accelerator has been operated up to four times the design power to investigate sparking and heat distribution problems. This cavity was fabricated of oxygen-free high-conductivity copper forgings using techniques suitable for mass production. The power source used was a 100-kw, 800-Mc power amplifier running at 6% duty factor. No sustained sparking has been observed even at the highest power levels. Data taken on cavity clean up, equilibrating times, x-ray yield and resonant frequency versus power input are given. Details of the cavity fabrication, waveguide matching, and the waveguide vacuum window are discussed.

Introduction

High-power tests were conducted on a cloverleaf cavity assembly to investigate sparking and heat dissipation characteristics which this particular geometry might have. Specifically, a study of vacuum dependence on RF drive, multipactoring, detuning at high power, and conditioning time after exposure to air was conducted. The detuning data was considered particularly important as it would determine to what extent the temperature of the structure would have to be varied to retain resonance under all power conditions. To facilitate these tests a one-cell plus two half-cell cavity assembly was set up and driven by a power amplifier capable of delivering 100 kw of RF power at 800 Mc/sec.

Fabrication of Cloverleaf Test Cavity Assembly

The cloverleaf test cavity is comprised of five principal parts (see Fig. 1), the RF window flange with integral coupling iris, two head pieces, and two machined forgings. The latter establish the central cloverleaf cavity and the two terminating cloverleaf half-cells. Each forging, which we call a cloverleaf segment, is a septum wall with a half-cell on either side. OFHC copper is used throughout to permit hydrogen brazing.

Before assembly, all parts were machine-finished to the desired dimensions and then vapor degreased in boiling trichlorethylene. The brazing surfaces were then cleaned with a "bright-dip" solution (dilute nitric and hydrochloric acid). The acid was then flushed off with distilled water and all parts washed with acetone.

Assembly was accomplished in two brazing operations. First, with their axes vertical, the two cloverleaf segments were stacked with the two head pieces. Twelve dowel pins precisely located all parts. As the parts were stacked, a two-mil strip of preformed brazing alloy (72% silver and 28% copper) material was placed between brazing surfaces. The complete assembly was then placed in an electrically heated retort furnace which provided a controlled atmosphere of dry hydrogen while bringing the assembly up to the brazing temperature of 1480°F.

Before the second brazing operation an opening was milled between two adjacent nose cones for installation of the RF window flange. The diameter of the cavity assembly was then machined to match the radius of the RF window flange. Holes were also drilled at this time for three "pads", for a monitoring loop, ion gauge, and observation port. The more than 400-pound cavity assembly was then placed on the RF window flange with brazing preforms of a different alloy between cavity, flange, and pads. Again, dowel pins precisely located RF parts. For the second braze, a 63% silver, 27% copper, and 10% indium alloy was used and the brazing done as before except that the temperature was 1400°F.

Matching to Waveguide

To couple RF power from the waveguide into the cavity, an iris was cut in the wall of the cavity between two nose cones. The coupling iris is thus in a low-field region of the full cell of the cavity. At resonance the voltage-standing-wave ratio in the waveguide due to mismatch at the iris was less than 1.05.

Waveguide Vacuum Window

A symmetrical window was fabricated as a simple sandwich of a 1/2" thick slab of Teflon between (with appropriate "O" rings) two 3/8" thick plates of aluminum. Rectangular apertures 3" x 7-3/8" with rounded corners and edges were cut in the aluminum plates. These dimensions were determined experimentally and provided a match such that the VSWR was less than 1.04. Toward the end of the tests, however, vacuum leaks did develop at this window, possibly due to cold-flow of the Teflon.

Test Set-Up

The test set-up is illustrated in Fig. 1. Power is transmitted from the 100 kw amplifier to the waveguide section by a 1-5/8" coax line. A standard coax-to-waveguide transition couples the power to the waveguide. The first section of waveguide is a reflectometer to monitor forward and reflected power. The power then passes through the Teflon vacuum window into a pump-out section of waveguide. A pump-out slot in the wide wall of the waveguide is connected directly to an ion

---

*Work performed under the auspices of the U. S. Atomic Energy Commission.

vacuum pump. The load end of the pump-out section is connected to the vacuum-window flange of the test cavity.

Conventional water-cooling equipment was used with a cold water mix tank and a pneumatically operated regulating valve. Water temperature was regulated within $\pm 1/2^{\circ}$F. The cooling was done by circulating water through the cloverleaf noses rapidly.

During operation internal fields were sampled by a small pick-up loop in a low-field lobe of the full cell. Calibration of the power measuring equipment was done calorimetrically with a water load.

Design Power Rating of Test Cavity

The power P required to produce an energy gain $\int E(z,t)dz$ can be obtained from the relation

$$P = \frac{\left\{\frac{1}{L}\int_o^L E(z,t)dz\right\}^2 L}{ZT^2}$$

where ZT^2 is the effective shunt impedance in ohms/meter, L is the cavity length in meters, and $\frac{1}{L}\int_o^L E(z,t)dz$ is the effective energy gain in volts/meter for a proton centered in the cavity at peak field. ZT^2/Q was measured by standard perturbation techniques and found to be 1650 ohms/meter. Q is reduced from the nominal value quoted[1] for long accelerator tanks to ~ 13,000 due to end losses in the two half cavities, yielding a shunt impedance $ZT^2 = 21.5$ megohms/meter. For an effective energy gain of 1.268 Mv/m (the proposed gradient for $\beta = 0.71$, $E_p = 395$ Mev), a synchronous angle $\cos \varphi_s = 0.9$, and $L = 0.264$ meter we obtain $P = 24.4$ kw.

Dielectric bead measurements over the surface of the drift tubes indicate that this power level will produce a peak surface field of approximately 7 Mv/m.

Resonant Frequency vs Temperature

A standard signal generator was used to determine the cavity resonant frequency as a function of cavity temperature. This was done at the milliwatt level to avoid localized heating. As is to be expected, since the test cavity is a homogeneous structure and there was no localized heating, the temperature dependence exactly matched the temperature coefficient of copper, producing a coefficient of 7.6 kc/°F.

Resonant Frequency vs Peak Power

As the power to the cavity is increased, new equilibrium temperature distributions will change the resonant cavity frequency with a fixed circulating water temperature. Since the drift tube region is expected to become the warmest region in the system, resonant frequencies are expected to fall with increasing power.

The resonant frequency was determined by adjusting the frequency until the return power indicated by the reflectometer was zero. The precision of this measurement was better than a part in 10^5. At each increment of power the frequency was adjusted to follow cavity resonance until equilibrium was reached. The equilibrium time was seven to eight minutes. The resulting set of data is shown in Fig. 2. The frequency dependence at the design power level (25 kw) is

$$\frac{\Delta f}{f} = 2 \times 10^{-4} \frac{\Delta P}{P}.$$

Sparking

For the power tests vacua better than 10^{-6} Torr were obtained before power was applied. Water temperature was held constant ($84.5 \pm 0.5^{\circ}$F) with the conventional recirculating water system described earlier. Typically, upon start-up after exposure to air some sparking (as detected by an impedance mismatch at the iris coupler into the cavity, causing a large reflected power signal) would be observed at as low a power as 8 kw peak. As power was increased the frequency of sparking would increase, but a return to a previous power setting would indicate cavity clean-up. During one run-up a continuous glow discharge was initiated at about 60 kw. After a brief conditioning run of this type the power level could be raised above 90 kw with no sustained sparking observed. Figure 3 shows the square of the cavity field level, as observed with a magnetic pickup loop, plotted vs input power. Excellent tracking is observed out to the maximum supplied power.

One exception to the above sequence followed a scrupulous cleaning before pump-down. The cavity was washed with MEK and rinsed with ethanol. It was then evacuated with a cold-trapped roughing pump while nearly boiling water was flushed through its cooling passages for over twelve hours. The initial run-up following this treatment was identical to the second run-up described above.

At each increase in input power the cavity pressure would rise rapidly and then return to its original value. At 60 kw the vacuum increment sometimes placed operation in the glow-discharge region, which the vacuum system was not able to overcome. It is believed that with a better vacuum system the glow discharge would not occur.

X-Ray Level vs Peak Power

While the above data was being taken the x-ray level at the top side of the cavity was monitored with a low energy dependence RF shielded survey meter (Victoreen Model 440). The resulting data, shown in Fig. 4, display the expected strong dependence on the power level. The x-ray level at design power input is negligibly low.

An interesting aspect of the x rays was that the spectrum, analyzed with a gamma-ray spectrometer, did not change with power level. Two peaks were observed, one at 6 kev being five times as high as the second at 11 kev.

Multipactoring

No evidence of multipactoring was found.

Conclusions

The above data indicate that in every way the design is very conservative. Even with the relatively poor vacuum obtained operation was entirely satisfactory at peak powers approaching four times the design value. It is particularly gratifying that no evidence of multipactoring was found. Cavity operation should be entirely satisfactory even at four times peak power input when the vacuum system is improved. The design should be more than conservative enough to allow for the changes which will no doubt arise with the introduction of a beam.

Acknowledgments

The authors wish to express appreciation for assistance from the following Laboratory people: E. O. Beckwith, J. L. Sherwood, and H. G. Worstell on the vacuum system; V. E. Hart and W. L. Jennings on the water system; and M. J. Engelke and D. E. Hankins on x-ray measurements.

References

1. E. A. Knapp, Proceedings of the MURA Linear Accelerator Conference, 1964.

FULL VOLTAGE TEST EXPERIMENT CLOVERLEAF CAVITY

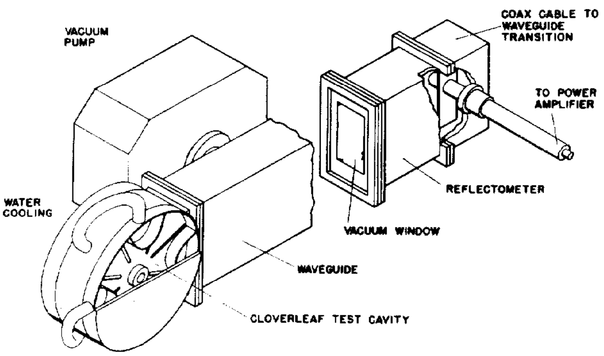

Fig. 1. High-power sparking test setup.

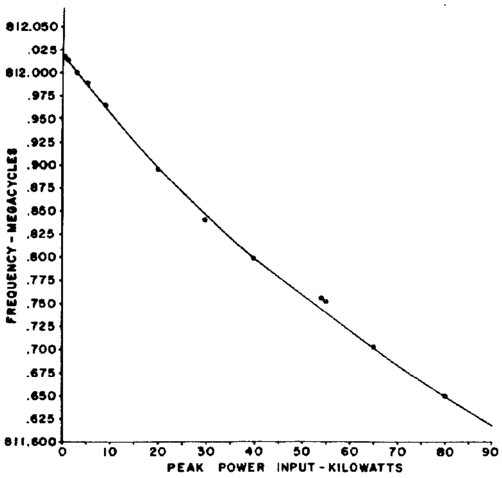

Fig. 2.

Resonant frequency vs peak power input at 6% duty.

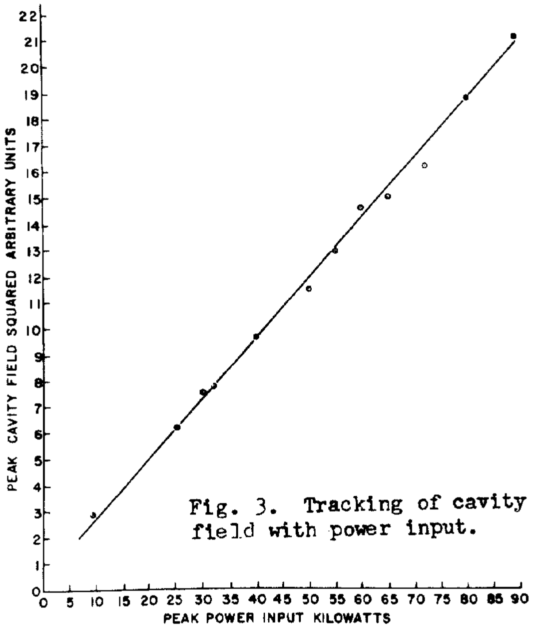

Fig. 3. Tracking of cavity field with power input.

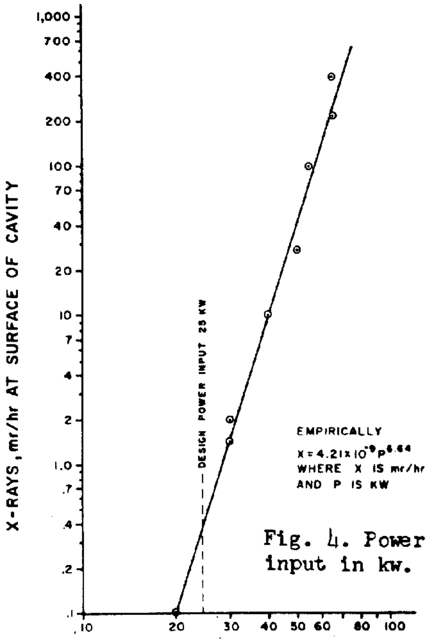

Fig. 4. Power input in kw.