OPERATING CHARACTERISTICS OF A FULL POWER CLOVERLEAF ACCELERATOR TANK*

D. R. Copenhagen, E. A. Knapp, J. M. Potter
Los Alamos Scientific Laboratory
Los Alamos, New Mexico

Summary

An 805 MHz, forty-one cell cloverleaf accelerator tank has been fabricated and evaluated. The operating parameters as well as the tuning procedures and problems associated with this particular model are discussed. Results from both low and high power tests are included.

Introduction

The synthesis of the cloverleaf structure from a system suitable for traveling wave tube use[1] into a standing wave accelerator tank[2,3,4,5] has been described previously. We wish to report the results of high power tests run on a prototype tank, and techniques of tuning and matching which have proved suitable for this type structure.

Model B is a prototype cloverleaf accelerator tank designed for a proton energy of 390 MeV (β = 0.71). It is a forty-one cell, full scale structure with a constant phase velocity. An energy gain gradient of 1.25 MV/m at $\cos \varphi_s = 0.9$ is a typical operating gradient. To excite the tank to this gradient, 365 kW of peak power are required. The shunt impedance (ZT^2) as measured at low power levels using perturbation techniques is ~26 MΩ/m. The completed accelerator tank at the rf test stand is shown in Fig. 1.

A picture of a single segment of Model B can be seen in Fig. 2. Each segment consists of two half accelerating cells divided by a septum into which are cut coupling slots. In the integral tank a braze joint exists on the wall at the median of each accelerating cell. Figure 2 illustrates a typical segment.

The purposes in building Model B were to study the problems involved in fabricating a long structure such as this and to evaluate the characteristics of such a long tank. Of interest also were the problems inherent in tuning and flattening and in operation at high power levels.

Fabrication

A complete description of the fabrication of Model B is covered in a paper presented by H. G. Worstell at this conference.[6]

Tuning

The tuning of Model B was actually performed in two separate stages. Prior to brazing, the resonant frequency of the individual segments were tuned. After brazing, the overall tank resonant frequency in the operational π-mode was adjusted to 805 MHz. Additionally, the field amplitudes in the individual cells were equalized.

To determine the resonant frequency in the pre-braze "tune-up", the ends of each segment were terminated in aluminum end plates machined to fit the curvatures of the segment. To raise the resonant frequency, copper was removed from the top of each drift tube. Of interest here may be the fact that it was found necessary to coat the rf joints with silver conducting paint in order to achieve an adequate Q. Spring rings were tried but results from one test to another were not reproducible. While tuning, an obvious point was proved once again. Being in high axial electric field regions, the dimensions of the radii machined on the drift tubes were very critical in determining the resonant frequency. All of the segments were tuned to 804.500 MHz (+0.45 MHz, -0.60 MHz). 72.5% of them resonated within ±0.150 MHz of 804.500 MHz.

In the post-braze "tune-up" the resonant frequency of the complete structure was brought to 805.00 MHz under vacuum at 90°F. The field levels were all adjusted to within ±5%. For shorter π-mode structures and $\pi/2$-mode structures it is possible to use perturbation techniques to investigate the axial field strengths. Due to the large number of cells in Model B it was impossible to use this technique. The reason is that the size of the perturbation object or "bead" needed to obtain any degree of precision is so large that the tank is actually detuned or unflattened by the "bead".

The particular solution employed to monitor the field levels involved sampling the magnetic field at the outer wall in each cell. To expedite this sampling a forty-position, one pole coaxial switch was fabricated. The output of the switch was fed to a power or volt meter. For sequential runs the dc output voltage of the meter was recorded. The control electronics stepped through the forty positions sequentially or allowed the selection of any one position. The individual pickup loops and coaxial cables had to be calibrated in the tank.

The actual tuning involved deforming the noses in each cell to raise its individual frequency and thus field level. The deformation was done through the cooling water holes not being employed for low power testing. (One line was connected for temperature stabilization during tuning.) It was only possible to raise the frequency of each cell and the overall frequency of the tank by this technique. For this reason the π-mode was initially set at a low value. After several hundred hammer thrusts the π-mode frequency reached designed value. The field levels were not equalized as much as was originally desired for this structure, but further adjustments had to be curtailed due to the overall frequency limitations. A final field flatness of ±5% was achieved.

Matching to Waveguide

To couple rf power from the waveguide into the tank an iris was cut in the wall of the median cell in the tank. This iris was located in the low field region between nose cones. The width of the iris was enlarged until the input VSWR at resonance was ~1.18:1 (coupling coefficient ~0.84).

Because the sides of the iris extended into very low field regions, the input VSWR reached a limiting value. Figure 3 shows a plot of input VSWR vs. length of iris.

Low Power Evaluation

The power flow phase shift, essential for power transmission in the π-mode, was measured. Figure 4 shows the results of the measurement. The measured values generally agree with the theoretical value predicted from coupled circuit analysis done at LASL. The variations represent individual cell frequency errors. The effective coupling coefficient K_{eff} of this particular tank is $\approx$16%. The coupling slot resonant frequency of interest is ~900 MHz.

Using low power signal generator the frequency dependence on temperature was investigated. Over the temperature range 75° to 90°F the resonant frequency of the operational mode changed 7.2 kc/°F. The temperature was controlled to within ±0.3°F using one line of the tank cooling system.

A characteristic of π-mode accelerator tanks is that resonant frequency, as determined by the maximum excited field in any one cell, is cell dependent. This effect is covered in detail in the proceedings of Yale Conference.[2] Figure 5 shows resonant frequency of the tank as measured in various cells, while being driven from the center cell. Once again the variations are caused by individual cell frequency errors. Because of this cell dependence effect, the true resonant frequency of the tank is defined as the frequency of minimum VSWR at the input iris.

The dispersion curve for Model B is shown in Fig. 6. Only the accelerating passband is shown. The proper modes of the coupling slot could not be determined accurately. When drive and pickup probes are located at opposite ends of the tank, 60 resonances are easily observed in the passband of the slots. Unless the configuration of the fields around the slots can be determined, as has been done previously in air models, it is difficult to determine the modes roughly corresponding to the TM_{01} mode. The spurious modes show an azimuthal phase dependence and as a result, all eight slots do not have identical field intensities.

After matching the tank to the waveguide, the unloaded Q, Q_o, was measured using the VSWR vs. frequency information. The Q_o was 16,500. This was about 25% higher than a smaller model fabricated of identical segments but comprised of only one full cell and two half cells. The difference is due to the increased effects of the termination end wall losses in the shorter model.

High Power Testing

Model B was driven by the 1 Megawatt RCA Coaxitron (the A1 5191). The power was fed into the structure through a vacuum window of high density alumina and was transmitted in WR 975 waveguide. The complete test set up is covered thoroughly in a paper by R. A. Jameson at this conference.[7]

During high power operation Model B was run to 400 kW peak power at 1% duty factor. Because of marginal operation of the Coaxitron it was impossible to raise the peak input power to a higher value. However, at power levels above design values, no sparking was detected beyond the normal cleanup type. On the whole the structure performed very well at high power and was easily controlled. This system has been used extensively for rf phase control measurements. These results are reported elsewhere[7] in this conference.

Conclusion

Much valuable information has been gained during fabrication tuning and evaluation of Model B. The structure performed as was expected and was the best π-mode accelerator structure built at LASL. Because the side coupled structures look more promising as structures for the proposed LASL accelerator, work on the cloverleaf models has been terminated.

Acknowledgments

The authors wish to acknowledge the cooperative effort of several people at LASL: Don Hagerman, Bob Jameson and Dick Eichor for providing rf power and making high power tests, and Bob Sharp for his work on the initial segment tuning and coupling iris enlargement.

References

1. M. Chodorow and R. A. Craig, Proc. I.R.E., 45, 1106 (1957).
2. E. A. Knapp, "Accelerating Structure Research at Los Alamos", Proc. of the Yale Conference on Proton Linear Accelerators, 131, 1963.
3. A. Carne, "Crossbar and Cloverleaf Structures at Rutherford", Proc. of the Yale Conference on Proton Linear Accelerators, 104, 1963.
4. E. A. Knapp, "800 MeV RF Structures", Proc. of the MURA Linear Accelerator Conference, TID-4500 (37th edition), July 20-24, 1964.
5. "A Proposal for a High Flux Meson Facility", Los Alamos Scientific Laboratory, Sept. 1964.
6. H. G. Worstell, "Design, Development, and Fabrication of Multicavity 805 MHz Accelerator Tanks", Proc. of the 1966 Linac Conference, Los Alamos Scientific Laboratory, Oct. 3-7, 1966, p. 159.
7. R. A. Jameson, "Fast RF Control Work at LASL", Proc. of the 1966 Linac Conference, Los Alamos Scientific Laboratory, Oct. 3-7, 1966. p. 460.

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

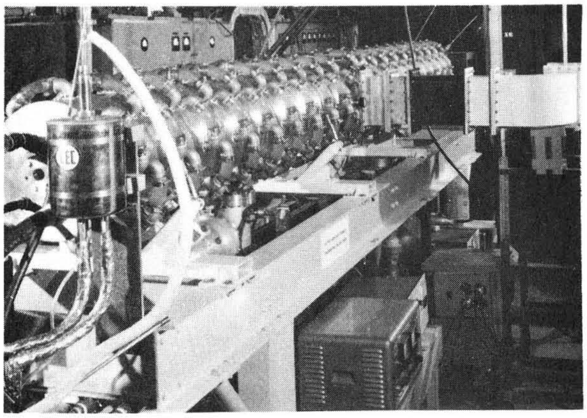

Fig. 1. Model B at high power rf test stand. Complete water and vacuum systems are in place.

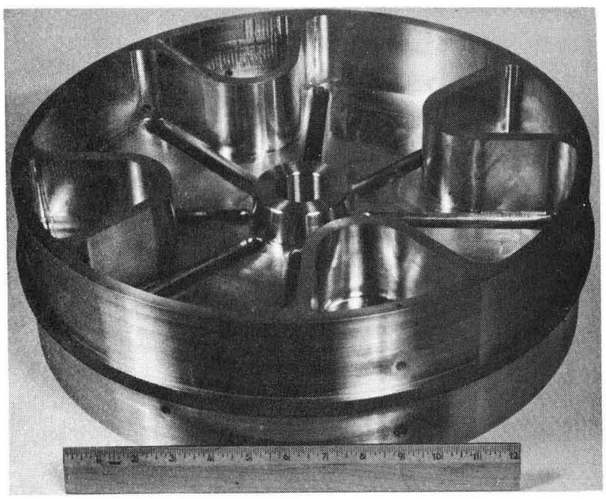

Fig. 2. Typical cloverleaf segment used in Model B.

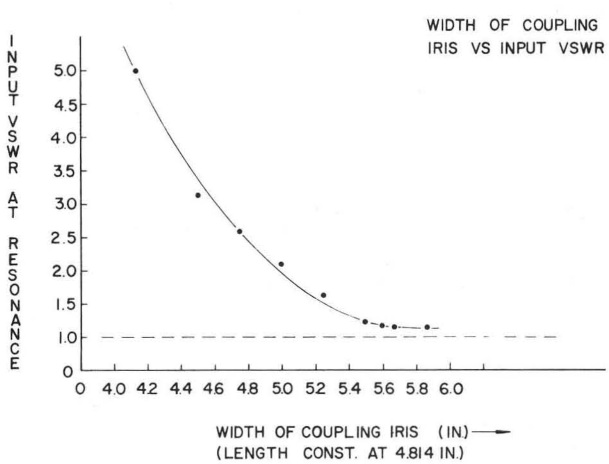

Fig. 3. Plot of input VSWR vs size of iris. From data taken it appeared no further cutting would enable tank to be perfectly matched to waveguide.

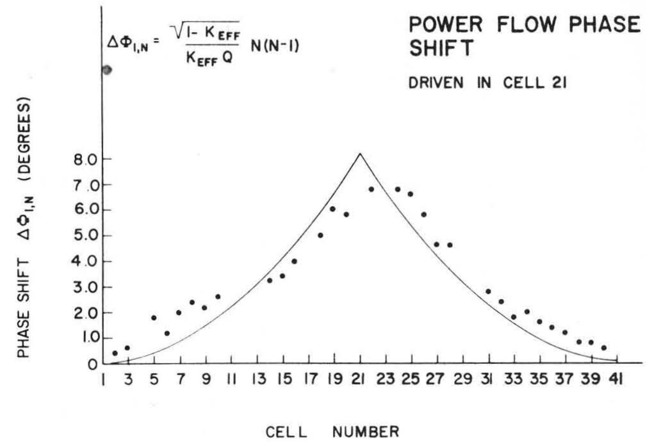

Fig. 4. Power flow phase shift measured in Model B. Solid line is theoretical expression derived using K_{eff} and Q. Deviations about theoretical curve are individual cell frequency errors.

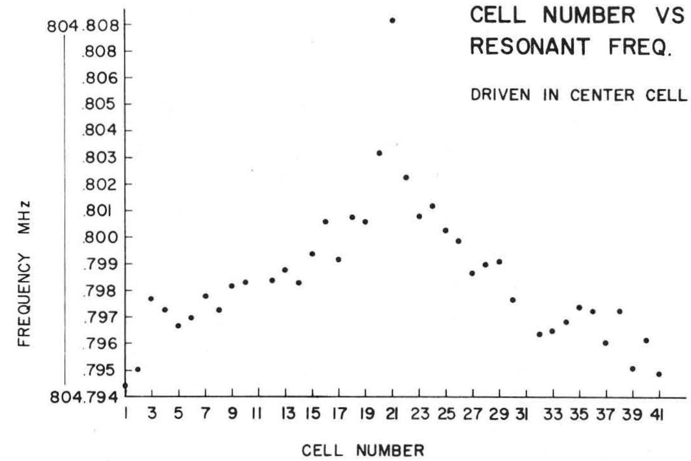

Fig. 5. Resonant frequency as measured in various cells.

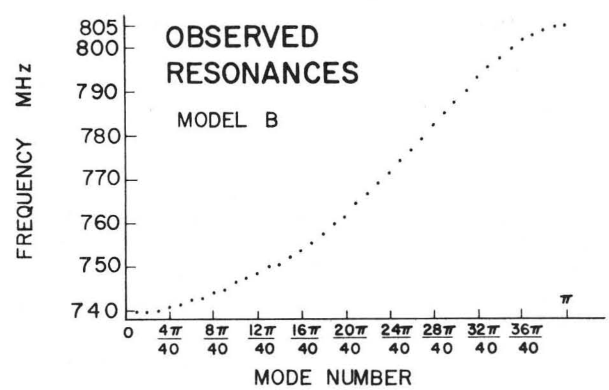

Fig. 6. Measured points on the dispersion curve showing accelerating cell passband only.