CAVITY SHAPE CONSIDERATIONS FOR PILAC AND OTHER HIGH-GRADIENT SUPERCONDUCTING LINAC APPLICATIONS*

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Abstract

Superconducting linac cavities show promise of achieving accelerating gradients of 10 MV/m or more, when heat treatment above 1400 C or high peak rf power processing is used to reduce field emission effects. PILAC, a proposed superconducting linear accelerator for pions at LAMPF, planned to use a cavity shape that keeps the peak electric field at the surface at about 2 times the effective accelerating field, and to handle only small beam currents. For other applications being considered, proton beam currents may be of the order of 15 mA, and higher-order mode effects may be significant. For any high-gradient superconducting application, the peak magnetic field at the surface is also important. The effects of mid-cell and end-cell cavity geometry on peak surface fields and on the external Q's of higher-order modes are discussed.

Introduction

The PILAC project envisioned using superconducting cavities to accelerate a low-current beam of pions from 360 MeV to various energies up to 1070 MeV. The PILAC cavity was designed for this application, and has a design beta of 0.9759, which corresponds to 500 MeV pions. At this beta, the cell length is 181.718 mm. The purpose of the work reported here was to see if small changes to the 805-MHz PILAC cavity geometry would give a cavity which would be suitable for other higher-current applications for which higher-order modes (HOM's) might be important.

In this study, we have examined the effect of various shape changes on the peak surface electric and magnetic fields, and on the external Q of the cavity. External Q is a rating of how well particular modes of a cavity can be damped. In order to damp HOM's, we might connect dampers by waveguides to the beam tubes at the end of the cavity. It is not practical to simulate a cavity plus HOM dampers with the computer codes we have available. We have taken the approach that we can approximate the effect of the dampers by placing a dissipative band around the inside of the beam tube on the computer model at the place where the damper would be connected.[1] Measurements have confirmed this is a reasonable approach.[2,3]

We define the external Q as follows: We let the Q of the cavity without the dissipative band, the unloaded Q, be Q_U. Similarly, we let the Q of the cavity with loading from the dissipative band be Q_L. The external Q is then such that

$$\frac{1}{Q_{ext}} = \frac{1}{Q_L} - \frac{1}{Q_U} .$$

This means that the external Q is equal to the resonant angular frequency ω times the peak stored energy divided by the additional power dissipation due to the band. We have assumed that only longitudinal wall currents in the band produce dissipation, as it is these currents that normally couple power into the waveguide to a HOM damper. We assumed the surface resistance of the dissipative band was 2500 times the surface resistance of copper, as in Ref. [4].

Procedure for Calculating Accelerating and HOM Fields and External Q's

We used the computer code SUPERFISH to do the designs for the cavity mid cells and find the peak surface electric and magnetic fields. Then we used the computer code URMEL to calculate the HOM fields and stored energy for the whole cavity for each geometry considered. We then used a code named URQ to calculate how much each mode would be damped by a resistive band in the tube at the end of the cavity. The code URQ reads the output file from URMEL and extracts the azimuthal H field values at the radius of the end tubes for each mode, and calculates the power that would be dissipated in a resistive band there, and uses the stored energy value to calculate the external Q.

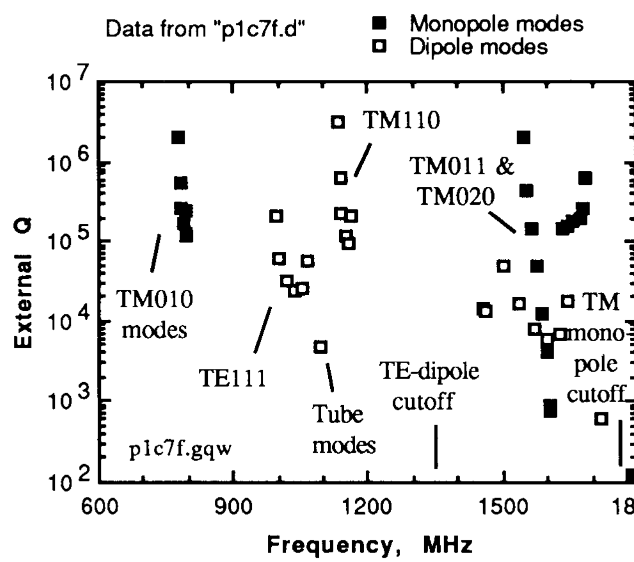

Fig. 1. Characterization of the higher-order modes of the PILAC cavity. The resistive band was 78.7 mm wide, beginning 12.1 mm away from the end cell.

Classification of the Groups of HOM's

We used the field plots generated by URMEL to classify the modes by their resemblance to the modes in a simple pillbox cavity. The resulting classification of the groups of HOM's is shown in Fig. 1. For a few of the modes, most of the energy in the field is in the end cells and the adjacent end tubes. These are not straightforwardly related to the modes of a pillbox cavity, and hence we have designated them 'tube modes'. For the PILAC cavity and others with 130 mm diameter end

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tubes, the TE and TM dipole cutoff frequencies are 1352 and 2813 Mhz. The TM monopole cutoff frequency is 1765 MHz.

Effects of End-Cell and End-Tube Changes

The simplest change in the PILAC end cells that affects the external Q's is to go from the unsymmetrical PILAC end cell geometry to a symmetrical one. (Compare Figs. 1 and 2.) For the symmetrical end cells, the external Q's for the TM011-TM020 band are a factor of ten lower. The Q's of the TE111 band are about the same, but the Q's of the TM110 band are about a factor of two higher (worse).

We tried a number of changes to the end tube that might affect the external Q's of the PILAC cavity. In order to make the end condition more like the connection between mid cells, we tried an end cell with a nose on the tube end: the nose radius of the end cell continues on into the end tube, opening out to a larger tube, as in Fig. 3. The External Q's for this configuration are shown in Fig. 4. The external Q's for the TE111 band are about the same as for the PILAC cavity, but those of the TM110 band are much worse.

If simply an enlarged beam pipe (151.7 mm dia. vs 130 mm) is used at the ends of the cavity, the external Q's of the TE111 band are slightly lower; those of the TM110 band, slightly higher; and those of the TM011-TM020 band are about a factor of three lower.

The effect of decreasing the width of the end cells is shown in Fig. 5. Decreasing the width brought the TM110 band down to about the same level as the TE111 band, but raised the external Q's of the TM011-TM020 band.

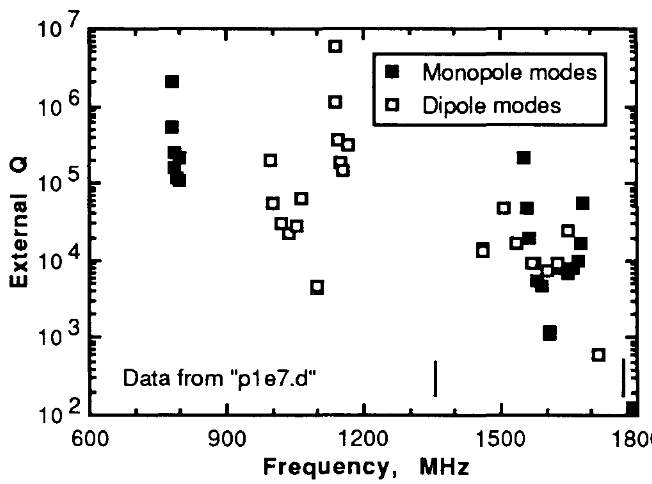

Fig. 2. A cavity like PILAC but with symmetrical end cells on both ends.

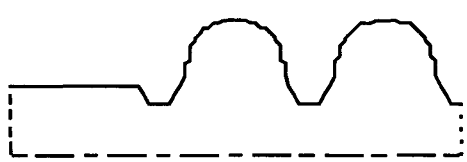

Fig. 3. End tube and first two cells for the case with a nose on the end tube.

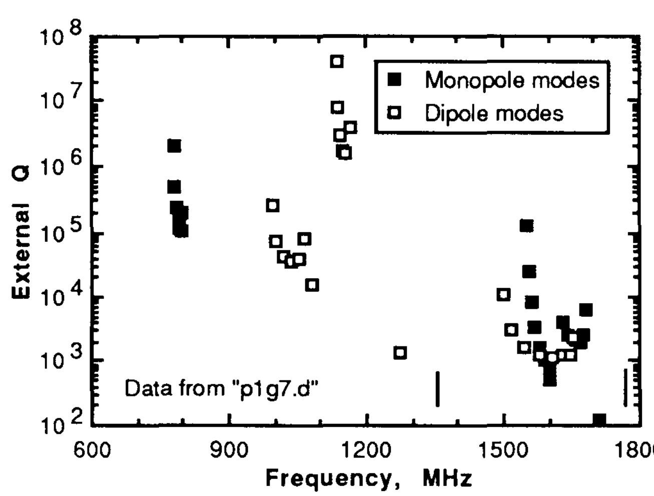

Fig. 4. External Q's for the case with end tubes with noses.

Effects of Changes to Mid Cells

If we modify the iris size, nose radius, and slope of the PILAC cavity to be more like the TESLA LTP shape, leaving the cell length at 181.718, we find the pattern of external Q's (Fig. 6) is similar to that of the LTP cavity. We designate this

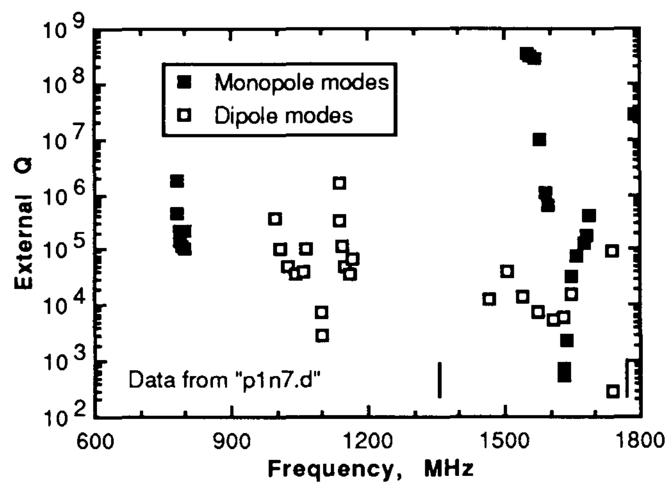

Fig. 5. Effect of width of end cells: End cells narrower than mid cells by 6.057 mm.

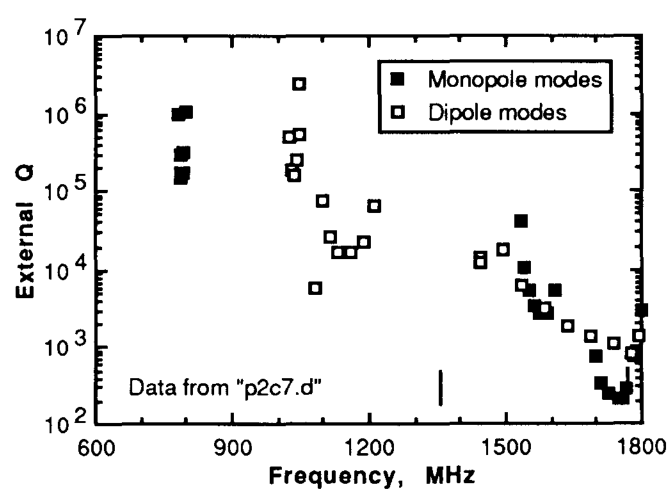

Fig. 6. External Q's for the p2 cavity, which is similar to the TESLA LTP cavity, but for a beta of 0.9759.

case 'p2' (the PILAC cell shape being 'p1'). For the p2 cavity, the Q's of the TE111 band are higher and those of the TM110 band are lower than for the TESLA shape. The principal dimensions and the calculated peak surface electric and magnetic fields, transit-time factors, shunt impedances over Q, and cell-to-cell couplings for the various cases are listed in Table 1. The values for the LTP cavity assume the cavity is scaled for 805 MHz.

TABLE 1
Dimensions and Calculated Parameters

	LTP	p1	p2	p5	p7
Cell L, mm	= 183.63	181.72	181.72	181.72	181.72
Nose tip R1, mm	= 35.497	19.735	35.000	35.000	32.000
Nose R2, mm	= 35.497	87.432	45.000	45.000	50.000
Iris R, mm	= 66.261	65.000	66.261	65.000	65.000
Waist R, mm	= 176.68	170.40	177.38	170.67	170.41
Slope, deg	= 20.000	10.000	20.000	10.000	10.000
Es/E0T	= 1.997	2.05	1.989	2.048	1.999
Hs/E0T (A/MV)	= 4319.	3775.	4436.	4102.	4011.
T	= 0.785	0.775	0.780	0.779	0.778
R/Q (ohms/m)	= 246.7	256.2	238.0	254.0	255.7
Coup. k (%)	= 1.842	2.619	1.869	1.820	1.962

For the LTP cavity and the p2 cavity, the minimum slope for draining when the cavity is on end during fabrication is 20 degrees. We found that going to a lower slope does not greatly affect the external Q's, and allows us to obtain a lower peak surface magnetic field. In cases p5 and p7 we see the effect of changing the nose radius on a shape that is otherwise similar to the PILAC shape. Case p5 uses a 3.5 cm radius nose; and p7, a 3.2 cm radius. (The PILAC nose radius is about 2 cm.) We used symmetrical end cells in order to lower the Q's of the TM011 - TM020 band. For p5, the Q's of the TM110 band are lower than those of the TE111 band, but for p7 they are higher. (See Figs. 7 and 8.) Thus we may adjust the relative positions of these bands by adjusting the nose radius. For p7, we used a half-cavity model consisting of one end tube, three full cells, and one half cell. This allowed us to go to 60 mesh points per cell, instead of 30. There was no obvious change in the results due to the finer mesh.

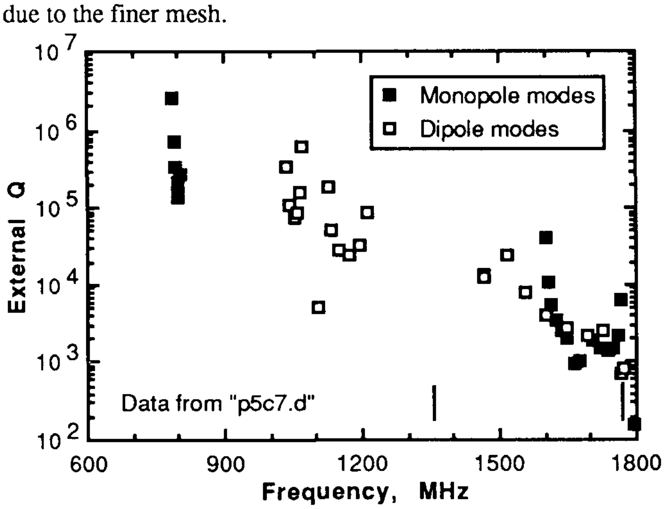

Fig. 7. Cavity similar to PILAC, but with a cell nose of 35 mm radius.

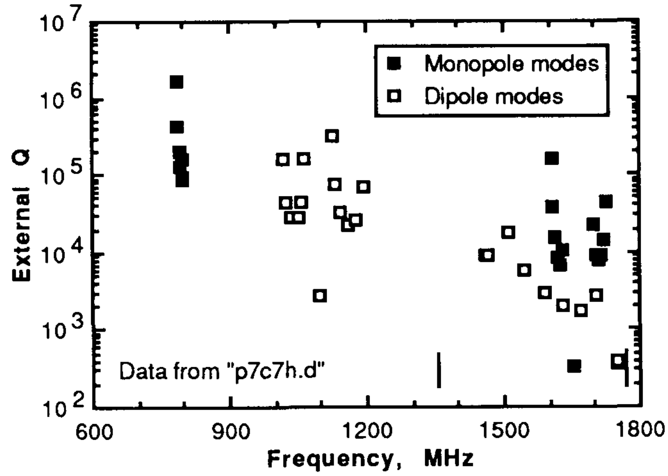

Fig. 8. Cavity similar to PILAC cavity, but with a nose tip radius of 32 mm.

Conclusions

For the PILAC cavity, the external Q's of the TM110 passband are higher (and hence worse) than for cavity shapes closer to the TESLA cavity shape. Changes in the end tube were not effective in lowering the Q's of this passband, although the Q's of other passbands were often improved. Shortening the length of the end cells of the cavity improved the external Q's of the TM110 passband, but made the Q's of some of the higher monopole passbands worse. In order to improve the Q's of the TM110 passband, the best approach that we found was to increase the nose-tip radius for the nose at the iris of the cells.

Further details are available in technical notes on the original PILAC cavity design[5] and on the study of external Q's for higher-order modes[6].

References

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[6] G. Swain, "External Q's for the Higher-Order Modes of Superconducting Cavities," Los Alamos National Lab. PILAC Technical Note No. 56 (July 30, 1992).