

# Study on TESLA Cavity Shape\*

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## Abstract

A new 9-cell cavity shape is designed for Tev Superconducting Linear Accelerators (TESLA). The ratio of the maximal Surface electric field to the accelerating gradient,  $E_{pk}/E_{acc}$ , was lowered down to 2.024 in the center cell while the cell to cell coupling is 1.95% for the 1.3GHz accelerating mode. The properties of the higher order modes were investigated with a "dissipated band model".

## Introduction

At this time in the development of superconducting RF accelerating cavities, the accelerating gradient is limited by two phenomena, electron field emission and thermal breakdown. The first of these makes it imperative to choose a cell shape that minimizes  $E_{pk}/E_{acc}$  and the second phenomena to minimize  $H_{pk}/E_{acc}$ . As field emission is the dominant gradient limitation, there is considerable premium in lowering  $E_{pk}/E_{acc}$ . The cell to cell coupling ( $k$ ) is also effected by the shape.

## The concept of multicell cavity

As everyone know, for the standing-wave modes, the multi-cell cavities behave like weakly coupled oscillators. When going from a single-cell cavity to a multicell cavity with  $n$  cells, one single-cell mode splits into  $n$  different multicell modes, each of which has a slightly different frequency in a "passband" and a different phase shift  $\Phi$  between different cells. The  $q$ th mode eigen frequency  $\omega_q$  and its longitudinal electric field  $E_n(q, t)$  in the  $n$ th cell can be expressed as following formula respectively:

$$\omega_q = \omega_0 \times (1 + k(1 - \cos\alpha_q))^{\frac{1}{2}} \quad (1)$$

$$E_n(q, t) = E_0 \sin\left(\frac{2n-1}{2}\alpha_q\right) \cos\omega_q t \quad (2)$$

Where  $k$  is the cell to cell coupling. The  $E_0$  is the maximum of longitudinal electric field. The  $\alpha_q$  is the phase shift.

$$\alpha_q = q \cdot \frac{\pi}{n} \quad (q = 1, 2, \dots, n) \quad (3)$$

The cell to cell coupling  $k$  could be indicated as following:

$$k = \frac{f_\pi^2 - f_{\pi/n}^2}{2f_{\pi/n}^2 - (1 - \cos\frac{\pi}{n})f_\pi^2} \quad (4)$$

The  $f_\pi$  is the  $\pi$  mode frequency, in which adjacent cells oscillate with the opposite phase. Apparently,  $\pi$  mode is just the accelerating mode. The  $f_{\pi/n}$  is called "in phase" mode frequency. As  $n$  goes to infinity, the  $\alpha_1 = \pi/n$  mode becomes a

$\alpha_1 = 0$  mode. Sometime one also likes to use term  $\Delta f/f$  indicating the size of dispersion. It is defined as following:

$$\frac{\Delta f}{f} = \frac{2(f_\pi - f_{\pi/n})}{f_\pi + f_{\pi/n}} \quad (5)$$

## Searching for a new cell shape

The goal of searching for a cell Shape is following:

1.  $E_{pk}/E_{acc} \rightarrow 2$ , cell number  $\rightarrow 9$ ;
2. cell to cell coupling  $k$  in the TM010 mode  $\geq 1.8\%$ ;
3. Tolerable  $Q_{ext}$  in all HOMs with couplers on the beam

pipe.

Five independent variables describes a "CSC" (circle — straight—circle) type cell shape:

OR: cell outer radius;

IR: beam tube radius;

R1: curvature radius at iris;

L: length of half cell;

TD: degrees inclination of wall.

The L is determined by the frequency as the particles to be accelerated must be kept in phase with the RF oscillation. The TD is held in  $79^\circ$  in consideration of stability mechanically. This leaves three parameters to explore. Because each of the three parameters affects the fundamental mode frequency, our strategy is adjusting the IR as well as R1 for a certain OR value to obtain the right frequency 1.3 GHz.

According to our knowledge, the LEP 4-cell shape has the minimum in OR, R1 and IR and Cornell 10-cell TESLA1 shape has the maximum if they all are scaled to 1.3GHz. We try to choose a shape between the two set of extreme parameters. We found that it was important to keep the resonant frequency nearly equal to 1.3GHz in order to get the true  $E_{pk}/E_{acc}$ . We also found that the IR nearly is proportional to the OR when R1 and TD keep invariant while TM010 frequency is kept at 1.3GHz, as show in figure 1.

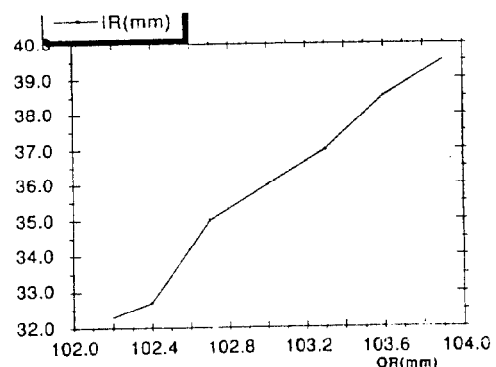


Fig. 1. Relationship between IR and OR when keeping the resonant frequency of fundamental mode @1.3GHz and R1=10mm, TD=79 degree

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In URMEL<sup>[1]</sup>, the term NPMAX is the maximum of number of mesh points. D. Proch and our experience tell us  $E_{pk}/E_{acc}$  is strongly a function of NPMAX as well as mesh density ratio  $D/d$ , as show in Figure 2 and Figure 3.

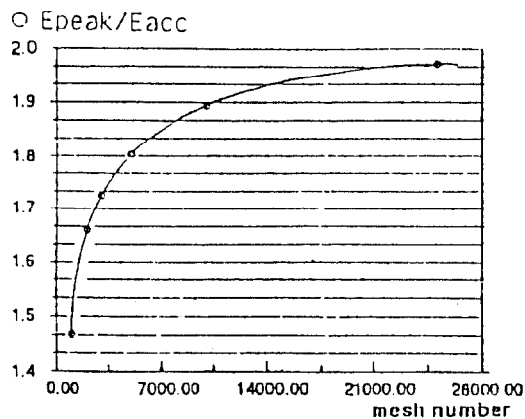


Fig. 2 The  $E_{pk}/E_{acc}$  of a single cell sc cavity as a function of mesh number.

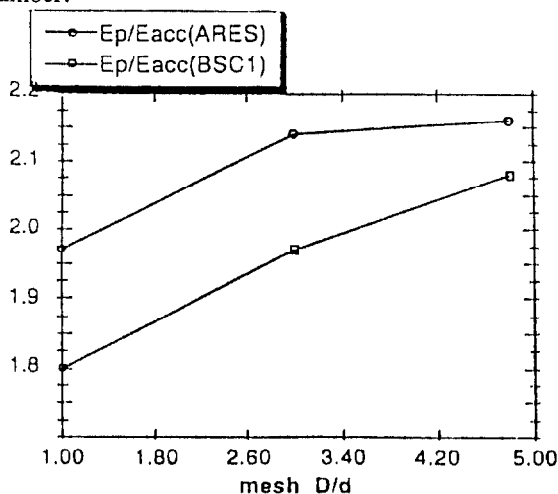


Fig. 3. The  $E_{pk}/E_{acc}$  of two single cell SC cavity as a function of mesh density ratio  $D/d$ .

The true  $E_{pk}/E_{acc}$  must be calculated with 25000 Mesh points. It seems difficult to get a shape with  $E_{pk}/E_{acc}=2.0$  and  $k \geq 1.8\%$  for a "CSC" type cell.

We try a "CSE" (circle-straight-ellipse) type cell. The  $A_2$  and  $B_2$  are the semi-axis length of ellipse at iris at y and x directions respectively. The others are the same as that of "CSC" type. Eventually we found a shape with  $E_{pk}/E_{acc}=2.024$  and  $k=1.95\%$  for a 9-cell structure. Figure 4 shows the cell shape named BT shape.

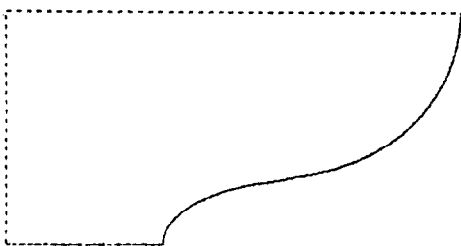


Fig. 4. BT cell shape

## properties of accelerating mode of BT cell Shape

We have re-calculated the cell shape of Cornell TESLA<sup>[2]</sup>, KEK TESLA1 and LEP 4-cell with single in cell. The table 1 compares the properties of the fundamental mode of BT cell shape with that of the others. The data of Saclay and DESY TESLA shape (in designing) come from D. Proch. All of them are scaled to 1.3GHz.

### Computer tuning of BT cavity

We tune the 9-cell BT cavity by changing the end half cell length with URMEL, 25000 mesh points. Fig. 5 shows the half cavity input and the tuning curves. The field flatness ( $\Delta E_z/\bar{E}_z$ ) is nearly 0.028. The tuning sensitivity is 2880 Hz per micrometer.

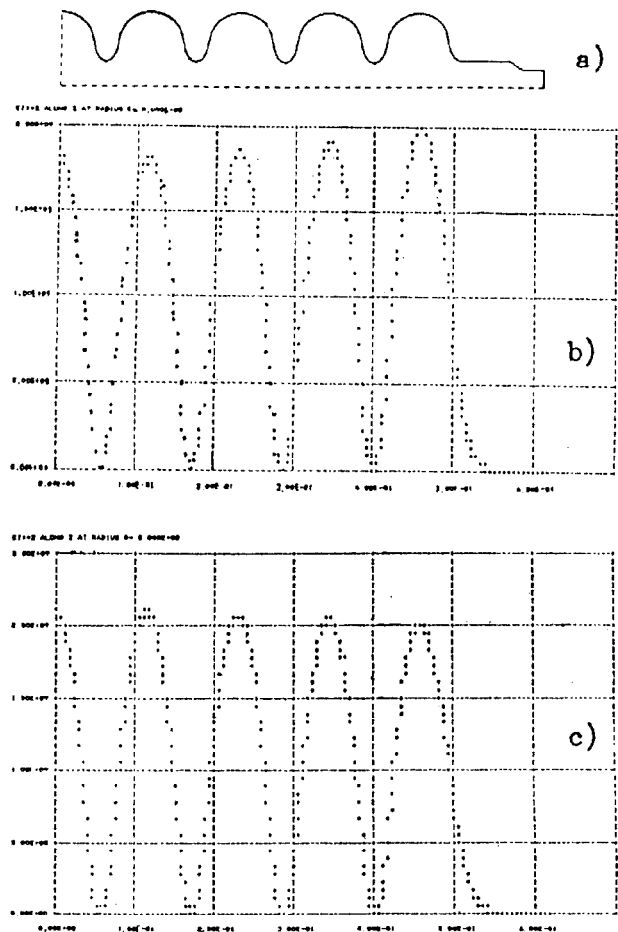


Fig. 5. (a) Input shape of 9-cell BT structure for URMEL. (b) tuning curve when  $L=5.27\text{cm}$ , (c) tuning curve when  $L=5.28\text{cm}$ .

### TM monopole HOMs of BT cell shape

We calculated the half-cell E field pattern of the BT shape and LEP 4-cell shape. The spreads of the higher order monopole modes of the two structures scaled to 1.3GHz are showed in Figure 6. The BT shape likes as LEP shape, has no mode passband overlap of the longitudinal mode and therefore

no true multicell trapped modes results from the mode mixing.

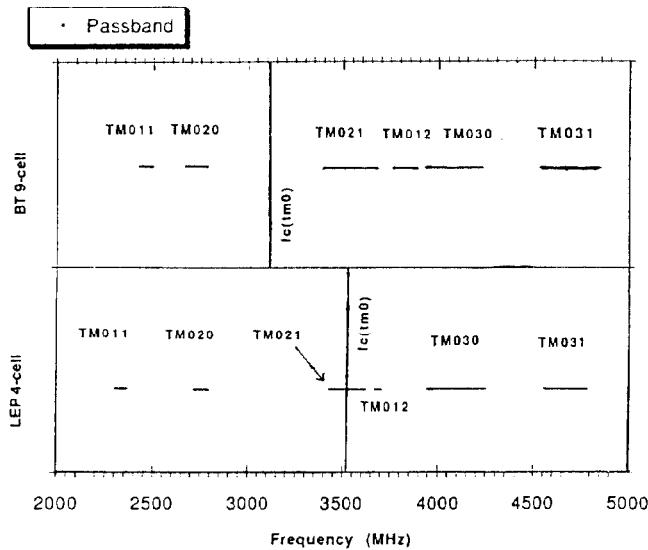


Fig.6. The spreads of the six higher order longitudinal modes for the BT cell shape and the LEP cell shape.

## Conclusion

Fig. 7 Shows the geometry and dimensions of the 9-cell BT structure ( $A_2=32$ ,  $B_2=16$ ).

Although the dispersion diagrams, R/Q and Qext of the first 80 monopole modes of the structure and the first 50 monopole modes of LEP 4-cell structure were examined with URMEL-T using "dissipated band model"<sup>[3]</sup> developed by W. Hartung for comparison purpose. They still need to be examined with I-V method<sup>[4]</sup>. However it seems to be a promising TESLA shape candidate.

## Acknowledgement

Thanks are due to H. Padamsee and W. Hartung for their guidance and giving SHAPE, SUMURM programs and D. Proch for his parameter list and helpful discussions.

Table 1: Comparison of various TESLA Shape (LEP is non TESLA)

|                                                         | LEP    | Cornell | KEK1   | KEK2   | Beijing | Saclay | DESY   |
|---------------------------------------------------------|--------|---------|--------|--------|---------|--------|--------|
| Numbers of cells                                        | 4      | 10      | 9      | 9      | 9       | 9      | 9      |
| Requator (mm)                                           | 102.2  | 109.0   | 104.15 | 103.3  | 103.6   | 102.2  | 103.3  |
| Riris (mm)                                              | 32.67  | 40.9    | 40.0   | 38.0   | 35.8    | 32.31  | 35.0   |
| NP MAX in URMEL                                         | 20000  | 20000   | 20000  | 25000  | 25000   | 25000  | 25000  |
| Hpk/Eacc (Oe/(MV/m))                                    | 39.33  | 54.30   | 49.86  | 43.10  | 42.91   | 39.70  | 41.70  |
| cell to cell coupling k (%)                             | 2.0    | 1.8     | 1.22   | 2.66   | 1.95    | 1:42   | 1.85   |
| R/Q ( $\Omega$ ) per cell                               | 121.48 | 90.96   | 112.12 | 108.00 | 110.87  | 124.33 | 115.22 |
| Epk/Eacc                                                | 2.359  | 2.054   | 2.039  | 2.220  | 2.024   | 2.000  | 2.070  |
| type of structure                                       | CSC    | CSC     | SCSCS  |        | CSE     | CSC    | CSC    |
| Trapped monopole modes under 3 times of fund. frequency | no     |         |        |        | no      |        |        |

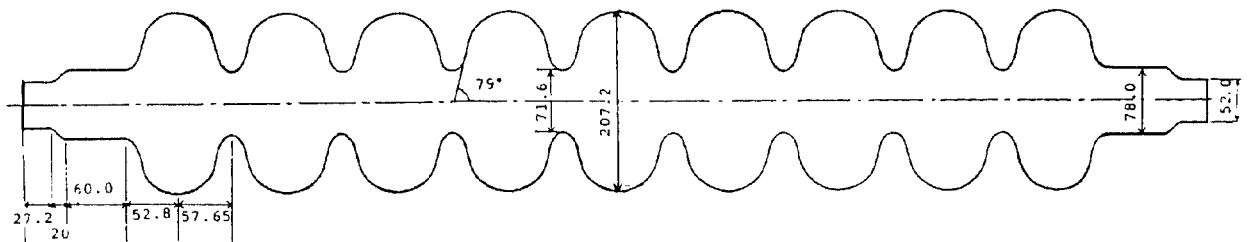


Fig.7. Geometry and dimensions of 9-cell BT superconducting accelerating structure.

## References

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- [2] H. Padamsee et al, "A New Shape Candidate for a Multicell Superconducting Cavity for TESLA" CLNS 90-985
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