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Design of half-reentrant SRF cavities

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Abstract

The shape of a TeSLA inner cell can be improved to lower the peak surface magnetic field at the expense of a higher peak surface electric field by making the cell reentrant. Such a single-cell cavity was designed and tested at Cornell, setting a world record accelerating gradient [V. Shemelin et al., An optimized shape cavity for TESLA: concept and fabrication, 11th Workshop on RF Superconductivity, Travemünde, Germany, September 8–12, 2003; R. Geng, H. Padamsee, Reentrant cavity and first test result, Pushing the Limits of RF Superconductivity Workshop, Argonne National Laboratory, September 22–24, 2004]. However, the disadvantage to a cavity is that liquids become trapped in the reentrant portion when it is vertically hung during high pressure rinsing. While this was overcome for Cornell's single-cell cavity by flipping it several times between high pressure rinse cycles, this may not be feasible for a multi-cell cavity. One solution to this problem is to make the cavity reentrant on only one side, leaving the opposite wall angle at six degrees for fluid drainage. This idea was first presented in 2004 [T.L. Grimm et al., IEEE Transactions on Applied Superconductivity 15(6) (2005) 2393]. Preliminary designs of two new half-reentrant (HR) inner cells have since been completed, one at a high cell-to-cell coupling of 2.1% (high-k_{cc} HR) and the other at 1.5% (low-k_{cc} HR). The parameters of a HR cavity are comparable to a fully reentrant cavity, with the added benefit that a HR cavity can be easily cleaned with current technology.

Keywords: Superconducting RF; Reentrant; High gradients; Linear accelerator; Linear collider

1. Codes and geometry

The code used to optimize the cell shape was Analyst [1], which calculates parameters within 2% of SUPERFISH. Table 1 compares the results of Analyst to SUPERFISH for the TeSLA inner cell geometry. Analyst was used because it allows periodic boundary conditions with a phase advance of 180° to be placed on the far left and right surfaces of Fig. 1. Periodic boundary conditions are required for a HR cell because the electric field is not exactly perpendicular to the beam axis on those boundary surfaces as is the case with a symmetrical cell shape.

The geometry used for the HR shape is shown in Fig. 1. The geometrical parameters in Fig. 1 have been modified from the proposed shapes to make them clearly identifiable. The reentrant half of the cell consists of two ellipses in the iris region connected by a straight section to an ellipse in the high magnetic field region. The non-reentrant half consists of one ellipse in the iris region connected by a straight section to an ellipse in the high magnetic field region. In addition, there is a straight section along the top of the cell. Four conditions were placed on the cavity geometry: the length of the cell equals $\lambda/2$, the equatorial radius is set to maintain a frequency of 1300 MHz, the slope of the cavity wall must be continuous, and the non-reentrant wall angle (θ_{nr}) is 6°. With these four conditions, there are twelve remaining geometrical variables. If fluids are shown to easily drain from the non-reentrant wall, the wall angle could be reduced to less than 6° and improved cavity parameters would be expected.

2. Comparison of inner cells

The inner cell geometry primarily determines the parameters of a multi-cell cavity. Table 2 lists the inner cell parameters for TeSLA [2], the reentrant cavity fabricated at Cornell [3,4], and a low-loss cavity designed for the

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Table 1
Comparison of TeSLA inner cell parameters using Analyst versus SUPERFISH

	SUPERFISH	Analyst
Frequency (MHz)	1301	1301
E_{peak}/E_{acc} (−)	1.95	1.99
B_{peak}/E_{acc} $\left(\frac{mT}{MV/m}\right)$	4.17	4.17
R/Q (Ω)	113.3	113.5
G (Ω)	271.2	270.9
k_{cc} (%)	1.90	1.86

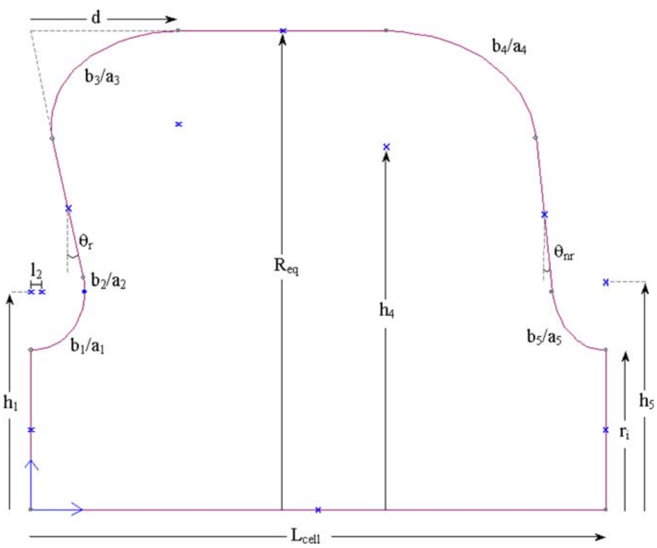

Fig. 1. Half-reentrant inner cell geometry.

Table 2
Inner cell parameters for three existing cavity designs

	TeSLA	Cornell reentrant	CEBAF Low-Loss
Frequency (MHz)	1300	1300	1500
E_{peak}/E_{acc} (−)	2.00	2.40	2.17
B_{peak}/E_{acc} $\left(\frac{mT}{MV/m}\right)$	4.26	3.78	3.74
R/Q (Ω)	115	121	129
G (Ω)	270	280	280
$(R/Q)\cdot G$ (Ω^2)	31,050	33,768	36,103
k_{cc} (%)	1.87	2.38	1.49
r_i (cm)	3.5	3.5	2.65

Table 3
Parameters of the two proposed half-reentrant inner cells compared to the proposed Low Loss ILC geometry

	High-k_{cc} HR	Low-k_{cc} HR	Low Loss ILC
Frequency (MHz)	1300	1300	1300
Wall angle (°)	6	6	0.165
E_{peak}/E_{acc} (−)	2.40	2.38	2.36
B_{peak}/E_{acc} $\left(\frac{mT}{MV/m}\right)$	3.78	3.60	3.61
R/Q (Ω)	123	135	134
G (Ω)	283	283	284
$(R/Q)\cdot G$ (Ω^2)	34,673	38,021	37,970
k_{cc} (%)	2.09	1.51	1.52
r_i (cm)	3.34	2.97	3.00

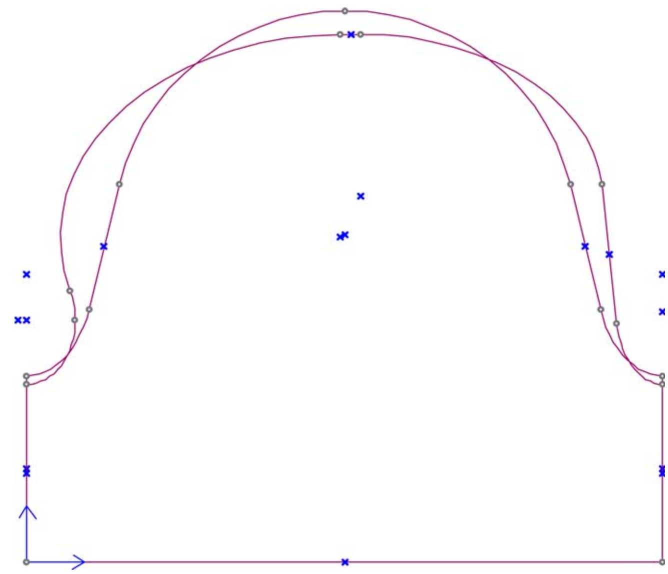

Fig. 2. Comparison of proposed high-k HR shape to a TeSLA inner cell.

CEBAF upgrade [5]. Table 3 lists the results from simulations of the two proposed HR inner cells and compares them to a proposed low-loss cavity for the International Linear Collider [6]. Fig. 2 compares the geometry of the proposed high-k_{cc} HR shape to a TeSLA inner cell.

2.1. B_{peak}/E_{acc} ratio

There are two approaches to achieving higher accelerating gradients: using a material with a higher RF critical magnetic field than Nb to increase the theoretical maximum accelerating gradient, or improving the cell shape to lower B_{peak}/E_{acc}. The latter was done for the two proposed HR cells by making the cell reentrant on one side, thus increasing the inductance at the expense of E_{peak}/E_{acc}. B_{peak}/E_{acc} for the high-k_{cc} HR shape is the same as Cornell's reentrant cavity. The low-k_{cc} HR shape reduces B_{peak}/E_{acc} 15.5% below that of a TeSLA inner cell, making it comparable to the Low Loss ILC cavity. For the proposed low-k_{cc} HR shape, with a B_{peak} of 185 mT, an accelerating gradient of 51 MV/m is foreseeable.

2.2. E_{peak}/E_{acc} ratio

For both HR shapes, and reentrant shaped cavities in general, a lower B_{peak}/E_{acc} comes at the expense of a higher E_{peak}/E_{acc}. However, E_{peak}/E_{acc} must be kept tolerable for high gradient cavities. For both of the proposed HR shapes, E_{peak}/E_{acc} was chosen to be no more than 2.40, as a world record of E_{acc} was already achieved with a cell designed with this value [7].

2.3. Shunt impedance and geometry factor

A higher $(R/Q)\cdot G$ lowers the cavity losses for a given surface resistance and accelerating gradient: