Geometric optimization of the 56MHz SRF cavity and its frequency table

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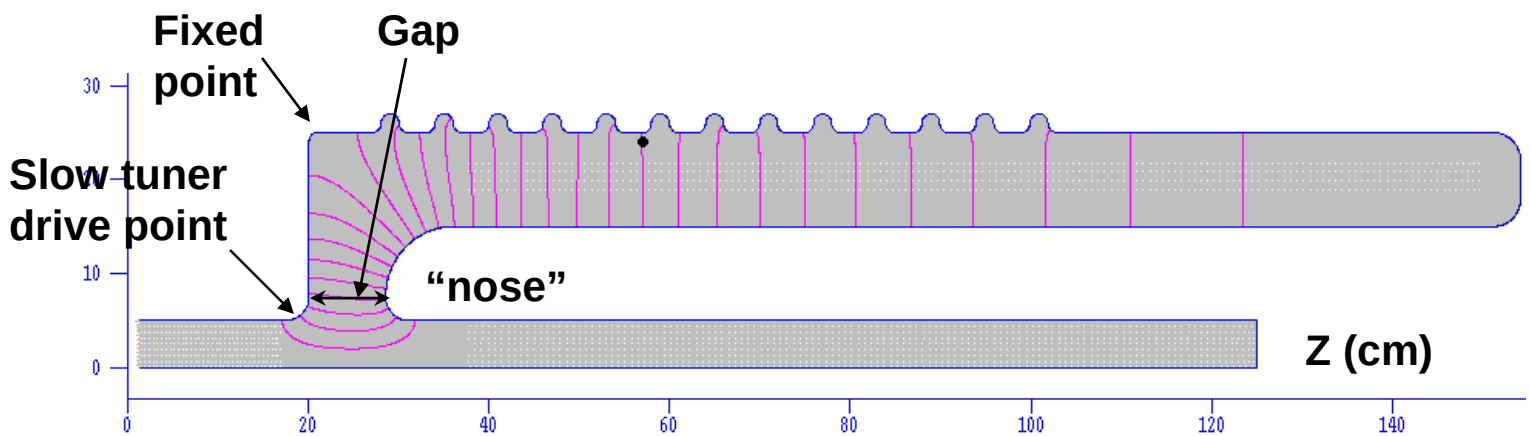
Introduction

- The voltage across the 56MHz SRF cavity is a critical parameter for its use.
- Optimize the geometry to lower the peak field at fixed voltage.
- The frequency sensitivity of the slow tuner adjustment is also critical for the operation.
  - Increase the frequency tolerance
  - Increase the detune during the energy ramping up
- The frequency table tracks the frequency change from “just being fabricated” to the final operation state. The frequency is the most important parameter for the fabrication.



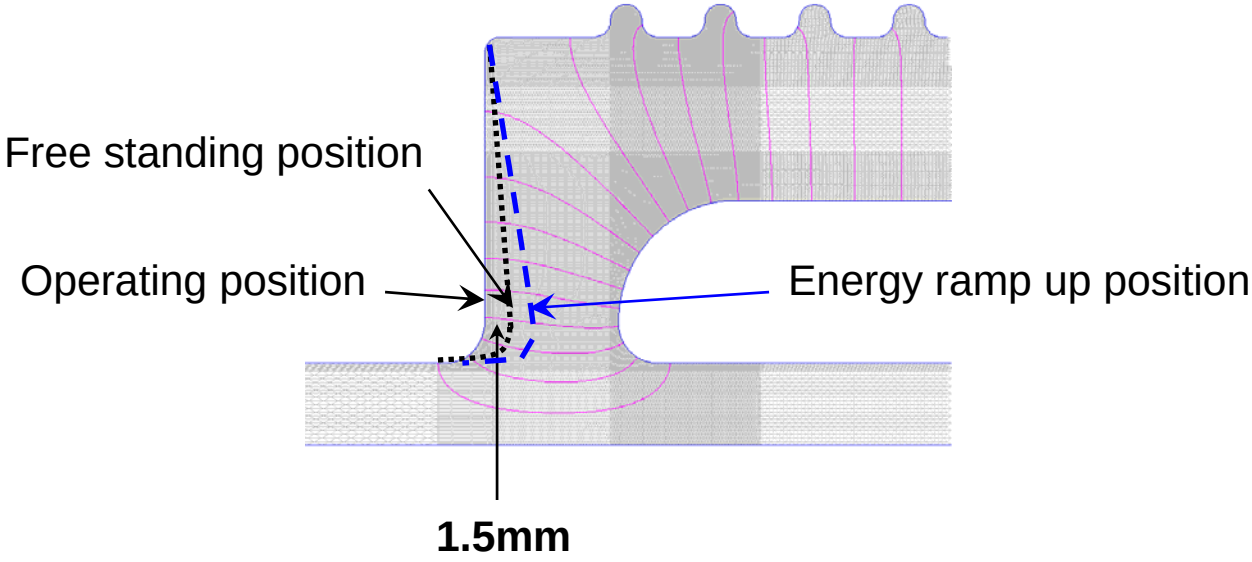
Frequency changes

- The operating frequency:
  - $\gamma = \infty$ 56.30133 MHz
  - $\gamma = 250$ 56.30088 MHz
  - $\gamma = 100$ (Cavity resonance frequency) 56.2985 MHz
- +5.6kHz/damper. 4 dampers
- Chemical cleaning: -15 kHz/mm. 100μm material loss.
- Pump down:
  - -0.28 KHz due to the geometry deformation
  - permittivity change: $f_{Vac} / f_{Air} = \sqrt{\varepsilon_r(air)} \approx 1.00027$ (+15.2 kHz)
- Cooling down: Geometry change coefficient: 0.00143. (+80.36 kHz)
- Slow tuner tuning: +17 kHz/mm. 1.5mm outward, +25.5 kHz
- Welding shrinkage: 0.6±0.06mm (will be measured experimentally). -23kHz/mm

Status					Actions	Freq. [MHz]	Freq. change [kHz]	Error (kHz)
Operation position (0mm)	Cooling down	Vacuum	After chemical treatment	With 4 HOM dampers		56.2985		0
Detune position (1.5mm)	Cooling down (4.2K)	Vacuum	After chemical treatment	With 4 HOM dampers	Tuner moves inward	56.2730	-25.5 (17kHz/mm)	0.5
Detune position	Room temp.	Vacuum (ε_r=1)	After chemical treatment	With 4 HOM dampers	Warm up to R.T. (expansion)	56.1925	-80.5 (α=0.00143 4.2k~293k)	0.5 (7.3E-6/K, 0.4kHz/K @ 273K)
Detune position	Room temp.	In air (ε_r= 1.00054)	After chemical treatment	With 4 HOM dampers	Fill in air (pressure deformation)	56.1928	+0.28	0.01
Detune position	Room temp.	In air	After chemical treatment (100um loss)	With 4 HOM dampers	Fill in air (Permittivity change)	56.1776	-15.2 (ε=1.00054)	0.3
Detune position	Room temp.	In air	Before chemical treatment	With 4 HOM dampers	Undo the effect of chemistry	56.1791	+1.5 (-15kHz/mm)	0.5
Detune position	Room temp.	In air	Before chemical treatment	Without HOM dampers	Remove 4 HOM dampers (As fabricated)	56.1567	-22.4 (5.6kHz /damper)	1
Detune position	Room temp.	In air	Before chemical treatment	Without HOM dampers	Before welding the last piece	56.1705	+13.8kHz (-23kHz/mm)	1.4

Frequency errors

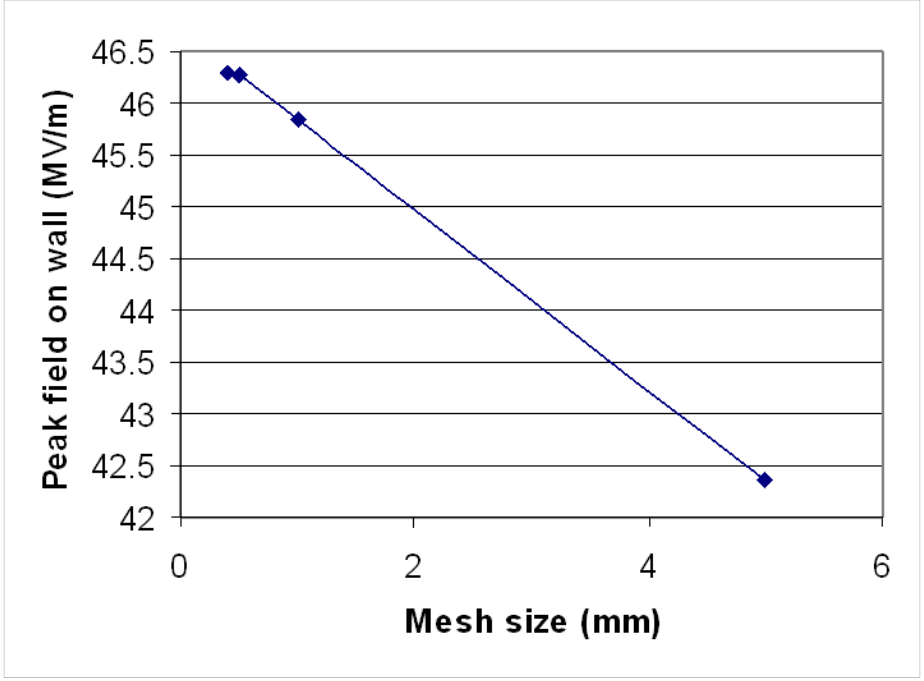
- The total frequency error is 2.5kHz from the last table.
- The slow tuner adjustment range at operation point is ±9kHz
- The γ coverage is from γ=49±6 to $\gamma=\infty$



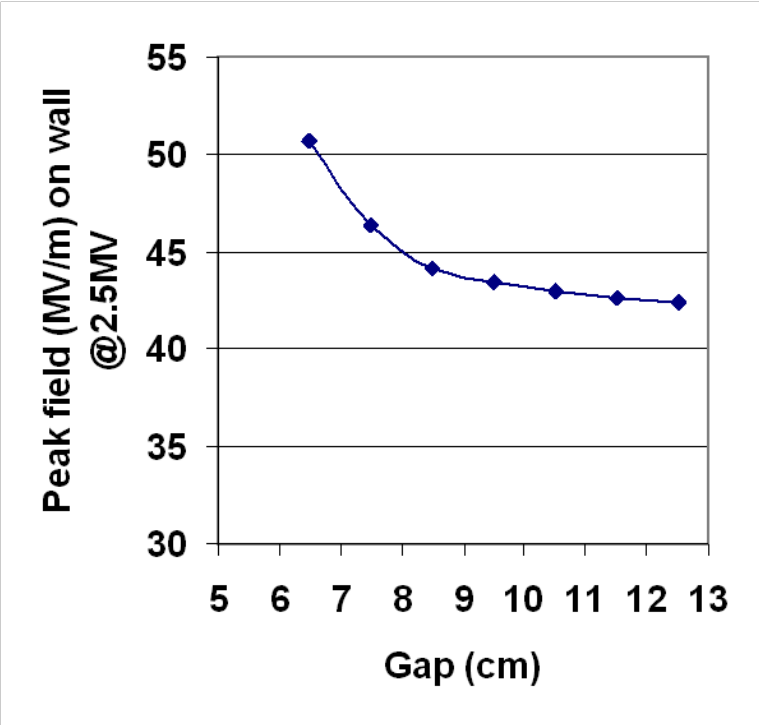
Gap optimization

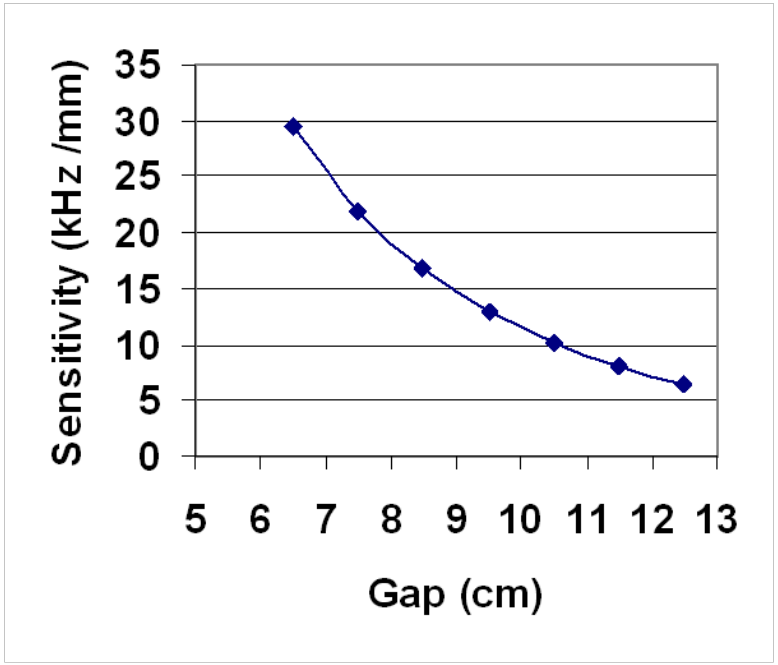
Mesh size and accuracy

0.5mm in our simulation



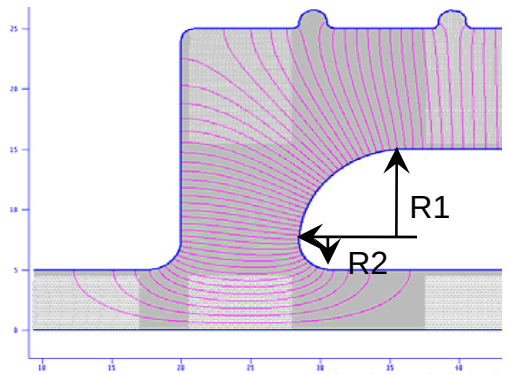
- Peak electric-field and sensitivity vs. gap
- Gap =8.5cm

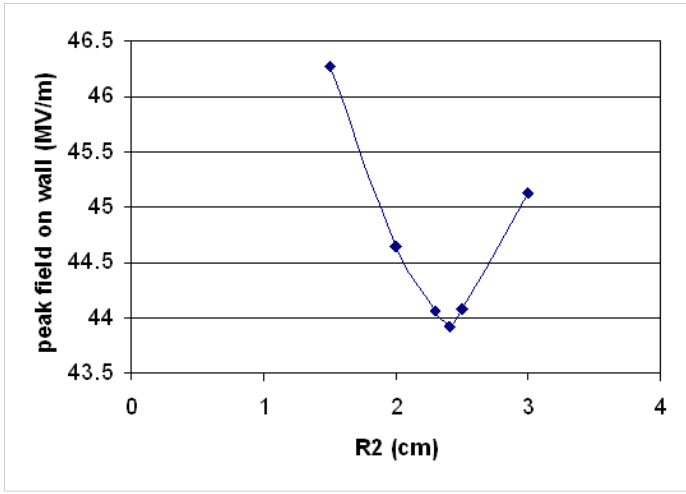




“nose” optimization

- R_2=2.5cm





Peak electric-field vs. R_2

Parameters list @ 2.5MV voltage

- Frequency = 56.29903 MHz
- Stored energy = 214.43 Joules
- Operating temperature = 4.2000 K
- Cryogenic power dissipation = 42.23 W
- Q = 1.796E+9
- Shunt impedance = 74002 MOhm/m
- r/Q = 81.95 Ohm
- Maximum H (at Z,R = 151.27,14.97) = 83483.4A/m
- Maximum E (at Z,R = 30.12,12.15) = 44.09 MV/m
- Slow tuner sensitivity = 17 kHz/mm

Conclusions

- The frequency at the fabrication stage is 56.1567MHz under present assumptions
- Optimized gap is 8.5cm
- Optimized “nose” radii are 2.5cm+7.5cm
- Peak electric field is 44.1MV/m and peak magnetic field is 1050G @ 2.5MV voltage. Slow tuner sensitivity is 17kHz/mm.
- The slow tuner adjustment range is sufficient to cover the frequency errors
- The γ coverage is from $\gamma=49\pm6$ to $\gamma=\infty$