ALTERNATIVE DESIGN OF A 5-CELL CAVITY FOR THE OPERATING POINT

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Content

• SRF overview – $t^-$ operating point

• Machine parameters

• Review of the baseline design (FCCUROS5)

• Aim

• Cavity Design

• Comparison with FCCUROS5

• Summary and Outlook
SRF Overview

• The previous RF baseline presented in the CDR [1] considers:
  – Hybrid system 4-cell 400 MHz and 5-cell 800 MHz cavities - tă working point [2]

• The current RF baseline considers:
  – Hybrid system 2-cell 400 MHz and 5-cell 800 MHz cavities - tă working point [2]

• The FCCUROS5 is a cavity geometry design proposed for the tă working point [2, p. 68]

## Machine Parameters

<table>
<thead>
<tr>
<th>Machine parameter</th>
<th>Operating Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam energy [GeV]</td>
<td>182.5</td>
</tr>
<tr>
<td>Beam current [mA]</td>
<td>10</td>
</tr>
<tr>
<td>Beam RF voltage [GV]</td>
<td>9.2</td>
</tr>
<tr>
<td>Bunch intensity ([10^{11}])</td>
<td>2.26</td>
</tr>
<tr>
<td>Bunch SR length [mm]</td>
<td>1.67</td>
</tr>
<tr>
<td>Bunch BS length [mm]</td>
<td>2.54</td>
</tr>
</tbody>
</table>
Review of FCCUROS5 (2019)

• The plots show that the FCCUROS5 is still suitable for operation at the operating point.
Aim

• Investigate the possibility of improving the performance of the FCCUROS5 for the tī operating point, especially concerning higher-order modes (HOMs) effects.

• Also, considering the high beam current of 140 mA for the Z booster, by improving the HOM characteristics of the 5-cell cavities, the same type of 5-cell 800 MHz cavities can be used for the boosters of all four operating points.
Design Procedure

\[
\min_{x_l, x_u \in \mathbf{X}} \left( \frac{E_{pk}}{E_{acc}}, \frac{B_{pk}}{E_{acc}}, -\frac{R}{Q}, |Z_{\parallel,p}|, |Z_{\perp,q}| \right)
\]

s.t. 
\[
R_{eq}/\text{mm} = \arg \min_{R_{eq}} f(R_{eq}) - f_{FM},
\]
\[
L_e/\text{mm} = \arg \min_{L_e} f(L_e) - f_{FM},
\]
\[
A_{i,e}, B_{i,e}/\text{mm} \in [20, 80],
\]
\[
a_{i,e}, b_{i,e}/\text{mm} \in [10, 60],
\]
\[
R_{i,i,e}/\text{mm} \in [60, 85],
\]
\[
L_l/\text{mm} = 93.5,
\]
\[
\alpha_l \geq 90^\circ,
\]
\[
\frac{E_{pk}}{E_{acc}} \leq 3,
\]
\[
\frac{B_{pk}}{E_{acc}} \leq \frac{\text{mT}}{\text{MV/m}} \leq 5,
\]

Algorithm 1 Pareto-based Genetic Algorithm

Initialisation: \( \mathbf{X} = (x_1, \ldots, x_Q), n = 0, \nu_l; \)

\( \triangleright \) First generation, \( \nu_l \) : hypervolume threshold value.

while \( n < N \) do \( \triangleright \) Generation loop

for \( x = x_1, \ldots, x_Q \) do \( \triangleright \) Half-cell geometry loop

run SLANS, ABCI

\( \triangleright \) for \( \frac{E_{pk}}{E_{acc}}, \frac{B_{pk}}{E_{acc}}, -\frac{R}{Q}, |Z_{\parallel,p}|, |Z_{\perp,q}| \)

\( \mathbf{P}_n \leftarrow \) Evaluate and interpolate Pareto hypersurface

if \( n > 0 \) then

Evaluate hypervolume \( \nu \) between \( \mathbf{P}_n \) and \( \mathbf{P}_{n-1} \)

if \( \nu < \nu_l \) then

break

do Ranking and Selection, Crossover, Mutation

do Introduce random half-cell geometries

\( \mathbf{X} \leftarrow \) newly created geometries

return \( \mathbf{P}_n \)
## Geometric Parameters

<table>
<thead>
<tr>
<th>Variable</th>
<th>C3795</th>
<th>FCCUROS5</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_i, R_{ie}$ [mm]</td>
<td>72/80</td>
<td>60/78</td>
</tr>
</tbody>
</table>

![Graphs showing mid and end half-cell contours](image_url)
Design Comparison
## Fundamental Mode Figures of Merit Comparison

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$R/Q , [\Omega]$</td>
<td>521.06</td>
<td>448.1244</td>
</tr>
<tr>
<td>$G , [\Omega]$</td>
<td>272.93</td>
<td>261.63</td>
</tr>
<tr>
<td>$G \cdot R/Q , [\Omega^2]$</td>
<td>1.422e5</td>
<td>1.172e5</td>
</tr>
<tr>
<td>$k_{cc} , [%]$</td>
<td>2.04</td>
<td>2.64</td>
</tr>
<tr>
<td>$E_{pk}/E_{acc} , [-]$</td>
<td>2.05</td>
<td>2.43</td>
</tr>
<tr>
<td>$B_{pk}/E_{acc} , [mT/MV/m]$</td>
<td>4.33</td>
<td>4.88</td>
</tr>
</tbody>
</table>
Impedance Plot Comparison

Longitudinal impedance plot

Transverse impedance plot
# HOM Figures of Merit Comparison

|----------|-----------------|--------------|
| $k_{||} [V/pC]$  
$(SR, \sigma_z=1.67 \text{ mm})$ | 3.784 | 2.632 |
| $k_{\perp} [V/pC/m]$  
$(SR, \sigma_z=1.67 \text{ mm})$ | 3.539 | 2.017 |
| $P_{HOM} [W]$  
$(SR, \sigma_z=1.67 \text{ mm})$ | 1115 | 698 |

Beam Current [mA] = 10mA, Bunch Intensity $N_b [10^{11}] = 2.26$
FM and HOM Figs. of Merit Comparison Summary

Bar plot summary of FM and HOM figures of merit.

FM Figures of Merit
- $e_{pk}/e_{acc}$: 19% ↑
- $b_{pk}/e_{acc}$: 13% ↑
- $k_{cc}$: 29% ↑
- $r/q$: 14% ↓
- $g$: 4% ↓

HOM Figures of Merit
- $|k|$: 30% ↓
- $k_{\perp}$: 43% ↓
- $p_{HOM/CAV}$: 34% ↓
### Power Comparison

**Plot of static and dynamic power loss, no of cav and input power ($P_{in}$) vs $E_{acc}$**

<table>
<thead>
<tr>
<th>Variable</th>
<th>C3795</th>
<th>FCUROS5</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n_{cav}$</td>
<td>488</td>
<td>488</td>
</tr>
<tr>
<td>$P_{stat}$ (kW)</td>
<td>5.19</td>
<td>5.19</td>
</tr>
<tr>
<td>$P_{dyn}$ (kW)</td>
<td>12.89</td>
<td>11.10</td>
</tr>
<tr>
<td>$P_{wp}$ (MW)</td>
<td>12.1</td>
<td>13.47</td>
</tr>
<tr>
<td>$P_{HOM,tot}$ (kW)</td>
<td>340.44</td>
<td>543.94</td>
</tr>
</tbody>
</table>

Assumed $Q_0 = 3.0E10$

Bar plot summary dynamic, wall and HOM power comparison.
C3795 + HOM Couplers Study
Transmission properties of LHC-type hook coupler (HC), double quarter wave (DQW), and DQW double notch (DQW_DN) coupler.
Lossy Eigenmode Impedance Plot for Cavity + HOM Couplers

Cavity + HOM coupler assembly transverse impedance plot showing first dipole passband modes

Cavity + HOM coupler assembly longitudinal impedance plot

*Assumed current for Z-booster operating point is 128mA
Summary and Outlook

- A 5-cell elliptical cavity geometry (C3795) was optimised for operation at the t∓ operating point
- C3795 untraps the first longitudinal HOM and is better in the longitudinal plane at the cost of FM degradation
- FCCUROS5 cavity remains a good option for the t∓ operating point
- The HOM power is 34% less for the C3795. The cost of this reduction is an increase of 19% and 13% in peak electric and magnetic fields, respectively
- The C3795 cavity geometry is better suited for the booster cavities of the Z-working point than the FCCUROS5 cavity geometry
- Study on HOM coupler is ongoing
Appendix
## Designed Cavity

### Geometric Variables

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A, A_e$ [mm]</td>
<td>62.22/62.58</td>
</tr>
<tr>
<td>$B, B_e$ [mm]</td>
<td>66.13/57.54</td>
</tr>
<tr>
<td>$a, a_e$ [mm]</td>
<td>30.22/17.21</td>
</tr>
<tr>
<td>$b, b_e$ [mm]</td>
<td>23.11/12.00</td>
</tr>
<tr>
<td>$R_i, R_{ie}$ [mm]</td>
<td>72/80</td>
</tr>
<tr>
<td>$L, L_e$ [mm]</td>
<td>93.5/93.795</td>
</tr>
<tr>
<td>$R_{eq}$ [mm]</td>
<td>171.20</td>
</tr>
<tr>
<td>$\alpha$ [$^\circ$]</td>
<td>94.50, 112.09</td>
</tr>
</tbody>
</table>

### Fundamental Mode Figures of Merit

<table>
<thead>
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<th>Parameter</th>
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<tr>
<td>$R/Q$ [$\Omega$]</td>
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<tr>
<td>$G$ [$\Omega$]</td>
<td>261.63</td>
</tr>
<tr>
<td>$GQ$ [$\Omega^2$]</td>
<td>1.172e5</td>
</tr>
<tr>
<td>$E_{pk}/E_{acc}$ [-]</td>
<td>2.43</td>
</tr>
<tr>
<td>$B_{pk}/E_{acc}$ [mT/MV/m]</td>
<td>4.88</td>
</tr>
</tbody>
</table>

### Higher-Order Mode Figures of Merit

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_\parallel$ [V/pC] ($SR, \sigma_z=1.67$ mm)</td>
<td>2.639</td>
</tr>
<tr>
<td>$k_\perp$ [V/pC/m] ($SR, \sigma_z=1.67$ mm)</td>
<td>2.014</td>
</tr>
<tr>
<td>$P_{HOM}$ [W] ($SR, \sigma_z=1.67$ mm)</td>
<td>375.48</td>
</tr>
</tbody>
</table>

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**Image:** Designed cavity - C3795

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