An Integrated Design for a $\beta=0.175$ Spoke Resonator and Associated Power Coupler

Frank Krawczyk, LANL
for the AAA Project
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Introduction

Acknowledgements: B. Rusnak, LLNL, K. Shepard and M. Kelly, ANL, G. Corniani, Zanon C. Pagani’s group at INFN-Milano

Structure: 2-gap spoke resonator at 350 MHz w/ power coupler (coaxial, 75 Ω)

- Integration process
- Spoke cavity and coupler interface results
- Coupler results
- Other interface effects
- Construction and planned testing
Design Integration: Standard Procedure

If minor perturbation occurs when cavity and coupler are interfaced, independent designs can be done.

If major perturbation occurs, e.g. significant volume change due to ports → interface must to be considered
Design Integration: Overview

**Standard Design**

- **Cavity Issues**
  - RF structural

- **Coupler Issues**
  - RF structural
  - RF thermal

- **Minor interface issues**

**Final Design**

**Integrated Design**

- **Cavity Issues**
  - Cavity + Interface

- **Coupler Issues**
  - RF structural
  - RF thermal

- **Minor interface issues**

**Interface issues solved here already**

**Final Design**
Design Integration: Where are we?

Integrated Design

Cavity Issues

Coupler Issues

Cavity + Interface

RF structural thermal

RF structural

Minor interface issues

Final Design
Design Integration: 1) Interface Consideration

Include ports as part of the initial cavity model. This integrates the impact of the coupler interface into the solution already.
Design Integration: Where are we?

Integrated Design

- Cavity Issues
- Coupler Issues

- Cavity + Interface
- RF structural thermal
- RF structural
- Minor interface issues

Final Design
Design Integration: 2a) RF and Structural Design

Quality Assurance

Common CAD Model

RF Models

Structural Shell Model
RF effects of deformations:
Tuning Sensitivity/ Forces

Shell Mesh ← Volume Mesh
Common nodes allow recalculation of RF-case without re-meshing (reduces discretization error)
Design Integration: Benchmark

Argonne National Lab (ANL) Cavity Used for Benchmark

<table>
<thead>
<tr>
<th></th>
<th>Measured</th>
<th>Cosmos/Micav</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_0$</td>
<td>339.699 MHz</td>
<td>338.821 MHz</td>
<td>-0.26%</td>
</tr>
<tr>
<td>$df/dz$</td>
<td>9.356 MHz/in</td>
<td>11.32 MHz/in</td>
<td>21%</td>
</tr>
<tr>
<td>stiffness</td>
<td>34.36 lb/mil</td>
<td>44.4 lb/mil</td>
<td>29%</td>
</tr>
<tr>
<td>$df/force$</td>
<td>0.272 kHz/lb</td>
<td>0.255 kHz/lb</td>
<td>-6.35%</td>
</tr>
</tbody>
</table>

Common nodes concept does allow calculation of volume changes. →

A “3D-Slater” theorem calculation could be implemented. This would give a more accurate prediction of the tuning sensitivity.
Spoke Cavity: Structural Results

Stresses due to external vacuum load

Stresses due to tuning deformation

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EPAC 2002, Paris, France
Spoke Cavity: RF Results

Electric Field of Acceleration Mode

Magnetic Field of Acceleration Mode
### RF Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_0$ (4 K)</td>
<td>$1.05 \times 10^9$ (for 61 nΩ)</td>
</tr>
<tr>
<td>$T$ ($\beta_g$)</td>
<td>0.7765 ($\beta_g=0.175$)</td>
</tr>
<tr>
<td>$T_{\text{max}}$ ($\beta$)</td>
<td>0.8063 (@ $\beta=0.21$)</td>
</tr>
<tr>
<td>$G$</td>
<td>64.1 Ω</td>
</tr>
<tr>
<td>$E_{pk}/E_0T$</td>
<td>2.82</td>
</tr>
<tr>
<td>$H_{pk}/E_0T$</td>
<td>73.8 G/MV/m</td>
</tr>
<tr>
<td>$P_{\text{cav}}$ (4 K)</td>
<td>4.63 W @ 7.5 MV/m</td>
</tr>
<tr>
<td>$R/Q$</td>
<td>124 Ω</td>
</tr>
</tbody>
</table>

### Effects of 2 atm external differential load

<table>
<thead>
<tr>
<th>Ring diameter [cm]</th>
<th>Reaction-force [lbs]</th>
<th>Von Mises Stress [psi]</th>
<th>$\Delta f$ [kHz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>28 cm</td>
<td>3875</td>
<td>5172</td>
<td>-94.98</td>
</tr>
<tr>
<td>26 cm</td>
<td>3776</td>
<td>5177</td>
<td>-87.96</td>
</tr>
<tr>
<td>24 cm</td>
<td>3743</td>
<td>5181</td>
<td>-74.94</td>
</tr>
</tbody>
</table>

### Tuning sensitivities

<table>
<thead>
<tr>
<th>Ring Diameter [cm]</th>
<th>Boundary Condition</th>
<th>Tuning Sensitivity kHz/lbs</th>
<th>kHz/mil</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>Moving</td>
<td>-0.3542</td>
<td>-45.148</td>
</tr>
<tr>
<td>28</td>
<td>Fixed</td>
<td>-0.3108</td>
<td>-25.845</td>
</tr>
<tr>
<td>26</td>
<td>Moving</td>
<td>-0.3914</td>
<td>-45.404</td>
</tr>
<tr>
<td>26</td>
<td>Fixed</td>
<td>-0.3504</td>
<td>-25.664</td>
</tr>
<tr>
<td>24</td>
<td>Moving</td>
<td>-0.4012</td>
<td>-46.076</td>
</tr>
<tr>
<td>24</td>
<td>Fixed</td>
<td>-0.3490</td>
<td>-25.370</td>
</tr>
</tbody>
</table>
Design Integration: Where are we?

Integrated Design

Cavity Issues

Coupler Issues

Cavity + Interface

RF structural

Minor interface issues

RF structural thermal

Final Design
Power Coupler: Concept

Vacuum Port

Coaxial Short

Warm part of the coupler

Waveguide

Short

Cylindrical Alumina Window

Waveguide Feed

Coax diameter 103 mm
Coax impedance 75 Ω
Waveguide WR3200
Window-type cylindrical
Window-material 95% pure (ε = 9.1, tan δ = 0.0027)
Window OD 139.7 mm
Thickness 4.8 mm
Transition ½-height waveguide to λ/4 stub

Cavity Interface
Power Coupler: RF Results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coax short</td>
<td>305.5 mm to window center</td>
</tr>
<tr>
<td>Waveguide short</td>
<td>130 mm to window center</td>
</tr>
<tr>
<td>Vacuum port</td>
<td>140 mm to waveguide top</td>
</tr>
<tr>
<td>Coax-length</td>
<td>1196.7 mm from short to tip</td>
</tr>
<tr>
<td>Pump flange</td>
<td>450 mm to coax center</td>
</tr>
<tr>
<td>Orientation</td>
<td>45 degrees from spoke</td>
</tr>
<tr>
<td>( F_{\text{match}} )</td>
<td>350.1 MHz</td>
</tr>
<tr>
<td>( S_{11} )</td>
<td>-45 dB</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>( \pm 11 ) MHz at (-20 ) (30) dB</td>
</tr>
</tbody>
</table>

S-parameters
Power Coupler: Thermal/Structural Evaluation

Goals:
1. Input for thermal
2. Critical spots
3. Cooling needs

<table>
<thead>
<tr>
<th>Beam Current</th>
<th>Transmitted Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.3 mA</td>
<td>8.5 kW</td>
</tr>
<tr>
<td>20 mA</td>
<td>12.8 kW</td>
</tr>
<tr>
<td>100 mA</td>
<td>63.6 kW</td>
</tr>
</tbody>
</table>

Coax-center, Straight Coax
- 3.6 W
- 5.135 W
- 26.90 W

Coax-center, Actual Coupler
- 3.94 W
- 5.93 W
- 29.48 W

Coax Short
- 113 mW
- 170 mW
- 843 mW

Waveguide Short
- 116 mW
- 174 mW
- 865 mW

Window Ceramic
- 6.6 W
- 9.9 W
- 49.4 W

Peak Loss in Window [W/cm³]
- 0.04
- 0.06
- 0.27

Peak Temperature on Window
- < 47° C

dT_max across Window
- 2° - 22° C

Inner conductor cooling: GHe
Window cooling: dry air

Cylindrical Alumina Window
Design Integration: Where are we?

Integrated Design

- Cavity Issues
- Coupler Issues
  - Cavity + Interface
  - RF structural thermal

RF structural

Minor interface issues

Final Design
Design Integration: 3a) TW Properties at Interface

6.5 mW/cm² @ 8.5 kW

Losses @ 8.5 kW

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_{\text{tip, max}}$</td>
<td>4.82 W/cm²</td>
</tr>
<tr>
<td>$P_{\text{tip, total}}$</td>
<td>25.2 W</td>
</tr>
<tr>
<td>$T_{\text{tip}}$</td>
<td>52°C</td>
</tr>
<tr>
<td>$P_{\text{thermal}}$</td>
<td>0.5 W</td>
</tr>
</tbody>
</table>
Design Integration: 3b) Coupling Evaluation

Goal: 1. Tip position
2. Frequency

<table>
<thead>
<tr>
<th>I [mA]</th>
<th>$Q_x$</th>
<th>$\Delta f$ [kHz]</th>
<th>z [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.3</td>
<td>2.13E+6</td>
<td>reference</td>
<td>23</td>
</tr>
<tr>
<td>20.0</td>
<td>1.42E+6</td>
<td>-200</td>
<td>20</td>
</tr>
<tr>
<td>100.0</td>
<td>2.83E+6</td>
<td>-970</td>
<td>9</td>
</tr>
</tbody>
</table>
Design Integration: Where are we?

Integrated Design

- Cavity Issues
- Coupler Issues
- Cavity + Interface
- RF structural thermal
- RF structural
- Minor interface issues

Final Design
Cryogenic Cavity Test, Interface Verification

- Spoke Cavity is built by ZANON w/ INFN Milan,
- Coupler production pending
- Vertical test will use 2 coupler for $Q_x(z)$, $df(z)$, $Q_0$

Cavity ready 2nd week of June, 2002

Variable probe in high B-field

Fixed probe in low B-field
Summary

- Tools and strategies for an integrated cavity/coupler design have been presented.
- The integrated design of the spoke cavity and associated power coupler was presented.
- Single steps have been benchmarked.
- A good understanding of the system has been achieved.
- Verification under cryogenic conditions will happen within a few months.