Outline

• Longitudinal impedance model of the SPS
• Measurement setup & method
• Fundamental pass band: Results
• Higher Order Modes: Results
• 1.4 GHz band
• Conclusions
Why do we need this?

Longitudinal impedance model of the SPS

Beam dynamics codes

- 200 MHz TWC FPB
- 800 MHz TWC FPB
- 200 MHz TWC HOM @ 630 MHz
- Flanges
- BPMs

Impedance, modulus, [MΩ]

Frequency, [GHz]
Measurement setup & method

SPS 200 MHz TWC in the ring:
• 4 to 5 sections / cavity system

Test device: One section
• 4.114 m long
• 11 drift tubes
• No power couplers
• No HOM couplers
• Short circuited
→ Standing wave measurements
Measurement setup & method

What we’re after:

Fundamental pass band model with HOMs of the SPS 200 MHz TWC

200MHz SPS Cavity - One Shortcircuited Tank

- Simulation 1
- Simulation 2
- Measurements 2014
- Measurements 2015
- G. Dome
Measurement setup & method

- **Goal:** Obtain longitudinal impedance of SPS 200 MHz TWC

- **Method:** Bead-pull measurements

- **Main concept:** Introducing a conductor / dielectric / ferromagnetic into a resonator $\rightarrow$ Frequency change (Perturbation theory).

$$\frac{\Delta f}{f_0} = \frac{\iiint_{V_{\text{bead}}} (\vec{E}_1 \cdot \vec{D}_0 - \vec{E}_0 \cdot \vec{D}_1 - \vec{H}_1 \cdot \vec{B}_0 + \vec{H}_0 \cdot \vec{B}_1) \, dv}{\iiint_{V} (\vec{E}_0 \cdot \vec{D}_1 - \vec{H}_0 \cdot \vec{B}_1) \, dv}$$

Assumptions:  
- Homogeneous bead ($\vec{D}, \vec{B} \rightarrow \vec{E}, \vec{H}, \varepsilon, \mu$)  
- Small perturbation  
- Small bead: $\vec{E}, \vec{H}$ constant within  
- $\vec{E}, \vec{H}$ outside bead: unchanged  
- Only $E_z$ sensitive: metallic + needle shape bead

$$\rightarrow \frac{\Delta f}{f_0} \approx \frac{1}{W_0} (K_1 \varepsilon_0 |E_z|^2)$$  
with $K_1$ a constant related to the bead dimensions, $W_0$ the total time averaged mean stored energy in the cavity.

F. Caspers, G. Dôme, CERN-SPS 85-46
Measurement setup & method

- **Goal:** Obtain longitudinal impedance of SPS 200 MHz TWC

- **Method:** Bead-pull measurements

- **Main concept:** Introducing a conductor / dielectric / ferromagnetic into a resonator → Frequency change (Perturbation theory).

\[
\Delta f_0 \sim \frac{|E_z(z)|^2}{\sqrt{W}} \rightarrow \text{Excite with } f_0 \text{ + move bead & measure } \Delta f_0
\]

→ In practice: easier

\[
\frac{\Delta f_0}{f_0} \approx \frac{1}{2Q_L} \tan(\Delta \phi)
\]

→ Semi-automated (single \( f_0 \))

(motor + VNA + acquisition soft)
Measurement setup & method

Typical transmission measurement for a needle moving in the SPS 200 MHz TWC in standing wave mode @ 202 MHz

Very accurate $E_z$ measurement $\rightarrow$ R/Q, but time consuming
Measurement setup & method

Typical Result: SPS 200 MHz TWC FPB @ 202 MHz
Simulation vs. measurement: $E_z$ along cavity section
Fundamental pass band of the SPS 200 MHz TWC

- 11 modes in standing wave measurements ↔ 25 MHz pass band: 192 MHz – 217 MHz in travelling wave operation
- High R/Q: 198.6 MHz and 202.0 MHz
Higher Order Modes: Results

SPS 200 MHz TWC:

- Current impedance model (TWC) →
- HOM coupler @ 628 MHz (Longit. mode)
- HOM coupler @ 939 MHz (Transv. mode)
- HOM coupler @ 460 MHz (Transv. mode)

Measurement situation SPS 200 MHz TWC:

! Remember!

- Single 4m section
- No FPC
- No HOM couplers
- Short circuited

<table>
<thead>
<tr>
<th>f [MHz]</th>
<th>Z [kΩ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 (4-cav)</td>
<td>1752</td>
</tr>
<tr>
<td>200 (5-cav)</td>
<td>2760</td>
</tr>
<tr>
<td>629 (both)</td>
<td>388</td>
</tr>
</tbody>
</table>
Higher Order Modes: Results

SPS 200 MHz TWC

Simulation results

FPB @ 198 MHz and 202 MHz

Detailed view on next slide
Higher Order Modes: Results

SPS 200 MHz TWC

Simulation results

FPB
HOM coupler @ 628 MHz

“High”
“Medium”
“Low”

(points removed)
Higher Order Modes: Results

SPS 200 MHz TWC

Simulations vs. measurements: comparison

Detailed view on next slide
Higher Order Modes: Results

SPS 200 MHz TWC

Simulations vs. measurements: comparison

- 287 MHz
- 328 MHz
- 550 MHz
- 915 MHz
- 908 MHz

Graph showing simulations and measurements at various frequencies.
Higher Order Modes: Results

SPS 200 MHz TWC

<table>
<thead>
<tr>
<th></th>
<th>Simulation</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f$ [MHz]</td>
<td>287</td>
<td></td>
</tr>
<tr>
<td>$\Delta\phi$ [$^\circ$]</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>$R/Q$ [Ω]</td>
<td>19.6</td>
<td>20.6</td>
</tr>
<tr>
<td>$Q$</td>
<td></td>
<td>25013</td>
</tr>
</tbody>
</table>
Higher Order Modes: Results

SPS 200 MHz TWC

<table>
<thead>
<tr>
<th></th>
<th>Simulation</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f$ [MHz]</td>
<td>328</td>
<td></td>
</tr>
<tr>
<td>$\Delta \phi$ [$^\circ$]</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>$R/Q$ [Ω]</td>
<td>12.0</td>
<td>11.5</td>
</tr>
<tr>
<td>$Q$</td>
<td>28666</td>
<td></td>
</tr>
</tbody>
</table>
Higher Order Modes: Results

SPS 200 MHz TWC

Simulations vs. measurements: comparison

![Graph comparing simulations and measurements for SPS 200 MHz TWC. The graph shows the comparison at 550 MHz.](image)
Higher Order Modes: Results

SPS 200 MHz TWC

Noisy data: Small $\Delta \phi$, to be improved

<table>
<thead>
<tr>
<th></th>
<th>Simulation</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f$ [MHz]</td>
<td>550</td>
<td></td>
</tr>
<tr>
<td>$\Delta \phi$ [$^\circ$]</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>$R/Q$ [$\Omega$]</td>
<td>27</td>
<td>9.4</td>
</tr>
<tr>
<td>$Q$</td>
<td>40492</td>
<td></td>
</tr>
</tbody>
</table>
Higher Order Modes: Results

Other reasons for mismatch:

- Noisy data
- Asymmetry: Intrinsic to cavity or… ?

<table>
<thead>
<tr>
<th>Simulation</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>f [MHz]</td>
<td>622</td>
</tr>
<tr>
<td>Δφ [°]</td>
<td>30</td>
</tr>
<tr>
<td>R/Q [Ω]</td>
<td>7.2</td>
</tr>
<tr>
<td>Q</td>
<td>16356</td>
</tr>
</tbody>
</table>
Higher Order Modes: Results

Other reasons for mismatch:

- Noisy data
- Asymmetry
- Local mismatch (= reality)

<table>
<thead>
<tr>
<th></th>
<th>Simulation</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>f [MHz]</td>
<td>624</td>
<td></td>
</tr>
<tr>
<td>$\Delta \phi$ [°]</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>R/Q [$\Omega$]</td>
<td>0.5</td>
<td>1.1</td>
</tr>
<tr>
<td>Q</td>
<td></td>
<td>18418</td>
</tr>
</tbody>
</table>

![Graph showing the comparison between simulation and measurement results](image)
Higher Order Modes: Results

Other reasons for mismatch:

- Noisy data
- Asymmetry
- Local mismatch (= reality)

<table>
<thead>
<tr>
<th></th>
<th>Simulation</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f$ [MHz]</td>
<td>631</td>
<td></td>
</tr>
<tr>
<td>$\Delta\phi$ [$^\circ$]</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>$R/Q$ [Ω]</td>
<td>27.1</td>
<td>34.8</td>
</tr>
<tr>
<td>$Q$</td>
<td>19519</td>
<td></td>
</tr>
</tbody>
</table>
1.4 GHz band

1.4 GHz band: Longit. modes

Simulation ↔ Measurements: Noisy, but no indications

200 MHz TWC: no harmful resonance @ 1.4 GHz
Conclusions

SPS 200 MHz TWC impedance measurements
• Fundamental pass band: 11 modes, 25 MHz bandwidth
  • Good agreement sim. – meas.

• HOM: Overall good agreement sim. – meas.
  • Documented HOMs:
    • 628 MHz
  • Additional identified HOMs in standing wave:
    • 287 MHz
    • 328 MHz
    • 550 MHz
    • 908 MHz
    • 915 MHz
  
  To be investigated in-depth
  (TW, FPC and HOM couplers in place...)

• No indications of harmful longit. modes at 1.4 GHz