LHC Crab Cavities
Impedance and Multipole Update

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SPS DQW antenna was dual function: HOM damper and fundamental mode antenna.

Functions split because damping geometry coupled to beam (perturbing LLRF signal).

Figure 1: SPS (left) and LHC (right) DQW crab cavities with beampipe ancillaries highlighted.
Crab Cavity Impedance

- DQW model: EDMS No. 2009911 - Alumina ceramics, Nb HF-Damper, Cu Antenna.
- RFD model: EDMS No. 1347072
- RFD was benchmarked with ACE3P results from Z. Li.
Concerning Modes

- Limits: $\perp = 1 \text{ M}\Omega/m/\text{cavity}$, $\parallel = 200 \text{ k}\Omega/\text{cavity}$.

<table>
<thead>
<tr>
<th>$f$ [MHz]</th>
<th>$Q_e$</th>
<th>$R_v$ [kΩ/m]</th>
<th>$R_h$ [kΩ/m]</th>
<th>$R_l$ [kΩ]</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>583.59</td>
<td>4381</td>
<td>-</td>
<td>-</td>
<td>243.00</td>
<td>Far from bunch spacing harmonic.</td>
</tr>
<tr>
<td>960.87</td>
<td>507</td>
<td>-</td>
<td>-</td>
<td>4.70</td>
<td>Close to bunch spacing harmonic.</td>
</tr>
<tr>
<td>1500.20</td>
<td>23200</td>
<td>-</td>
<td>2009</td>
<td>-</td>
<td>$Al_2O_3$: $R_l + 27%$.</td>
</tr>
<tr>
<td>1754.40</td>
<td>8522</td>
<td>-</td>
<td>751</td>
<td>-</td>
<td>$Al_2O_3$: Frequency + 0.75 MHz.</td>
</tr>
<tr>
<td>1921.98</td>
<td>60600</td>
<td>-</td>
<td>2505</td>
<td>-</td>
<td>Not mesh converged.</td>
</tr>
</tbody>
</table>

Table 1: DQW

<table>
<thead>
<tr>
<th>$f$ [MHz]</th>
<th>$Q_e$</th>
<th>$R_v$ [kΩ/m]</th>
<th>$R_h$ [kΩ/m]</th>
<th>$R_l$ [kΩ]</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>752.06</td>
<td>217</td>
<td>-</td>
<td>-</td>
<td>19.4</td>
<td>9.4 MHz from bunch harmonic.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Not simulated with HOM coupler ceramics.</td>
</tr>
</tbody>
</table>

Table 2: RFD

$19^{th}$ and $24^{th}$ bunch spacing harmonics: 761.52 MHz and 961.92 MHz
HOM Power

- HL-LHC beam parameters from [1].
- Mode frequency and Q varied: 1000 stochastic variations.
- Limits from SPS DQW measurements.
- Q: factor 0.5→2.0, f: -0.1→0.9%

<table>
<thead>
<tr>
<th>Cavity</th>
<th>$P_{max}$ (Gaussian) [W]</th>
<th>$P_{max}$ (Binomial) [W]</th>
<th>Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>DQW</td>
<td>1000</td>
<td>1000</td>
<td>961 MHz</td>
</tr>
<tr>
<td>RFD</td>
<td>8500</td>
<td>8200</td>
<td>752 MHz</td>
</tr>
</tbody>
</table>

**Table 3: Maximum HOM power values.**

Average DQW 960 MHz shifts
f: +0.35%, Q: $0.77 \times Q_{sim}$
From measured RFD HOM deviations [Berrutti et. al.]
f: +0.342 MHz, Q: $1.26 \times Q_{sim}$
DQW Feedthroughs - Tuning

(a) Nominal, \( \text{int}_1 = 14 \text{ mm} \)

(b) \( \text{int}_1 = 30 \text{ mm} \)

(c) Frequency

(d) Longitudinal Impedance
Multipole Components

- Last meetings: Questions about $b_4$ magnitude.
- Re-visited: Issues with CST field export and convergence
  Panofsky Wenzel method did not converge. Lorentz Force does.
- Solved. Benchmarked with K. Papke’s code.

<table>
<thead>
<tr>
<th></th>
<th>SPS DQW (Dressed)</th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>b1</td>
<td>b2</td>
<td>b3</td>
</tr>
<tr>
<td>LF</td>
<td>Re</td>
<td>33</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Im</td>
<td>0</td>
<td>-2</td>
</tr>
<tr>
<td>LHC DQW (Dressed)</td>
<td></td>
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<tr>
<td>LF</td>
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</tr>
<tr>
<td></td>
<td>Im</td>
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</tr>
<tr>
<td>LHC RFD (Dressed)</td>
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<tr>
<td>LF</td>
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<td>0</td>
<td>0</td>
</tr>
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</table>

**Table 4:** Evolution of $b_n$ in units of mT/m$^{n-1}$. Values correspond to a transverse deflecting voltage of 10 MV and are evaluated with 64 points around the azimuth at a radius of 30 mm.

- TDR: Limit of $b_4$ was 1000 units.
- TDR: Limits pending for higher components.
Conclusions

- DQW HOMs: two horizontal modes 2.5 times over threshold.

- Worst case HOM Power in DQW (1000 W - very pessimistic) is more likely. But it is manageable.

- Heat load in RFD could be problematic (8 times threshold), f-shift is unlikely - measure during upcoming manufacture.

- Damping and tuning method for DQW 960 MHz mode.

- Multipoles: b4 are now more realistic → in limits. Limits for b5?
Appendix
Figure 4: Measured impedance spectra in SPS.
Figure 5: Multipole coefficients as a function of longitudinal position. Panofsky-Wenzel and Lorentz Force decomposition methods shown in blue and red dashed lines respectively.
- Measurement technique developed on aluminium prototype (PoP design).
- TDR: Limits pending for higher components.

![Image]

- Work from and detailed in the summer student report by P. Gapais.
- 1500 MHz mode $Q$ can be reduced using a more complex HOM damper.
- Probe material still under investigation - if copper can bring down by 25%.

- 1920 MHz mode is under investigation. I see a decrease in $Q$ with mesh convergence, beam-pipe length and without ports.
- There are also big differences between broadband and narrow band solvers.
R. Tomas, Presentation: Parameter update for the nominal HL-LHC: Standard, BCMS, and 8b + 4e