EXPECTED IMPEDANCE & HEAT LOAD OF THE PRESENT DESIGN OF THE HL-LHC BPMs

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From R. Jones, HL-LHC PLC meeting (18/01/2013):

Could think of Duplicating in these regions for more redundancy

- HL-LHC (round - 15cm)
- HL-LHC (flat - 30cm/7.5cm)
- nominal LHC (55cm)

This one has the same effect as hundreds of BPMs with average beta functions.

=> In total: $7 \times 2$ (2 sides of the IP) $\times 2$ (2 IPs) = 28 BPMs
Impedance contributions, with crab cav., longitudinal:

- Real part
- Imaginary part

![Graphs showing impedance contributions](image-url)
- Impedance contributions, with crab cav., horizontal dipolar:

Real part

Imaginary part

Visible effect
• Impedance contributions, with crab cav., vertical dipolar:

Real part

Imaginary part

Visible effect
Table 5.4: LHC broad-band impedance budget. The first three columns report element name, latest relevant reference, and inner vertical aperture $b$ in mm. The last two columns give the effective longitudinal and transverse impedance in the vertical plane, the latter being multiplied by $\beta/\langle\beta\rangle$, where $\langle\beta\rangle = 70$ m.

<table>
<thead>
<tr>
<th>element</th>
<th>Ref.</th>
<th>$b$ (mm)</th>
<th>Im($Z/n$)</th>
<th>Im($Z_\perp$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pumping slots</td>
<td>[23]</td>
<td>18</td>
<td>0.017</td>
<td>0.5</td>
</tr>
<tr>
<td>BPM’s</td>
<td>[24]</td>
<td>25</td>
<td>0.0021</td>
<td>0.3</td>
</tr>
<tr>
<td>Unshielded bellows</td>
<td></td>
<td>25</td>
<td>0.0046</td>
<td>0.06</td>
</tr>
<tr>
<td>Shielded bellows</td>
<td></td>
<td>20</td>
<td>0.010</td>
<td>0.265</td>
</tr>
<tr>
<td>Vacuum valves</td>
<td></td>
<td>40</td>
<td>0.005</td>
<td>0.035</td>
</tr>
<tr>
<td>Experimental chambers</td>
<td></td>
<td>-</td>
<td>0.010</td>
<td>-</td>
</tr>
<tr>
<td>RF Cavities (400 MHz)</td>
<td></td>
<td>150</td>
<td>0.010</td>
<td>(0.011)</td>
</tr>
<tr>
<td>RF Cavities (200 MHz)</td>
<td></td>
<td>50</td>
<td>0.015</td>
<td>(0.155)</td>
</tr>
<tr>
<td>Y-chambers (8)</td>
<td>[25]</td>
<td>-</td>
<td>0.001</td>
<td>-</td>
</tr>
<tr>
<td>BI (non-BPM instruments)</td>
<td></td>
<td>40</td>
<td>0.001</td>
<td>0.012</td>
</tr>
<tr>
<td>space charge @injection</td>
<td>[2]</td>
<td>18</td>
<td>-0.006</td>
<td>0.02</td>
</tr>
<tr>
<td>Collimators @injection optics</td>
<td></td>
<td>4.4 ÷ 8</td>
<td>0.0005</td>
<td>0.15</td>
</tr>
<tr>
<td>Collimators @squeezed optics</td>
<td></td>
<td>1.3 ÷ 3.8</td>
<td>0.0005</td>
<td>1.5</td>
</tr>
<tr>
<td>TOTAL broad-band @injection optics</td>
<td></td>
<td></td>
<td>0.070</td>
<td>1.34</td>
</tr>
<tr>
<td>TOTAL broad-band @squeezed optics</td>
<td></td>
<td></td>
<td>0.076</td>
<td>2.67</td>
</tr>
</tbody>
</table>

For the BPM’s a 0.5 mm slit between electrode and body is assumed. The ‘monitor’ inductance per electrode is 4 $\mu$H, the ‘slit’ inductance 9 $\mu$H, and the ‘cavity’ inductance 4 $\mu$H, giving a total of about 60 $\mu$H or $Z/n = j 4.2 \mu\Omega/$monitor. 500 monitors including some overhead for special and warm BPM’s are considered.
BPMs: geometric impedance

- All stripline BPMs \( l=0.12 \text{m} \) for the strip length, except one combined BPM (buttons / stripline) in front of Q1.

- Diameter \( D \) between electrodes:
  - \( D=60 \text{mm} \) for the current ones (except the one at 70m from the IP \( \rightarrow 80 \text{mm} \)),
  - \( D=140 \text{mm} \) for the HL-LHC ones (scaling by the same factor the transverse dimension of the strip-lines).

- Two approaches:
  - analytic formula for stripline BPM by K. Y. Ng [Handbook of Acc. Phys. & Eng., Sec. 3.2] + values obtained for button BPM by B. Spataro [LHC Project Note 284],
  - CST simulations made by B. Salvant

→ agreement within a factor \( \sim 2 \).
Evaluated as a **broad-band model** → pessimistic: stripline BPM impedance actually decreases above a few hundreds of MHz:

\[ Z_y^{\text{dip}} [\Omega] \]
(with beam offset of 10mm)

Note: with tungsten shielding inserts, geometric impedance seems to decrease (to be confirmed).

→ Final broad-band impedances (including buttons before Q1): better with HL-LHC (due to higher radius)

<table>
<thead>
<tr>
<th>BPM type</th>
<th>Current combined (before Q1)</th>
<th>Current (after Q1)</th>
<th>Current (after Q3)</th>
<th>New combined (before Q1)</th>
<th>New (after Q1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D [mm]</td>
<td>60</td>
<td>60</td>
<td>80</td>
<td>140</td>
<td>140</td>
</tr>
<tr>
<td>Im(Z') [Ω/m]</td>
<td>880</td>
<td>800</td>
<td>300</td>
<td>130</td>
<td>100</td>
</tr>
</tbody>
</table>

From B. Salvant
Transverse impedance
(in $\Omega / 10$ mm displacement
=> i.e. in $100 \, \Omega / m$)
- Longitudinal impedance (in Ω)
- Beam-induced RF heating (from the geometric part)

<table>
<thead>
<tr>
<th>Power loss in W</th>
<th>Nominal 25 ns (2808*1.15, 1 ns, 7 TeV)</th>
<th>Before LS1 50 ns (1374*1.6e11 @1.25 ns, 4 TeV)</th>
<th>HL-LHC 25 ns (2808*2.2)</th>
<th>HL-LHC 50 ns (1404*3.5e11)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stripline (63 mm)</td>
<td>15</td>
<td>10</td>
<td>55</td>
<td>70</td>
</tr>
</tbody>
</table>

=> Most of this heat load should go into the coax ports. Is it a problem?
Beam-induced RF heating (from the “resistive-wall” part)

\[
P_{P, RW, 1beam}^{loss/m} = \frac{1}{2\pi R} \Gamma\left(\frac{3}{4}\right) \frac{M}{b} \left(\frac{N_b e}{2\pi}\right)^2 \sqrt{\frac{c \rho Z_0}{2}} \sigma_t^{-3/2} \approx 0.12 \text{ W/m}
\]

LHC circumference = \(L\)
= \(2\pi R = 26658.883 \text{ m}\)

\[
\Gamma\left(\frac{3}{4}\right) = 1.23
\]

\(M = 1404\)

\(N_b = 3.5 \times 10^{11} \text{ p/b}\)

\(b = 70 \text{ mm}\)

\(\sigma_t = 0.25 \text{ ns}\)

\(\rho_{Cu}^{20K, 7TeV} = 7.7 \times 10^{-10} \text{ \Omega m}\)

There is Cu coating for the current BPMs => Important to have Cu coating for HL-LHC. What will be the temperature?