The Wall Current Transformer
A new sensor for bunch-by-bunch intensity measurements in the LHC

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Outline

• Bunch current measurements in the LHC
• WCT principle of operation
• LHC implementation
• Laboratory measurements
• Beam measurements
• Conclusions
LHC bunch current measurements

bunch length: 1 – 1.5 ns (4σ)
bunch population: 5e9 – 1.5e11 (3e11) ppb
bunch charge: 0.8 - 24 (48) nC

Bunch charge:
\[ Q_B = \int i_B(t) \, dt \]

Number of particles:
\[ N = \frac{Q_B}{e} \]
LHC bunch current measurements

- **LHC Run 1 (2008-2012):** 4 Fast Beam Current Transformers (FBCT) bunch position sensitivity

- **LS1 (2013-2014):** Design of new monitors for absolute bunch-by-bunch intensity measurements. Two developments in parallel:
  - Integrating Current Transformer (ICT) in collaboration with the industry
  - Wall Current Transformer (WCT) by the CERN BI Group

- **2015:** FBCT + ICT, FBCT + WCT
- **2016:** 3 WCTs + ICT
- **2017+:** 4 WCTs
FBCT recap
FBCT recap
FBCT recap
FBCT recap
FBCT recap

![Diagram of a BCT (Beam Current Transformer) with labeled parts: image current bypass, dielectric insert, BCT secondary winding, sensing resistor, magnetic core, and $i_i$, $i_{BCT}$, $B_B$, and $V_{BCT}$.]
WCT principle of operation
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WCT principle of operation

- Housing
- RF transformer
- Conductive screw
- RF bypass
- Dielectric insert
- Ferrite core
WCT principle of operation

For the LHC implementation:

- $L_{LF} \sim 10 \, \mu H$
- $L_{RF} \sim 0.1 \, nH$
- $L_{WCT} \sim 1 \, mH$
- $L_{W} \sim 1 \, nH$
- $C_{RF} \sim 50 \, nF$
- $R_{WCT} \sim 5 \, \Omega$
- $R_{W} \sim 50 \, m\Omega$
- $R_{RF} \sim 1 \, \Omega$
- $N \sim 10$

Low cut-off: $\sim 500 \, Hz$

Sensitivity: $\sim 50 \, mV/A$

High cut-off: $\sim 500 \, MHz$

WCT transimpedance

Log frequency
LHC WCT

- vacuum chamber with dielectric insert
- ferrite cores
- rear copper interface
- rear end-cap
- front end-cap
- front copper interface
- housing
- 2 PCBs with 8 RF transformers

All parts cut in halves
Installation, removal and modification with no impact on the accelerator vacuum

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LHC WCT
LHC WCT
LHC WCT
Off the shelf cores
Vacuumschmelze cores with slight manual modifications
Signal winding:
- few turns
- low impedance
- averaging two nearest transformers on the PCB

Calibration winding:
- single turn for calibration with current
- low resistance at low frequencies (minimising power dissipation)
- high impedance at high frequencies (decoupling from beam)

Signal addition:
the four outputs are passively summed (averaged) outside, but close to, the monitor
LHC WCT

Design launched: 01/10/2013          First installation in the LHC: 02/03/2015
Bandwidth measured in the laboratory

Sensitivity:
- LHC WCT: 62.5 mV/A
- LHC ICT: ~ 20 dB more signal

Low cut-off frequency: < 1 kHz for all sensors
Time response to a nominal LHC bunch

![Graph showing time response to a nominal LHC bunch with different filters: FBCT Ring 2 (80 MHz LPF), ICT, WCT (Full BW), and WCT (120 MHz LPF).]
Beam position sensitivity measured with beam

Beam position sensitivity in %·mm⁻¹

<table>
<thead>
<tr>
<th>Axis</th>
<th>FBCT R1</th>
<th>FBCT R2</th>
<th>ICT</th>
<th>WCT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>0.65</td>
<td>0.51</td>
<td>0.02</td>
<td>&lt; 0.005</td>
</tr>
<tr>
<td>Vertical</td>
<td>0.14</td>
<td>0.82</td>
<td>0.01</td>
<td>&lt; 0.005</td>
</tr>
</tbody>
</table>
Impedance measured in the laboratory
Full BW time response to a nominal LHC bunch

- **WCM (Combined outputs):** The operational LHC WCM
- **WCM (Single output):** The LHC WCM used for specialised longitudinal diagnostics

![Graph showing time response](image)
Conclusions

• New bunch-by-bunch intensity monitor for the LHC
• Designed to not require vacuum intervention
• Designed for absolute calibration with current
• Optimised for nanosecond bunches spaced by 25 ns
• 400 MHz bandwidth limited by external filters
• Smaller output signals than the ICT / FBCT
• No measurable beam position sensitivity
• Low longitudinal impedance
• Encouraging first longitudinal measurements
Thank you for your attention!

Questions?

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