Beamline measurement of a non-invasive BCM: its advantages and limits

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Specific Diagnostic needs

• Beam parameter of interest: Beam intensity (Most Important)
• Two different modes of operation: Diagnostics for commissioning/Diagnostics for Standard operation
• Diagnostics for Standard Operation [1]:
  – To control and improve accelerator operation (precise)
  – Diagnosis of unwanted errors and to trigger interlocks
  – High demands for accuracy
  – Minimum beam disturbing schemes
• Repetitive and stable beam: CW system (Closed loop system)
• Signals are treated typically in Frequency domain
• Beam current is a non- or slowly varying parameter
• High precision by averaging
Standard Beam Current Measurements:
- Ionization chambers are the most commonly used detector type
- Caveat: intercept beam → decrease the beam’s quality by scattering

An alternative:
- A sensitive RF-based current monitor
- Fully non-interceptive beam current measurement
- Simple and robust system (KISS), good for safety purpose/applications

Challenge:
- For very low charge beams (bunch charge ~ 1.36e-17 C)
- Trade-off between bandwidth and sensitivity

Potential benefit:
- Design a new beam position monitor system using the same technics

Note: Slide provided by Pierre André Duperrex
<table>
<thead>
<tr>
<th>BPM types</th>
<th>Bunch/Beam size</th>
<th>Signal strength &amp; quality</th>
<th>Mechanical realization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear-cut</td>
<td>Longer</td>
<td>smaller &amp; deformations</td>
<td>complex</td>
</tr>
<tr>
<td>Button</td>
<td>comparable</td>
<td>smaller &amp; deformations</td>
<td>simple</td>
</tr>
<tr>
<td>Stripline</td>
<td>short</td>
<td>larger &amp; minor deformations</td>
<td>complex</td>
</tr>
<tr>
<td>Pill-box</td>
<td>very short</td>
<td>larger ; minuscule deformations</td>
<td>simple</td>
</tr>
<tr>
<td>Reentrant</td>
<td>very short</td>
<td>larger; minuscule deformations</td>
<td>simple</td>
</tr>
<tr>
<td>Resistive WCM</td>
<td>short</td>
<td>large with thermal noise</td>
<td>complex</td>
</tr>
<tr>
<td>Inductive WCM</td>
<td>short</td>
<td>better than linear-cut</td>
<td>complex</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BPM types</th>
<th>Advantages</th>
<th>Bandwidth</th>
<th>PROSCAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear-cut</td>
<td>highly linear and good position sensitivity</td>
<td>Broadband</td>
<td>No</td>
</tr>
<tr>
<td>Button</td>
<td>non-linear and good position sensitivity</td>
<td>Broadband</td>
<td>No</td>
</tr>
<tr>
<td>Stripline</td>
<td>directivity and better position sensitivity</td>
<td>Broadband</td>
<td>Yes (3)</td>
</tr>
<tr>
<td>Pill-box</td>
<td>extremely linear and highly position sensitive</td>
<td>Narrowband</td>
<td>Yes (2)</td>
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<tr>
<td>Reentrant</td>
<td>extremely linear and highly position sensitive</td>
<td>Narrowband</td>
<td>Yes (1)</td>
</tr>
<tr>
<td>Resistive WCM</td>
<td>linear and average position sensitivity</td>
<td>Broadband</td>
<td>No</td>
</tr>
<tr>
<td>Inductive WCM</td>
<td>linear and position sensitivity better than linear-cut</td>
<td>Broadband</td>
<td>No</td>
</tr>
</tbody>
</table>
Dielectric-Filled Reentrant Cavity Resonator as a Low-Intensity Proton Beam Diagnostic, *Instruments* 2018, 2, 24

\[ V_{out} = Q_{bunch} \omega_o \sqrt{\frac{R}{Q_{unloaded}}} Z_o \frac{Z_o}{Q_{ext}} = 59.85 nV \]

For 1nA at 145.7MHz

Matched to 2nd harmonic of the pulse repetition rate=72.85MHz
• BCM located at 22m from the cyclotron exit
• Placed behind an Ionization Chamber

Ionization Chamber used as reference for measurements
2*50Ohm LNA with a BP filter inbetween (center freq: 145.7MHz ; span=10MHz)

Subsystems of VME MESTRA (PSI developed)
- Preamplifier
- Digitizer (ADC); ADC3110 : max. input power of 10dBm (2V peak-peak) 16bit resolution (0.0001V)
- Digital Down Converter (DDC)
- Current Calculations

VME MESTRA converts RF signals to digital signals proportional to absolute beam current

Friss Formula
The typical power budget for the measurement system is:

- Resonator at 1nA: -134dBm
- Local amplifiers: +70dB -64dBm
- Cellflex cable 150m: -3dB -67dBm
- 1\textsuperscript{st} Amplifier: +25dB -42dBm
- 2\textsuperscript{nd} Amplifier: +25dB -17dBm

(0.089V peak to peak)

ResDDC Counts = $\sqrt{I^2 + Q^2}$
Uncertainty in noise arises from uncertainty of MMAC5 (15-20% measurement uncertainty)

\[ I_{ResDDC} = kI_{MMAC5} \]

\[ I_{ResDDC} = \sqrt{I_{ResNoise}^2 + k^2 I_{MMAC5}^2} \]
\[ X_n = \frac{A\Delta}{T} \text{sinc}(n\Delta / T) \]

For lower beam energies, energy spread is higher beyond degrader. Hence, pulse length increases thus decreasing the 2nd harmonic component of the beam current.
Influence of MMAC5

Resonator response for 231 MeV with and without MMAC5

\[ y = 2.1923e+10 \times x + 1.0826e+09 \]
\[ y = 3.3525e+10 \times x + 5.1716e+08 \]
For higher beam energy (200-230MeV), the influence of IC is minor.

As for lower beam energies, IC influence is detrimental affecting signal sensitivity.

IC has a huge measurement uncertainty (15-20%).

Beam measurements without IC in beamline recommended.
Summary

- TM010 resonance
- Energy spread affects signal level
- 60pA at 230MeV; 500pA at 140MeV
- Few 100ms integration time
- No activation unlike in IC
- NO IC in Beamline

Sudharsan Srinivasan, PSI
1. G.Kube, CAS on Beam Diagnostics, ```Specific diagnostic needs for different machines```, 2008.
2. J.C. Denard, CAS on Beam Diagnostics, ```Beam Current Monitors```, 2008
Thank You

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Questions???
Potential Benefits

TM110

Monopole (TM010)  Vertical polarization  Vertical polarization