Transmission Measurement of All the PSB Machine

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PSB Damping Resistors become too hot (~400°) after LIU Upgrade
Solution I: Double the Damping Resistor Value
Problem I: No knowledge about the reason for those resistors!
In 1970 those resistors were on the technical drawings then disappeared but eventually plugged into the PSB dipoles and quadrupoles in 1971.
Problem II:
- Michel Chanel vividly remembered a report about those resistors!
- Small Fraction in the PS Archive
- All reports found either in CERN or PS Archive, the latter scanned by Frank and passed on to the CERN Archive
  ➔ Total of 1465 reports 655 still to be digitized.
Solution II: Measure single dipole, quadrupoles, chain of magnets and all machine.
Problem III: No expert to take over!
Solution III: For the time being increase resistors but do simulations to confirm
Measurements

- PSB Dipole
  - 4 in Series
  - With and without Vacuum Chamber
  - \( \text{RD} = \{ \infty, 4\times(10/20/40) \} [\Omega] \)

- PSB Quad
  - QF
  - QDD
  - Vacuum Chamber
  - \( \text{RD} = 20, \infty [\Omega] \)

Since December

- Dipole Chain
- Quadrupole Chain
- All Machine
Symmetric 4-Pole Model

Damping Resistor

Eddy Currents – Vacuum chamber equivalent

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Eddy Currents – Vacuum Chamber

Example: SPS vacuum chamber very relevant

Eddy Currents become relevant
Transmission Line Model

\[ U e^{i\omega t} = a_1 e^{-\alpha x} e^{i(\omega t - \beta x)} + a_2 e^{\alpha x} e^{i(\omega t + \beta x)} \]

\[ I e^{i\omega t} = \frac{a_1}{Z_0} e^{-\alpha x} e^{i(\omega t - \beta x)} - \frac{a_2}{Z_0} e^{\alpha x} e^{i(\omega t + \beta x)} \]
Damping

Forward Wave
Reflected Wave
Resulting Wave
Damping exp(-ax)
Damping -exp(-ax)
Transport Matrix

\[ \gamma = \alpha + i \beta \]

\[
\begin{pmatrix}
U_1 \\
I_1 
\end{pmatrix} = \begin{pmatrix}
cosh(\gamma l) & Z_0 \sinh(\gamma l) \\
\frac{1}{Z_0} \sinh(\gamma l) & \cosh(\gamma l)
\end{pmatrix} \times \begin{pmatrix}
U_2 \\
I_2 
\end{pmatrix}
\]
PSB – All Machine Damping $1/\alpha$

RD nominal

RD doubled

Measurement

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PSB – Old PS System Harmonics

Magnet voltage ripples at Minimal Voltage condition

Magnet voltage harmonic spectrum at Minimal Voltage condition

Table 1. MPS magnet voltage (pk value) dominant harmonics at minimal voltage condition.

<table>
<thead>
<tr>
<th>Harmonic Frequency [Hz]</th>
<th>Harmonic Amplitude [V]</th>
</tr>
</thead>
<tbody>
<tr>
<td>600</td>
<td>8.04</td>
</tr>
<tr>
<td>1200</td>
<td>2.01</td>
</tr>
<tr>
<td>300</td>
<td>1.96</td>
</tr>
<tr>
<td>1800</td>
<td>1.8</td>
</tr>
</tbody>
</table>

\[
\sum a_n^2 = 9.169
\]

Figure 4: MPS magnet voltage at injection point

Magnet voltage ripples at Injection condition

Magnet voltage harmonic spectrum at Injection condition

Table 2. MPS magnet voltage dominant harmonics at injection.

<table>
<thead>
<tr>
<th>Harmonic Frequency [Hz]</th>
<th>Harmonic Amplitude [V]</th>
</tr>
</thead>
<tbody>
<tr>
<td>600</td>
<td>6.86</td>
</tr>
<tr>
<td>1200</td>
<td>1.67</td>
</tr>
<tr>
<td>300</td>
<td>5.75</td>
</tr>
<tr>
<td>1800</td>
<td>0.97</td>
</tr>
</tbody>
</table>

\[
\sum a_n^2 = 9.15
\]
Potential Total Tune Ripple

Scaling: 4.3/530*28
Conclusions

• Measurements of both dipoles and quadrupoles done

• Measurements done for single chains and the complete machine

• Signal Damping in reasonable good agreement

• High quality voltage of old PS system indicate that tune ripple might cause effect on beam stability at injection energy → Simulations foreseen in spring 2019

• New PS system at injection 1 or 2 voltage ripple (333 & 2kHz) lines smaller by factor of ~3 → Effect on beam stability unlikely!

• Continue with doubling of damping resistors by a factor of 2. Review!
Dipole, VC RD = ∞
Dipole, VC RD = 4*20 Ω

Impedance [dB] vs Frequency [Hz]

Closed Sim VC, RD 4*20
Open Sim VC, RD 4*20
Closed Meas VC, RD 4*20
Open Meas VC, RD 4*20

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Todo List

• Finish PSB Dipole

• Analyze PSB Quads

• Full Magnet Chains

• Measurement of Full Chain in 19th of June

• Proper Documentation missing from the early Days!

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