Noise studies:
On the 50Hz harmonics perturbation

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Thanks to WP2 & WP6
Overview

Motivation: Investigate the source of the 50 Hz harmonics and study possible implications on LHC & HL-LHC.

- Summary of observations during 2018:
  - Is it an instrumental effect?
  - Possible sources.
  - Tests with active filters of the main bends & correlation with voltage spectrum of sector12.

- Simulations for LHC

- Simulations for HL-LHC

- Conclusions & next steps
Introduction

- Harmonics of 50Hz have been observed in the beam spectrum.

No attenuation during RAMP  Not a tune modulation
Introduction

- Harmonics of 50Hz have been observed in the beam spectrum.
- Present in several instruments and in all beam modes.
Introduction

- Harmonics of 50Hz have been observed in the beam spectrum.

- Present in several instruments and in all beam modes.

- Visible in B1 & B2, mainly in the horizontal plane.

 Aliasing
Introduction

- Harmonics of 50Hz have been observed in the beam spectrum.
- Present in several instruments and in all beam modes.
- Visible in B1 & B2, mainly in the horizontal plane.
- The source of this perturbation is not yet understood.
- According to our observations concerning the source (see next slides), these harmonics may also be present in HL-LHC.
- Learning from the LHC experience, we would like to study possible implications for HL-LHC and define tolerances.
Not instrumental (I)

Phase scan of IP1 & IP5 B1
(MD#3583-Beam-Beam Long Range 2018)

Changing the phase advance between IP1 & IP5 in B1 affects the amplitude evolution of the harmonics in B1.
Phase advance of 50Hz harmonics
Compatible with the betatronic phase advance
90-110 degrees between PUs Q7 to Q9

- 2.7kHz: Mean = 94.65°
- 2.8kHz: Mean = 111.24°
- 3kHz: Mean = 103.44°
- 2.4kHz: Mean = 94.93°
Possible sources

PS magnetic spectrum

SPS magnetic spectrum

LHC
Possible sources

Patterns of Silicon Controlled Rectifier
Possible sources

Patterns of Silicon Controlled Rectifier

Voltage spectrum

Fill 7271, FLATTOP

PS magnetic spectrum

SPS magnetic spectrum

Fill 6711, B1H

Before tune jump
After tune jump

S. Kostoglou | 8th HL-LHC Collaboration Meeting
Possible sources

Patterns of Silicon Controlled Rectifier

### RAMPING CONVERTERS

<table>
<thead>
<tr>
<th># ARC Dipoles</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPTE.UA23.RB.A12, RPTE.UA27.RB.A23.R</td>
</tr>
<tr>
<td>RPTE.UA43.RB.A34, RPTE.UA47.RB.A45.R</td>
</tr>
<tr>
<td>RPTE.UA63.RB.A56, RPTE.UA67.RB.A67.RPT</td>
</tr>
<tr>
<td>RPTE.UA83.RB.A78, RPTE.UA87.RB.A81</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th># Dog-leg Dipole</th>
</tr>
</thead>
<tbody>
<tr>
<td>(spares of the switching mode converters)</td>
</tr>
<tr>
<td>RPTG.SR1.RD1.LR1, RPTG.SR3.RD34.LR3,</td>
</tr>
<tr>
<td>RPTG.SR5.RD1.LR5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th># Septa</th>
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</thead>
<tbody>
<tr>
<td>RPTM.SR6.RMSD.LR6B1, RPTM.SR6.RMSD.LR6B2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th># Quadrupoles</th>
</tr>
</thead>
</table>

### NOT RAMPING CONVERTERS

<table>
<thead>
<tr>
<th># Alice/LHC dipoles</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPTH.SX2.RXSOL.ALICE.RPT3.R12, RBAW.V.R2, RPTI.SR2.RBAV.R8, RPTJ.USC55.R</td>
</tr>
<tr>
<td>XPOL.CMS</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th># ALICE compensator</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPTL.SR2.RBWMDV.L2, RPTL.SR2.RBXWT.V.L2, RPTL.SR2.RBXWT.V.R2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th># LHCB Compensator</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPTN.SR8.RBXWSH.L8, RPTN.SR8.RBXWSH.L8, RPTN.SR8.RBXWSH.R8</td>
</tr>
</tbody>
</table>

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![PS magnetic spectrum](image1)

![SPS magnetic spectrum](image2)

![LHC magnetic spectrum](image3)
Jittering of the 50Hz

- These frequencies are not constant in time.
- Similar oscillation observed in all DCCTs, in the beam and in SPS B-Train.
Jittering of the 50Hz

- These frequencies are not constant in time.
- Similar oscillation observed in all DCCTs, in the beam and in SPS B-Train.

DCCTs & BBQ

![Graph showing jittering of 50Hz frequencies in DCCTs and BBQ](image)
Jittering of the 50Hz

- These frequencies are not constant in time.
- Similar oscillation observed in all DCCTs, in the beam and in SPS B-Train.

DCCTs & BBQ

SPS B-Train & LHC BBQ
Jittering of the 50Hz

- These frequencies are not constant in time.
- Similar oscillation observed in all DCCTs, in the beam and in SPS B-Train.

**DCCTs & BBQ**

**Voltage spectrum**

**SPS B-Train & LHC BBQ**
Active filters (I)

- Enabling/disabling the active filters: The status of the active filters of the main bends has an impact on their amplitude evolution.
Active filters (II)

- Enabling/disabling the active filters: Correlation between amplitude evolution of harmonics in the beam and in the voltage spectrum of RPTE.UA23.RB.A12 (instrumentation installed during TS2 from EPC)
Active filters (III)

- Enabling/disabling the active filters:

Voltage spectrum sector 12:
- Harmonics up to 1kHz decrease when active filter is enabled.
- Harmonics beyond 1kHz increase when active filter is enabled.
- Compatible with the different behaviour observed between 600 & 1.2kHz of the beam.
Simulations
For a simplified mode, we convert the offset observed in BPMCS.7L4.B1 to an equivalent dipolar kick at the same location.

\[ |X(s, N)| = \frac{\sqrt{\beta_{\text{Noise}}\beta(s)} |A_{\text{Noise}}|}{|1 - e^{2i\pi(Q_{\text{Noise}} - Q)}|} \]

Phase and distribution of the dipolar kicks along the main bends are not taken into account in this simplistic model.

7650 Hz: 400nm $\sim$ 1.73e-3 $\sigma$
LHC simulations

Without ripple

5D, E = 6.5 TeV, \( l_{\text{ext}} = 550 \, \text{A} \), Beam - beam & ho, \( t_0 = 2.0 \, \text{mm} \), \( N_{\text{ho}} = 1.25 \times 10^4 \)

\( (Q_x, Q_y) = (62.31, 60.32), \ V_{\text{ho}} \, \text{OFF}, \ \delta p = 23.12 e - 5, \ 99 \, \text{angles}, \ 0.1 - 6.1 \, \sigma \)
LHC simulations

Without ripple

With 50Hz ripples
LHC simulations

Expected impact on lifetime

Without ripple

With 50Hz ripples

Reduction of lifetime from ~295h to ~180h
LHC simulations

Kick in Q7 PU for different frequencies
Convert to offset
Compute minimum DA for each scenario
LHC simulations

Kick in Q7 PU for different frequencies

Convert to offset

Compute minimum DA for each scenario

Maximum offset observed

$6.5 \text{ TeV}, l_{\text{MO}}=550\text{A}, \epsilon_n = 2\mu\text{m}, (62.310, 60.315), Q_p = 15, l=1.25e11, x_{\text{ring}} = 160\mu\text{rad}, \text{Dipolar ripple at BPMCS.7L4.B1}$

$fx = 3486.105 \text{ Hz}$

Aliased 3545.5 Hz

Aliased 3595.5 Hz
HL-LHC simulations

With BB

7 TeV, $l_{MO} = -300 A, \epsilon_n = 2.5 \mu m, (62.315, 60.320), Q_p = 15$,

$l = 1.2 e 11, \beta^* = 15 cm$, Dipolar ripple at BPMCS.7L4.B1

$f_x = 3542.333 \text{ Hz}$

Aliased 3545.5 Hz

Aliased 3595.5 Hz
By applying an equivalent dipolar kick in the HL-LHC case (without BB at the moment) an emittance growth of 0.2μm/h is observed in the horizontal plane.

However, according to the distribution and phasing of the kicks along the main dipoles, the spectrum can significantly change.
The 50Hz harmonics are **not an instrumental effect.**

The spectrum indicates SCR as possible candidates and a **partial correlation between the spectrum of the beam and the spectrum of the power converter of sector12** has been established.

If the source is indeed the power converters of the main bends (at least for some of the harmonics), 50Hz harmonics **will also be visible in the HL-LHC.**

Simulations indicate that there is an **impact on the lifetime** of the beam.

By applying a similar perturbation in the HL-LHC case, simulations indicate that **they can cause emittance growth**, with **7.7 kHz** being the most dangerous frequency -for a WP of (62.315, 60.320).

**Next steps:**

- Analysis of the voltage/current measurements of sector12. Further studies for energy dependence.
- A noise model for the 50Hz from power converters of all sectors, including phase.
- Is there indeed an impact on lifetime?(MD#4)
- Can we inject controlled noise directly on the power converters of the main bends?(MD#4)
- How can these harmonics attenuate?
Backup
7.5kHz

5/10/2017 02:18 CET, before tune jump

5/10/2017 02:23 CET, after tune jump
LHC simulations

- For a simplified mode, we convert the offset observed in BPMCS.7L4.B1 to an equivalent dipolar kick at the same location.

\[ |X(s, N)| = \frac{\sqrt{\beta_{\text{noise}} \beta(s)} |A_{\text{noise}}|}{|1 - e^{2i\pi(Q_{\text{noise}} - Q)}|} \]

- Phase and distribution of the dipolar kicks along the main bends are not taken into account in this simplistic model.

**Note (I):**

The current needed from 1 dipole (eg. MB.A10R3.B1) to observe an offset of 400nm at 7650Hz is:

- \(\beta=105.98\text{m at Q7 location}\)
- \(\beta_{\text{noise}}=100.84\text{m}\)
- \(Q_{\text{noise}} = 7650/11245.5=0.6803\rightarrow0.3197\)
- \(Q_x = 0.31\)
- \(A_{\text{noise}} = 2.36e^{-10}\text{rad}\)
- \(\theta = 2\pi/1232\sim0.005\text{ rad per dipole, } I=11\text{kA}\)
- \(I_r = 11[\text{kA}]*2.3e^{-10}[\text{rad}]/0.005[\text{rad}] = 0.519*1e^{-3}\text{A}\)
For a simplified mode, we convert the offset observed in BPMCS.7L4.B1 to an equivalent dipolar kick at the same location.

\[ |X(s, N)| = \frac{\sqrt{\beta_{\text{Noise}}(s)} |A_{\text{Noise}}|}{|1 - e^{2\pi i (Q_{\text{Noise}} - Q)}|} \]

Phase and distribution of the dipolar kicks along the main bends are not taken into account in this simplistic model.

**Note (II):** There is a change in the spectrum during the tune jump at FLATTOP.