PSB to PS recombination kicker waveform measurements

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Acknowledgements:
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This presentation extends the one given at the **MSWG on 10\(^{th}\) June 2016**. The work is still in progress…

- **A new and automatic method** for beam-based kickers waveforms measurements.
- **Rise time** evaluation
- **BTM line sem-grids** for bunch length limits evaluation
Previous methods for beam-based kickers waveform measurements.

LHC BTV based

Bunch length much smaller than rise time \(\rightarrow\) beam can be used as a short sampler

Bunch lengths in the PSB are comparable to the rise time… How can we measure it?
A **new and automatic method** for beam-based kicker's waveforms measurements

**Requirements of the method:**

- **Best time resolution:** in the order of the max sampling frequency of the OASIS scopes -> **1-2 ns**
- **High granularity** for **reliable statistics**
- **Low losses**
- **Suitable for automated measurements**
- **To complement and validate lab measurements with search coil**
A **new and automatic method** for beam-based kicker's waveforms measurements

**Kickers displace the beam** horizontally or vertically imposing a deflection angle $\theta_{x,y} \rightarrow$ **BPMs** are the main device to measure displacement, statically and **dynamically** (BTVs are available but with bad resolution performances).

![Diagram](image)

The BPMs need a **minimum current** (line density) to work properly – intensity used from $30e10$ to $200e10$ ppb.

Kicker T.O.F. is around 5.6 ns (kickers length ~1.5 m, $\beta_{rel}=0.916$) and limits the resolution.

The kickers in the line can be **pulsed** with **fine time delays** in minimum steps of 1 ns.

The stability of the trigger (<10 ns min-max jitter) can be a **limit** to the dynamics resolutions

**Loss limits** can be guaranteed though the BLMs in the line and the surveillance (counter interlock).

**Note:**
- $\theta_{y} = \frac{e}{p} \int_{0}^{L} B_{x} dz$
A new and automatic method for beam-based kicker's waveforms measurements (BT2.KFA20 example)

The kicker magnetic field rise in time between two (consecutive) bunches (ex. after R4 and before R2)

The kicker is started with different delays touching eventually the two adjacent bunches...
A new and automatic method for beam-based kicker's waveforms measurements

- The kicker magnetic field rises in time between two (consecutive) bunches (ex. after R4 and before R2)
- R4 is un-kicked and passes first
- If R4 were fully kicked, it would get vertically lost at one side of the vacuum chamber
A new and automatic method for beam-based kicker's waveforms measurements

The kicker magnetic field rise in time between two (usually consecutive) bunches (ex. after R4 and before R2)

R2 is fully kicked and passes after R4

If R2 were un-kicked, it would get vertically lost on the vacuum chamber, at the opposite side w.r.t. to R4.
A new and automatic method for beam-based kicker's waveforms measurements

- BPM signals for different time delays of the KFA20
- The grey band is the fixed - gating - time window kept for the signal reconstruction
A new and automatic method for beam-based kickers waveforms measurements

Un-calibrated measurement

Grey band samples shifted by BT2X.SKFA20D delay

R4 no kick

R2 full kick

Calibration BPM40 vs. KFA voltage

Un-calibrated measurement

R4 no kick

R2 full kick

Correlation coefficient

NR. of samples

Time [ns]

BT2.KFA20 [kV]
A new and automatic method for beam-based kicker's waveforms measurements

Calibrated measurement

Grey band samples shifted by BT2X.SKFA20D delay

R4 no kick

R2 full kick

Time [ns]
A new and automatic method for beam-based kicker's waveforms measurements

- BT4.KFA10 strength (at 43 kV) vs. BT3.BPM20 ~25e10 ppb
A new and automatic method for beam-based kickers waveforms measurements

- BT1.KFA10 strength (at 42 kV) vs. BT2.BPM20 ~25e10 ppb
A new and automatic method for beam-based kicker's waveforms measurements

- BT1.KFA10 and BT4.KFA10, even if identical, gave different calibration (~factor 2 in the DC-gain) due to different hw amplification settings → BI issue, then fixed.
- This is an important check as BPMs are used to validate optics models.
BT1.KFA10 – BT4.KFA10 ~25e10 ppb

PSB to PS recombination kicker waveform measurements
BT2.KFA20
- BT4.KFA10 strength (at 43 kV) vs. BT3.BPM20 ~25e10 ppb

~25e10 ppb

~50e10 ppb

Double intensity (less ripple but still visible and coherent)
BT2.KFA20

- The large flat-top ripple almost disappears at higher intensity (~200e10 ppb).
- The measurement looks cleaner and smoother.
- Measurement performed with R3 and R1 (respectively first and last in batch) to have a large inspection window.

~200e10 ppb
**BT2.KFA20**

- The large flat-top ripple almost disappears at higher intensity (~200e10 ppb).
- The measurement looks cleaner and smoother at higher intensity (better BPM response).
BT2.KFA20 ~200e10 ppb

• The agreement with lab measurements (courtesy L. Sermeus) is very good

Current loop measurement (L. Sermeus)
Beam-based measurement (I=200e10 ppb)
Recombination kickers rise time estimations

- The 2-98% rise times have been estimated
- The sources of errors for the rise time estimation are being investigated. Common error sources are:
  - The bunch intensity, as it affects the BPMs response.
  - The beam reproducibility (measurements last typically 3-9 hrs (in parallel) …)
  - The calibration technique and the length in time of the gating window.

- The jitter in time of the kicker waveforms (~10 ns p-p)

<table>
<thead>
<tr>
<th></th>
<th>Rise time 2-98% (± 10 ns)</th>
<th>Intensity</th>
<th>Upper limit*</th>
</tr>
</thead>
<tbody>
<tr>
<td>BT1.KFA10</td>
<td>99 ns</td>
<td>30e10 ppb</td>
<td></td>
</tr>
<tr>
<td>BT4.KFA10</td>
<td>101 ns</td>
<td>30e10 ppb</td>
<td>105 ns</td>
</tr>
<tr>
<td>BT2.KFA20</td>
<td>109 ns</td>
<td>200e10 ppb</td>
<td></td>
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</tbody>
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*From “Specification for KICKER SYSTEMS FOR 2.0 GeV PSB to PS BEAM TRANSFER”
Ref: PS-MKKIK-ES-0001
HL-LHC limit (@ 2 GeV) ≤ 105 ns
A new and automatic method for beam-based kickers waveforms measurements

Emittance (beam size) blow-up due to un-synched kicks can be evaluated through the sem-grids.

3 sem-grids in the BTM line provide shot-by-shot the information about the beam sizes (thus the emittances) at 3 consecutive locations.

For a given vertical emittance the length in time of the intersections, where the emittance is un-touched (no kicker-dependent mismatch), gives directly space for bunch lengthening $d_{H2T4}$.

The minimum of these gaps (including KFA10s and PI.KFA45) will give the possible increase in bunch length for the 4 bunches.

Over this distance emittance blow-up (by mismatch) and losses occur!

Halo particles get lost at entrance in the PS
A new and automatic method for beam-based kickers waveforms measurements

$I \sim 40 \times 10^{10} \text{ ppb, } \varepsilon_{n,y} \sim 1 \text{ um}$

$\sigma_y^2$ vs. BT4.KFA10 delay [ns]

$\sigma_y^2$ vs. BT4.KFA10 delay [ns]

$d_{H4T3} \sim 90 \text{ ns}$

$\sigma_y^2$ vs. BT4.KFA10 delay [ns]

$\sigma_y^2$ vs. BT4.KFA10 delay [ns]

$d_{H4T3} \sim 75 \text{ ns}$

$d_{H4T3} = \text{ measured possible best-case margin for bunch lengthening (excluding PI.KFA45)}$
Summary and next steps

The necessity of knowing the maximum acceptable bunch lengths extracted from the PSB to the PS have driven the beam-based study for the KFA kickers rise-time.

It is difficult to produce with no losses from the PSB bunches much shorter than the kicker rise times.

A new method has been elaborated to derive the kickers waveforms from the BPM deflections in long nominal consecutive bunches (~180 ns vs rise times in the order of 100-140 ns)

The method minimizes losses, uses nominal bunches, has shown excellent results compared with lab measurements and is suitable for MD automation.

2-98% rise times have been computed: KFA10s are in agreement with requirements for the update. KFA20 is at the edge of the requirements.

The sem-grids have also been used to check the distance limits in terms of emittance blow-up and mismatch caused by un-synch KFA kicks → also useful for LIU parameters definition.

From the sem-grids analysis the recombination kickers gave a measured best margin of ~75 ns for bunch lengthening in order to keep a target vertical emittance of 1.7 um and ~150e10 ppb (~present LHC type beams). The margin depends on emittance for vertical losses due to scraping and on intensity, for RP limits.

First WS tests in the PS demonstrated that the vertical halo induced by the un-synchronization of the recombination kickers gets lost at the entrance in the PS and no blow-up has been seen in the PS ring.

New tests will be performed with the new 220 ns bunches (if stable!), prepared by S. Albright (BE-RF), in order to check the sem-grids criterium with future LHC bunch lengths.

Further analysis have to be performed to evaluate the resolution of the measurements and the frequency response of the system… is the beam perturbed at some frequencies at the PS entrance? Important for PS tr. feedback assessment…
Thanks
Appendix
Purpose of beam-based kickers waveforms measurements in the BTi-PI lines

To relax the space charge limit on the PS injection plateau and increase the LIU beams performances, it is wanted to lengthen the LHC bunches from the PSB to the PS (from ~180 ns to 220 ns).

Is it possible preserving the emittance and intensity?

Which are the boundaries? One has to check whether the physical dynamic quantities along the line are compatible with the requirements…
Purpose of beam-based kickers waveforms measurements in the BTi-PI lines

The vertical recombination kickers (BT1.KFA10, BT4.KFA10 and BT2.KFA20) are responsible for the PS batch formation, composed of max 4 “equal” bunches, 1 per PSB ring, in the BT-BTP line. The PI.KFA45 is the horizontal PS inj. kicker.

The KFAs are the main dynamic elements in the line.

The magnetic field rise time $\tau_{\text{rise}}$ is an important parameter to see whether the kickers dynamics may influence the emittance and the intensity of the bunches.
A new and automatic method for beam-based kickers waveforms measurements

- PI.KFA45 strength (at 308 kV) vs PR.UHZ47 (first BPM after injection)
- In this case the bunches were taken consecutive but not adjacent (1 empty bucket in between, ~655 ns spacing), at the very exact 2nd batch injection moment.
- The PS BPMs are capacitive, not wall current monitor as in the BT line $\rightarrow$ high sensitivity to losses with discharge phenomena $\rightarrow$ not easy for voltage calibration!

Patching by hand the two sides – "minimum standard deviation criterium" (educated guess)

KFAs rise time recomb kickers limits
HL-LHC limit (@ 2 GeV) $\leq 105$ ns
Ref: PS-MKKIK-ES-0001
A new and automatic method for beam-based kickers waveforms measurements

- Comparison with simulations for the PI.KFA45.
- Simulations courtesy of A. Ferrero Colomo (TE-ABT)

![Graph showing beam-based kicker waveforms measurements](image)

**KFAs rise time recomb kickers limits**

HL-LHC limit (@ 2 GeV) ≤ 105 ns

Ref: PS-MKKIK-ES-0001
First manual measurements with sem-grids

BT4.KFA10 ripple reduction with intensity

- May be due to BPM frequency response?

![Graph 1](image1.png)

1um, ~40e10 ppb

![Graph 2](image2.png)

1.7um, ~150e10 ppb
First manual measurements with sem-grids

BT2.KFA20

1 um R2
1 um R4
1.7 um R2
1.7 um R4

\[ \epsilon_{yn} \text{ [um]} \]

\[ \text{Time [ns]} \]

PSB to PS recombination kicker waveform measurements
BT.BTV40 example with NORMGPS user (very high intensity beam ~800e10 ppb)
Average position from sem-grid
Trigger stability

BT2.KFA20 strength [ns]

Time [ns]

< 10 ns min-max

PSB to PS recombination kicker waveform measurements

Credits

Special thanks to all the people who made and released these awesome resources for free:

◎ Presentation template by SlidesCarnival