Status of KFA45 magnet tests and field measurements

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Pre-LS2 KFA45 work

- Envisaging the LIU requirements [1,2] (almost current doubling in the magnet needed), KFA45 operation moved into short circuit (SC) instead of terminated mode.
- Because of this configuration:
  - Increased rise and fall times.
  - Oscillations (reflections) in the magnetic field pulse were observed at the flat top and post-pulse.
  - Linear range of the magnet ferrites could be exceeded – Ferrites driven into saturation [3].
- During Run 2, pulse generator main switch (MS) jitter of 7ns observed [4].
- To overcome all this issues, and comply with the required LUI performance, a combination of upgrades were planned to be carried out during the LS2 [5].
Pre-LS2 KFA45 work
LS2 KFA45 - Upgrading plans

- New KFA45 magnet featuring enlarge ferrites to avoid saturation at the highest archivable current (80kV, 3kA).
- New magnet connection box allowing the installation of RC filters (speed up networks) and ferrites to tune the pulse shape.
- Improvement of the MS triggering system to reduce the jitter figure.
- Replacement of the old SF6 filled TX cables by RG220 like ones. The removal of SF6 in the tunnel improves safety and handling. Operational risk lowered!

![Diagram of Upgrading Plans](image-url)
LS2 KFA45 – Test & measurement set up

- To safely deploy and test all needed modifications without compromising the operational equipment, it was decided to build a pulse generator replica in B867.
LS2 KFA45 – Test & measurement set up

• New magnet intensive testing, characterization + Adequate conditioning before its installation in January 2020.

• Intensive pulse generator tuning to meet the LUI requirements.

• Test the performance and ageing of the new RG220 like cables through intensive pulsing.
LS2 KFA45 – Test & measurement set up

Magnetic field observation by a probe inserted in the magnet aperture
LS2 KFA45 – New magnet characterization

• Measured magnet time of flight:
  • SC outside tank: 40.6ns (Old magnet configuration)
  • SC inside tank: 36.6ns (New magnet configuration)

• New magnet do not show saturation at higher excitation currents.
• Extended linear working range
LS2 KFA45 – New magnet characterization

- Nominal magnet transfer function (TF) - 0.205 mTm/kV (Opera 2D simulations)
- Measured TF on module 2 & 3 very close to nominal.
- Outer magnet modules (1 & 4) TF over the nominal value.
  - Hypothesis: Larger fringe field $\rightarrow$ Larger inductance $\rightarrow$ More Bdl for the same excitation current.

<table>
<thead>
<tr>
<th>Module</th>
<th>Mag. Kick strength TF [mTm / kV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module 1</td>
<td>0.221</td>
</tr>
<tr>
<td>Module 2</td>
<td>0.206</td>
</tr>
<tr>
<td>Module 3</td>
<td>0.202</td>
</tr>
<tr>
<td>Module 4</td>
<td>0.219</td>
</tr>
</tbody>
</table>
LS2 KFA45 – System tuning

RC filters

Gain of 66ns (green trace w.r.t blue trace)

- RC filters – They generate over or undershoot after any sudden $\frac{dl}{dt}$ change.
  - Good for shaping the rising/falling edge
  - The post-pulse gets boosted as well
  - Need to be the right capacitance value, too much slows down the overall $\frac{dl}{dt}$
LS2 KFA45 – System tuning

Ferrites

- Saturating ferrites – Rising edge compression and post pulse damping
  - Strong tendency to create ringing (either after rising or falling edge)
LS2 KFA45 – System tuning

Improved MS trigger electronics + New oil with higher $\varepsilon_r$

- Jitter reduced from 7ns to 1ns
- Large bump on the flat top up to 107% observed. Due to the bump position and shape $\Rightarrow$ MS capacitive mismatch

![New trigger system](image)

![Old trigger system](image)
LS2 KFA45 - System tuning

Common mode ferrites used to mitigate the flat top bump
LS2 KFA45 – System tuning

- Good suppression of the flat top bump.
- Strong degradation of rise and fall time.
- No available tools to decrease $t_{fall}$ and $t_{rise}$ afterwards.
LS2 KFA45 – System tuning

- Extra length of cable to shift the flat top bump by a different amount in each generator.
- Solution to be tested. Extra cable length might have a negative impact on the rise/fall time.
LS2 KFA45 – System tuning

No dephasing

With dephasing
Based on all presented tuning tools and through an iterative process of test & measurement supported by Pspice and educated guess (based on observations), a tuning configuration is proposed to meet KFA45 LUI requirements:

1x50mm + 8x20mm (all available space)

19x(W721) Ferrites

TX cable dephasing

1x (12 Ω / 150pF)

30mm

19xW721 + RC 12/150pF + MagCB 30mm + MSCB(1+8) – Vres 5.5
Table 1: Specifications for 2 GeV PS injection

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal kick</td>
<td>mrad</td>
<td>4.3</td>
</tr>
<tr>
<td>Max. kick</td>
<td>mrad</td>
<td>4.4</td>
</tr>
<tr>
<td>Beam Rigidity</td>
<td>T.m</td>
<td>9.28</td>
</tr>
<tr>
<td>$\int B.dl$</td>
<td>T.m</td>
<td>0.041</td>
</tr>
<tr>
<td>Rise &amp; fall time (2-98%)</td>
<td>ns</td>
<td>105</td>
</tr>
<tr>
<td>Min. flat top length</td>
<td>ns</td>
<td>2105</td>
</tr>
<tr>
<td>Flat top ripple (peak)</td>
<td>%</td>
<td>±2</td>
</tr>
</tbody>
</table>

KFA45 magnetic field. Module 4. -- January 2020 --

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Trise [ns]</th>
<th>Tfall [ns]</th>
<th>Flat top ripple</th>
<th>Post pulse</th>
</tr>
</thead>
<tbody>
<tr>
<td>2nd Injection BCMS</td>
<td>82</td>
<td>103</td>
<td>104.6%</td>
<td>OK</td>
</tr>
<tr>
<td>2nd Injection LCH standard</td>
<td>82</td>
<td>101</td>
<td>104.9%</td>
<td>OK</td>
</tr>
<tr>
<td>1st Injection</td>
<td>132</td>
<td>121</td>
<td>103.8%</td>
<td>OK</td>
</tr>
</tbody>
</table>
Conclusions

- New KFA45 magnet:
  - Measured and characterized.
  - Successfully conditioned (1M pulses @ 60kV) and installed in the PS ring in January 2020.

- Pulse generator:
  - After an intensive test & measurement campaign, a pulse generator tuned configuration to comply with the LUI requirements has been proposed.
  - Jitter is being reduced in the MS by an order of magnitude.
  - All the modifications are currently being deployed into the operational equipment.

- TX cables: Intensively tested (over 1.5M pulses at 60kV). No degradation observed.
References


6. “Analysis to assess feasibility to reach the ripple requirements” 27/02/2020