CERN’s High Gradient X-Band Test Stands: Status and Update

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2023 International Workshop on Future Linear Colliders.
High Gradient X-Band Test Stands

High power test stands, producing RF pulses at 11.9942 GHz

- Power amplification based on SSAs, feeding the high power klystrons (up to 50 MW in Xbox 2)
- Real-time monitoring and RF production to ensure phase and amplitude stability (up to 400 Hz in Xbox 3): LLRF (Down-mixing, Up-mixing...), digitalization and processing, breakdown detection and interlocking.
- Test: Normal Conducting RF accelerating structures (CLIC ...) and other components (pulse compressor, correction cavities, loads ...)
The X-Boxes

In recent years, enhancing the efficiency of our RF sources has been a priority, either by reducing energy consumption or increasing available power.

- **X-Box 1**
  - Waiting for the 50 MW CPI Klystron to be repaired.

- **X-Box 2**
  - SC Solenoid integration
  - Two TD31 accelerator structures.

- **X-Box 3**
  - CRAB cavity from Lancaster conditioned
  - Deflector SARI conditioned
  - 45 deg Spiral Loads
  - Two TD31 accelerator structures.
  - High Efficiency klystrons

2022: A total of 8 RF components have been installed, 6 test programs completed.
X-Box 2:

- MgB$_2$ SC solenoid for VKX-8331
- TD31 structures
X-Box 2 Layout
X-Box 2 MgB$_2$ Solenoid

- Prototype compatible with 50 MW CPI klystron
- KEK-CERN collaboration and manufactured by Hitachi
- MgB$_2$ wire for the klystron magnet, with a unit length of 5.6 km. Diameter 0.67 mm
- Central field 0.8 T @ 57 A
- High efficiency: Reduce the power consumption from 20 kW to 2 kW
- Very safe and stable operation

X-Box 2 MgB$_2$ Solenoid

- SC technology can be applied to klystron solenoid
- Energy consumption reduced by 90% →2 kW. Further reductions still possible
- Magnetic field very similar to the conventional magnet
- No interception
- Some adjustments needed to recover performance inside the tuning range of the power supply – 20%
  Counter-coil current adjustment, for smaller beam and match original gain
- Large operational margin makes it very stable and robust against failures
X-Box 2 MgB$_2$ Solenoid

With a high efficiency klystron, modulator AND a SC solenoid we will save >50% of the power for the same output RF power!

AC/RF efficiency = 15.2%
+ SC Solenoid

AC/RF efficiency = 20%
+ HE Klystron

AC/RF efficiency = 31.7%
X-Box 2 – TD31s

TD31 for CLIC 380:

- $P_{in} \text{ [MW]}$ for $<G=72\text{MV/m}>$
  Unloaded = 36.1 MW

- $P_{in} \text{ [MW]}$ for $<G=92\text{MV/m}>$
  Loaded = 59.2 MW

- Four structures manufactured and ready to test, N3 and N4 installed in Xbox 2
X-Box 2 TD31 N3

Maximum available power reached 36.1 MW at 50, 100, 150, 200 ns and 250 ns CP length, in 14 weeks conditioning.

Nominal unload $P_{in}$ reached at all pulse CP lengths.
Maximum available power reached 36.1 MW at 50, 100, 150, 200 ns and 250 ns CP length, in 14 weeks conditioning.

Nominal unload $P_{in}$ reached at all pulse CP lengths
X-Box 3:
- TD31 structures
- Canon HE Klystrons
X-Box 3 – TD31s

TD31 for CLIC 380:
- $P_{in}$ [MW] for $<G=72\text{MV/m}>$
  - Unloaded = 36.1 MW
- $P_{in}$ [MW] for $<G=92\text{MV/m}>$
  - Loaded = 59.2 MW
- Four structures manufactured and ready to test, N1 and N2 installed in Xbox 3
Maximum available power reached at 50 (39 MW), 100 (37 MW), 150 (35 MW) and 200 ns (33 MW) CP length, in 6 weeks conditioning.

Nominal unload $P_{in}$ reached at 50 and 100 ns

4 weeks of data points.
Maximum available power reached at 50 (39 MW), 100 (37 MW), 150 (35 MW) and 200 ns (33 MW) CP length, in 6 weeks conditioning.

Nominal unload $P_{\text{in}}$ reached at 50 and 100 ns

4 weeks of data points.

$$\frac{BDR}{E_{acc}^{30} \times \tau^5} = cnt$$
X-Box 3 – Line 2: TD31 N2

- Maximum available power reached at 50 (39 MW), 100 (37 MW), 150 (35 MW) and 200 ns (33 MW) CP length, in 6 weeks conditioning.
- Nominal unload $P_{in}$ reached at 50 and 100 ns
- 5 weeks of data points.
Maximum available power reached at 50 (39 MW), 100 (37 MW), 150 (35 MW) and 200 ns (33 MW) CP length, in 6 weeks conditioning.

Nominal unload $P_{\text{in}}$ reached at 50 and 100 ns

5 weeks of data points.

$$\frac{BDR}{E_{\text{acc}}^{30} \times \tau^5} = cnt$$
June 2023, the klystrons in X-Box 3 will be replaced by E37117 high-efficiency klystrons from Canon, providing up to 10 MW.

It will allow to continue the conditioning of the TD31 structures towards $P_{\text{in loaded}}$ (59.2 MW).

### E37117 design

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<th>Parameter</th>
<th>Value</th>
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<tr>
<td>Voltage, kV</td>
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<tr>
<td>Current, A</td>
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<td>Frequency, GHz</td>
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<td>Peak power, MW</td>
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<td>Sat. gain, dB</td>
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<td>Life time, hours</td>
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<td>Solenoidal magnetic field, T</td>
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<td>RF circuit length, m</td>
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</table>
We want to design and build a permanent magnet solenoid for an available HE klystron, to increase up to 35.5% efficiency in the global RF system.
Conclusions

- High Gradient X-Band Test Stands at CERN have been operational for almost 10 years. In this period, plenty accelerating structures and RF components have been successfully tested.
  - Currently, 4 TD31s accelerating structures for CLIC 380, are being conditioned, in parallel. Unloaded target power have been achieve for all of them (36.1 MW). Next goal: Loaded target power (60 MW)

- In recent years, we have been directing our efforts towards enhancing the efficiency of our RF sources, either by reducing energy consumption or increasing available power.
  - Xbox 2: A SC Solenoid has been integrated with the 50 MW CPI klystron, operating stably for more than a year. Reduction of 25% in power consumption
  - Xbox 3: HE Klystrons will be installed this month, increasing the available power from 6 MW to 10 MW per klystron.
Thanks

... S. Gonzalez Antón, N. Catalan Lasheras, A. Baig, R. Brouns, A.M. Chauchet, A Fontenla, A. Grudiev, L. Millar, P. Morales, I. Syratchev, M. Volpi, W. Wuensch, P. Wang, M. Wendelmuth ...