Xband Klystron/modulator experience at CERN

HG2017
G. McMonagle
16/06/2017

On behalf of all the Xbox team
OUTLINE

• Xbox1 and Xbox2
  – (summary)

• Xbox3
  – Modulators
  – klystrons

• IUWR90 Flanges

• Future
Scandinova solid state modulators

CPI Klystron (commercial SLAC XL5)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Specifications</th>
<th>units</th>
</tr>
</thead>
<tbody>
<tr>
<td>VKX-8311A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RF Frequency</td>
<td>11.9942</td>
<td>GHz</td>
</tr>
<tr>
<td>Peak RF power</td>
<td>50</td>
<td>MW</td>
</tr>
<tr>
<td>RF pulse length</td>
<td>1.5</td>
<td>µs</td>
</tr>
<tr>
<td>Pulse repetition rate</td>
<td>50 (100)</td>
<td>Hz</td>
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<tr>
<td>Klystron voltage</td>
<td>410-470</td>
<td>kV</td>
</tr>
<tr>
<td>Micro perveance</td>
<td>1.15E-6</td>
<td></td>
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</tbody>
</table>
Xbox1 and Xbox2

- **Xbox1**
  - Modulator installed since 2010 in CERN, first generation solid state K300
  - Initially with XL5 klystron now CPI
  - Structure testing in CTF2 or dogleg (beam tests CTF3)
  - LLRF getting ‘tired’, pulse compressor difficult to tune
  - Still running reasonably well with lots of babysitting
  - Never reached nominal power out of klystron, limited by the high power RF network
  - Using solid state 1.2KW klystron driver
Xbox1 and Xbox2

• Xbox2
  – same configuration as Xbox1 for modulator and klystron, (modulator more recent generation)
  – LLRF, National Instrument PXI development
  – New generation pulse compressor
• In commissioning with CPI klystron, oscillations observed (now disappeared)
• has been running very reliably this year, really good pulse to pulse stability
• TWT driver will be replaced with solid state amp next week
• 3rd Klystron ordered from CPI
• Klystron acceptance was done in January 2016
• When dismantling test load klystron went up to air
• Broken window
• Klystron repaired
• Initial testing (~January 2017) gun oscillation observed
• Discussions between CPI and SLAC
• Modification to gun and modulator tank (ferrite tiles)

• Acceptance tests next week
Ferrites added to inside of lead cylinder on subsequent iteration

Ferrite tiles on gun corona can

Ferrite tiles also on a plate resting on bottom of oil tank below gun

Hoping this is compatible with CERN modulator connectivity
multi slot High Gradient Test Facility

Turnkey solution

Toshiba E37113 klystrons
Scandinova solid state modulators

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<td>GHz</td>
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<tr>
<td>Peak RF power</td>
<td>6</td>
<td>MW</td>
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<tr>
<td>RF pulse length</td>
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<td>µs</td>
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<td>Pulse repetition rate</td>
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<td>Klystron voltage</td>
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<td>kV</td>
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<tr>
<td>Micro perveance</td>
<td>1.5</td>
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</tbody>
</table>
Xbox3_initial configuration

To lines 3 and 4

A
  #1
B
  #4
C
  #2
D
  #3

To lines 1 and 2
• all 4 modulators tested successfully in factory with klystron serial #1
• All four modulators delivered to CERN and installed with tubes serial #1-4
• SAT test in diode mode with Scandinavian technicians completed

• Software problem (while in remote mode) caused soft start board to burn out in charging supplies, resolved by Scandinavian,
• performance of modulator now excellent, more user friendly GUI
• Initial RF tests started with individual klystrons
• First three ok
• Fourth tube did not give any RF power output
• Full reflection on input cavity back to driver
• VNA measurement showed cavity detuned
• Sent back to Toshiba with solenoid

To lines 3 and 4

A #1

B #2

C #3

D
Klystron check at TETD

3-1. The klystron appearance check
   • No visible damage of the klystron outside
     No problem

3-2. Diode operation with the returned focusing magnet.
   — Operating parameter check

<table>
<thead>
<tr>
<th></th>
<th>Heater current</th>
<th>Heater voltage</th>
<th>Beam voltage</th>
<th>Beam current</th>
<th>Pervenance</th>
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</thead>
<tbody>
<tr>
<td>Prior to shipment</td>
<td>10.4A</td>
<td>15.2V</td>
<td>154.5kV</td>
<td>94.2A</td>
<td>1.55μP</td>
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<tr>
<td>Return after</td>
<td>10.4A</td>
<td>14.8V</td>
<td>155.6kV</td>
<td>94.1A</td>
<td>1.53μP</td>
</tr>
</tbody>
</table>

No problem
Klystron check at TETD

3-2. Diode operation with the returned focusing magnet.
   - Beam loss measurement
     (Kicked beam by gun oscillation)

Operation at the beam voltage of gun oscillation range was increased beam loss, but the value was within operation criteria.

No problem
3-3. Cavity resonant frequency check after disassembling

<table>
<thead>
<tr>
<th>Cavity Type</th>
<th>Difference between the set value and the measured value</th>
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<tbody>
<tr>
<td>Input cavity freq</td>
<td>$\Delta -640\text{MHz}$</td>
</tr>
<tr>
<td>2nd cavity freq</td>
<td>$\Delta -16\text{MHz}$</td>
</tr>
<tr>
<td>3rd cavity freq</td>
<td>$\Delta -2\text{MHz}$</td>
</tr>
<tr>
<td>4th cavity freq</td>
<td>$\Delta -2\text{MHz}$</td>
</tr>
</tbody>
</table>

Resonant frequency of the input and the 2nd cavity was changed.
Klystron check at TETD

3-3. Inside check after disassembling
   — Condition check of gun electrodes and cathode

Electron gun

No change in appearance.
Klystron check at TETD

Anode electrode

Discolored
Klystron check at TETD

3-3. Inside check after disassembling
   — Condition check of input cavity section
4. Consideration

4-1 Comparison with the simulation
   - Reverse polarity of counter coil field

Simulation result

Hit the drift (26% beam loss)

Possibility of hitting drift

Possibility of hitting drift

Hit the drift in same place with simulation
Reverse polarity of counter coil field

Beam landing position of reverse counter coil current operation

Simulation and the same trend
— Normal magnetic field

Simulation result
Without counter coil current

Simulation result

Beam radius becomes 98% of drift tube

Simulation and the similar trend
Without focusing magnetic field

Simulation result

100% of beam loss

Simulation and the different trend
4-2. Wiring of counter coil check

While checking the polarity of the power supply side.

CERN confirmed the correct connection.
Klystron check at TETD

Hit marks of electron beam were observed on the klystron drift tube.
5. Conclusion

• Hit marks of electron beam were observed on the klystron drift tube.

• Hit the drift in same place with reverse polarity or without current of counter coil simulation.

• Wiring of counter coil check
  — While checking the polarity of the power supply side. Unknown when the polarity is reversed.

When did this happen?
Why?
Why did the body delta T interlock not work?
Was it damaged at low rep rate hence no large temperature difference?
7. Refurbish schedule

### 12 GHz Klystron Refurbish schedule

<table>
<thead>
<tr>
<th>Klystron</th>
<th>S/N: 15G004</th>
<th>Year</th>
<th>Month</th>
<th>2017</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Jan</td>
<td></td>
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</tr>
<tr>
<td>beam transmission test</td>
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<td>Feb</td>
<td></td>
<td></td>
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<tr>
<td>klystron breakdown and study</td>
<td></td>
<td>Mar</td>
<td></td>
<td>4</td>
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<tr>
<td>breakdown report</td>
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<td>Apr</td>
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<tr>
<td>additional processing</td>
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<td>May</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>material procurement assembly</td>
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<td>Jun</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>aging/test ship back</td>
<td></td>
<td>Jul</td>
<td></td>
<td></td>
</tr>
<tr>
<td>shipping</td>
<td></td>
<td>Aug</td>
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<td>Sep</td>
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<td>Oct</td>
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<td>Nov</td>
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<td></td>
<td></td>
<td>Dec</td>
<td></td>
<td></td>
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</tbody>
</table>

- **Shipping the returned electromagnet**

<table>
<thead>
<tr>
<th>Klystron spare #1 (S/N: 17C006)</th>
<th>production</th>
<th>shipping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Klystron spare #2</td>
<td>production</td>
<td>shipping</td>
</tr>
</tbody>
</table>

TOSHIBA ELECTRON TUBES & DEVICES CO., LTD.
• #2 and #3 combined together
• #1 used to condition loads
• LLRF works very well
• Conditioned RF network without structure lines 3&4
• Opened network to install structure, klystron #3 vacuum problem,
• Toshiba engineer diagnoses window problem, tube sent back to Toshiba for evaluation last week
• Install #1 in modulator D to allow two klystron operation for lines 3 and 4
Implementation LLRF algorithm

- Works well in test bench
- Implemented on modulators C and D
- Combination of high power very good and switching between lines worked well (Matteo's talk)
- Operation problem when ramping up after breakdown, phase instability
- Investigation shows problem with tube #2
- Filament hours 4619, high voltage hours 3229

Solid state amplifier and low level changed
Problem stayed with klystron
Small changes in solenoid or counter coil only shifted the problem to different input power
VNA measurement on input cavity, frequency ok
Implementation LLRF algorithm

26th May

Increased radiation levels
Water cooling outlet of solenoid

9th June
Initially asked to investigate why power output had reduced on klystron

Noticed perveance change

Increased heater current by 1 amp and recovered tube perveance

Rep rate changed again perveance changed

More investigations
Heater curves #2

- Constant Klystron Voltage 150kV
- Limit of heater power supply in modulator
- Nominal operating point from factory test

Graphs showing:
- Klystron Current Amps vs. heater current (Amps)
- Heater voltage vs. heater current
- Micro perveance vs. heater voltage
Continue testing lines 3 and 4
With instability

First week in July do commissioning of #5 and #6 with Toshiba engineer

After successful tests remove #2 and replace with one of the new tubes

July/August hopefully receive refurbished #4 to complete lines 1 and 2
• New unisex Xband flanges are used in Xbox3
  – International committee with representatives of KEK, SLAC and CERN
  – Tested in SLAC up to 40 MW, 1us and 10 MW, 200 ns
  – Tested at CERN, 5us, 5 MW, 400 Hz and ~42 MW, 200 ns, 200 Hz
  – Copper plating optimised
  – Vacuum gasket optimised, tried machined gasket and stamped gasket
IUWR90 flanges

• Stamped gaskets
  – Friction fit
  – No problem in mounting
  – external machined edges of flange allowed alignment by touch

• Machined gasket
  – Loose fit needs to be held in place
  – Mounting jig needed

• Stamped gasket with friction fit is now being used
• Complete high gradient structure testing program by 2019

• Complete commissioning Xbox3 this year

• Configure Xbox1 to power structure in CLEAR (2018)
  • Upgrade LLRF? And change pulse compressor?
  • Upgrade existing modulator to 100Hz?

• Upgrade Xbox2
  – Two structure testing, variable attenuator (Veronicas talk)
  – Upgrade existing modulator to 100Hz

• Xbox3
  – 50% of Xbox3 to Melbourne, collaboration
  – Conditioning structures seems to be dependant on number of pulses
  – Higher rep rate faster conditioning?
DUAL X-BAND 2X 6MW RF UNIT
BASED ON K300 PLATFORM

K300 Platform front/side view
- Klystron based CLIC
- High efficiency klystron development (Igor's talk)?

- Would need two klystrons per 2 m of LINAC
- Compact modulator needed for tunnel integration
- Test stand at CERN?
DUAL X-BAND 2X 50MW RF UNIT
BASED ON K200 EXTENDED PLATFORM

Main Parameters | Values
--- | ---
RF Peak Power | 100 MW (2x50)
RF Average Power | 7.5 kW
Pulse Width | 1.5 µs
Pulse repetition | 50 Hz
Klystron Efficiency | 75%
Perveance | 0.86 µperv
Pulse Voltage | 360 kV
Pulse Current | 185 A
Mod. Average Power | 21 kW
Length | 1420 mm
Depth | 1815 mm
Height | 1990 mm
Thanks for your attention.

ANY QUESTIONS?