Operational experience of high-power RF at Diamond Light Source

Aleksander Bogusz, Peter Marten

Diamond Light Source
Diamond Light Source

- UK national synchrotron light source
- 3 GeV storage ring, 300 mA beam current
- Full energy booster and 100 MeV linac
- Running user beam since 2007, top-up since late 2008
- 2013 statistics:
  - 5088 hours to beamlines
  - > 98% beam delivery
  - RF is source of 60% of all beam trips

The RF Group

- Chris Christou
- Alek Bogusz
- Pengda Gu
- Matt Maddock
- Peter Marten
- Shivaji Pande
- Adam Rankin
- David Spink
- Alun Watkins
SR RF Systems

- RF test facility
- Cryogenic plant
- HV PSU
- Circulator and load
- LLRF, DAs and Aux Supplies
- IOTs and combiners
- Superconducting cavities
**SR: e2v IOTD2130**

- Two 4-IOT amplifiers driving cavities for normal operation
- One amplifier for test/conditioning/standby
- 300 mA needs > 50 kW per IOT
- Further spares “on shelf”
- Up to 40,000 hours operation

---

**Efficiency of Output Coupling on Efficiency**

- IOT Tuned for 80 and 60 kW @36 kV

---

**Filament hours**

- System 1 (standby)
- System 2 (active)
- System 3 (active)

---

**IOTD2130 efficiency at 500 MHz**

- Power Output (kW)
- Efficiency %
Other RF Systems

100 MeV SLS-style NC linac

5-cell copper booster cavity
Injector RF

Linac: Thales TH2100 klystrons
  - Rated at 37 MW, 100 Hz
  - Running at 16 MW, 5 Hz
  - Running open loop
  - Initial pair of klystrons replaced after 17,000 & 20,000 hours
  - Current pair of klystrons have run for over 30,000 hours each
  - Manage occasional arcs to minimise effect on machine operation
  - Triode gun with dispenser cathode
    - Changed once in August 2013

Booster: Thales TH793
  - Single IOT cycling to 50 kW at 5 Hz
  - 41,000 filament hours
  - “Second hand” spares from SR
  - Very reliable at low average power
RF faults

2013
46 faults

2014 so far
19 faults
IOT conditioning

- Condition selected IOTs every shutdown
- Emergency conditioning following ISC fault when appropriate
  - Using in-house spark box
  - Ramp to 45 kV and hold
- 2 ISC trips so far in 2014
- 14 + 6 ISC trips in 2013
- Not tested 350mA in 2014
- High power RF conditioning is an option

- IOT internal short was the biggest single cause of beam trips in 2013
- Increase in beam current to 350mA was disrupted by IOT reliability
- 350mA requires 65kW per IOT
- Two weeks of 350mA running caused ~1/3 of all IOT trips
- IOT 2/1 was replaced in May 2013
RF noise on infrared beamline

The high voltage power supply for the IOTs is a switched mode supply and as such generates noise on the voltage at the IGBT switching frequency and its harmonics

- Visible in HV spectrum
- Infra-red beamline notice the noise in their interferograms
- Broad-band measurement, so shifting frequency is not an option
Removing the switching noise

Switching noise can be removed by disabling the PWM operation
- Works for klystrons (at SLS) but IOT current drifts with power and system is destabilised during dither at integral module changeover
- Power drawn from IOTs depends on beam current
  - Varies during a fill and at different points in the top-up cycle
- Power drawn from IOTs depends on configuration of insertion devices
  - Out of control of RF group!

Must control switching of integral modules
- Dither must be removed by introducing a large hysteresis in HVPS current-control
- Possibly remove switching entirely and take up slack with LLRF loop
- Occasional shuffling of modules to ensure longevity
  - Weekly during periodic maintenance or during to-up when kickers dominate disturbance

Trials scheduled for June 2014…
IOT fault tolerance

- Can maintain beam when single IOT is switched off
  - 240 mA with IDs, 250 mA without
  - No interlocks violated
- Beam disturbance of several hundred microns in the horizontal plane
- Can we introduce fast switching to give a resilient system?
  - Suitable fast solid state switches available
    - Behlke, ...
- LLRF is critical
  - Speed of response and multiple cavities
  - Protect IOT and save beam within 500 turns
Summary

Diamond is a user facility and the RF group must cater to the beamline users

- **Reliability is paramount**
  - Multiple single points of failure in SR RF system
  - Noise or drifts are noticed immediately by beamlines
  - Injector faults will disrupt top-up

- **We are preparing for future machine developments**
  - RF system must develop as beam current increases
  - Continuity of supply must be ensured for IOTs, klystrons and critical smaller components

---

Thank you for your attention