RF Commissioning

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Outline

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• Data acquisition and diagnostic tools
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Introduction

• Based on experience with LHC and LEP SC RF commissioning

• Assumptions:
  – Power plant derived from 800MHz IOT amplifier system currently being specified for the SPS Landau cavities
  – Low Level RF similar to the LHC 400MHz system
  – Controls derived from LHC and SPS RF and integrated into the LHC control system
Introduction: LHC and SPS systems

• LHC acceleration system: 16 SC cavities @ 400MHz
  – each driven by 300kW klystron
• Power system (slow controls) using PLCs
  – high voltage power supplies, klystrons, RF power distribution, cryostats and ancillary equipment
• Low Level system (Cavity servo controller and Beam Control)
  – digital, FPGA at 80 MS/s, DSP for turn-by-turn (11 kS/s)
  – in parallel with fast analog for transient beamloading
  – 2 VME crates per cavity
• SPS Landau cavity system: 2 travelling wave cavities @800 MHz
  – each driven by 4 x 60kW IOT amplifiers (currently in procurement)
Commissioning: Equipment check-out

• RF and control cables: individual testing
  – reflection (short circuit) for cable identification and initial validation
  – transmission for phase sensitive signals
  – reflection tests with termination to assess damage, faulty connectors etc.
  – > 100 cables per cavity in LHC...

• Control racks equipped and tested in lab
  – after installation, signals test up to PLC control level

• Data exchange with vacuum, power converters, cryogenics

• Interlock system: individual test and validation, access, radioprotection
LHC ACS RF distribution scheme
Warm commissioning: amplifier

- Initial commissioning of power amplifiers done during reception tests

Technical Specification for
the Power Amplifier for the SPS 801 MHz RF system

12.8 Site acceptance tests
- 48 hour full power operational test, during which the frequency, phase, linearity, output power, stability and efficiency will be monitored.
- Measurement of gain.
- Output voltage and current.
- Output voltage ripple at specified frequency ranges.
- Power factor at full output.
- Harmonic injection into the mains supply at selected levels including full output.
- Time taken to switch to zero output on receipt of the ‘fast switch-off’ command.
- Energy deposited into a short-circuited output.
- Effectiveness of internal protection circuits.
- Temperature rise during ‘soak’ operation at full power of transformers, inductors and semi-conductors.
- Compliance with electromagnetic noise requirements (includes RF, x-rays).
- Compliance with acoustic noise requirements.
- Purity of IOT RF spectrum.
- Thermal run.
- Reproducibility check.
- Harmonic analysis.
- Inrush current measurement.
- Power factor correction test.
- Mains regulation tests.
- Line regulation tests.
- High voltage DC test to be carried out at an over-voltage to be agreed.
- Power Amplifier RF tests.
- etc...
Warm commissioning

- ... of complete power system with RF
  - waveguides short-circuited to isolate cavities
- HV and RF interlocks: individual tests
  - water flows, WG arc detectors etc
- Bring amplifier slowly to full RF power
  - calibration of power measurements (directional couplers) and attenuators for signal distribution
  - test and adjust circulator and load
- Long-term power test (100 hours)

If SPS type 800MHz power plant is used, most of the procedures will already be well defined
Low power measurements

• ... on cold cavities
• to confirm measurements from test stand
  – loaded Q
  – tuning range
• using resonant frequency and bandwidth measurements with network analyser
  – drive signal injected via coaxial transition on waveguide
  – return signal from cavity field measurement antenna

We can now remove the short circuit and proceed with high power testing...
High power tests: cavity conditioning

• Run cavity up to full power and voltage while observing vacuum and cavity field emission

• Vacuum
  – in practice, we are looking at the vacuum in the main input coupler
  – difficult to see outgassing in cavity (pumped by the cold surfaces)

• Field emission in the cavity
  – shows as He pressure excursions $\rightarrow$ RF trips
  – in LEP, feedback on X-ray emission was possible (total cryomodule voltage of 40MV)
  – radiation not detectable in LHC (single cavity, 2MV)

• The input couplers are equipped with a DC bias voltage to suppress multipacting during normal operation: this is switched OFF during conditioning
Cavity conditioning method

- Pulsed FM modulated RF power is applied to the cavity in a controlled way with vacuum feedback
- Two loops
  - Fast vacuum feedback
  - Slow computer controlled loop to generate AM envelope and increase field and power as conditioning progresses (pulse to pulse at 50Hz)
Cavity conditioning method

A

Increase Power using a fixed pulsewidth until $P_{\text{max}}$ is reached.

B

Increase Pulse width and proceed with the Power as above.

C

Finish with CW and proceed with the Power as above.

J. Molendijk
Conditioning: Implementation

- Conditioning system is fully integrated in LHC Low Level RF Cavity Controller
The Conditioning DDS Module

- Vacuum Loop CPLD
- RF Generator 2
- RF Summing & Gain Control
- RF Generator 1
- 500MHz Synthesizer (DDS clock)
- 4 Channel DDS
Conditioning DDS – I/Q plot of Dual FM sweeps

Actual Data Obtained from Forward Current, I/Q memory in the Tuner loop module
LHC SC RF Conditioning GUI

Cavity P Fwd

Cavity V gap

Pulse

Envelope & Power

Vacuum Loop

Dual FM Generator & Status

Global

J. Molendijk/F. Dubouchet
Conditioning: Summary

• Typical conditioning time to full power and voltage for an LHC cavity was a few days to 1 week
• Highly automated, but still requires regular human supervision to adjust parameters
• Integrated conditioning system in LLRF hardware has proved very efficient, and allows conditioning of multiple cavities in parallel

• Main power coupler DC bias switched on only after conditioning
LHC cavity Low Level

Cavity Servo Controller, Simplified Block Diagram

Signals: Digital: [Digital I/Q pair] Analog: [Analog I/Q pair]

Technology: DSP, CPLD or FPGA (40 or 80 MHz), Analog RF
Low Level RF commissioning

• Tuner loop
  – tuner phase adjustment to set the cavity on tune when the loop is closed

• RF feedback
  – phase alignment of digital and analog feedback branches
  – adjustment of feedback gain and phase before closing loop
  – measure closed loop response: important for
    • beam loading response
    • cavity impedance seen by beam
    • bandwidth of cavity voltage control
  – measure phase noise

• Amplifier phase/amplitude loop
  – adjust gain and phase setpoints
  – adjust dynamic loop responses

Lots of work with a network analyser, but new tools are at hand...
LLRF embedded data acquisition

• All LHC LLRF boards have on-board signal recording memory

• 2 parallel sets of buffers:
  – Post-Mortem capture
  – User “Observation”

• 64 turns @ 40Ms/s → 128kB/signal

• Revolution frequency tagging

RF feedback board
“Baseband network analyzer” (BBNWA)

- LLRF boards also have embedded memory buffers for “excitation data”: can inject signals into the loops
- Loops excited with noise
- Output signals recorded digitally
- Transfer function estimate program calculates frequency domain transfer function
- “Fit” an idealized linear model to the measured data and calculate recommended adjustments

MATLAB tools for remote setting-up of LLRF developed with US-LARP collaborators (D. Van Winkle, C. Rivetta et al.)
Open Loop Alignment

Un-Aligned Open Loop Response and Model Fit (SM18)
BBNWA contd.

- Comparison of closed loop response measured with instrument vs. embedded BBNWA measurements

Network analyzer (Agilent)  

BBNWA  

D. Van Winkle
Automated tuner setup

- MATLAB script for Automatic setup of tuner loop

Tuner sweep to find resonance

Sweep across resonance with different phase shifter values

Converge to optimum phase
LLRF: Summary

• It took almost 1 month to set up the Low-Level RF of the first cavity

• Once the procedures were well defined, the last few cavities took about 1 day each

• New automated tools using MATLAB and the BBNWA feature of the LLRF hardware will save a lot of time

→ Many thanks to our US-LARP colleagues from SLAC
Controls and software

- PLCs and Low-Level crates interfaced via FESA (Front End Software Architecture)
  - a “FESA class” software module is written for each type of equipment
  - communication via the CERN Controls Middleware

- Application software:
  - LabView expert synoptic panels
  - Matlab scripts for more sophisticated specialist applications
  - LSA (standard machine operations software) manages settings and sequencing
  - Logging and Post Mortem
  - Alarms (LASER)
  - ...
Summary

• Power system commissioning procedures will be well known if using existing power source (SPS type 800MHz)

• Controls and application software should be based on standard CERN controls infrastructure

• LHC low-level electronics has built-in conditioning and diagnostics facilities, and is already well integrated into the control system

• Powerful tools are being developed for LLRF setting-up which could equally be applied to the crab cavity system