Jörn Jacob, ESRF
on behalf of the colleagues of the RF Group and many other ESRF Groups

14th ESLS RF Meeting 2010
ELETTRA, 29th – 30th September

ESRF RF System Status – Operation & Upgrade

Jörn Jacob, ESRF
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Existing 352.2 MHz ESRF RF system
Existing Operation at 200 mA
- 1.3 MW klystron transmitters: Redundancy in case of any transmitter failure (waveguide switching)
- Suppression of HOM driven Longitudinal Coupled Bunch Instabilities by Cavity Temperature regulation

Current upgrade to 300 mA
- No transmitter redundancy
- Need LFB to stabilize HOM driven instabilities
- Increased voltage to master Robinson Instability

Long term
- Only 1 manufacturer left for this type of klystrons ☢ possible obsolescence

352 MHz 1.3 MW Klystron
Thales TH 2089

5-cell cavities: strong HOM!

R/Q = 139 Ω / cell
Q₀ = 38500
Rs = 26.8 MΩ (5 cells)
V_{nom} = 1.4 \ldots 2.5 MV
2 couplers: \(\beta_{max} = 4.4\)
Max 170 kW / coupler
Existing 352.2 MHz ESRF RF system

Problem with SR Cavity 5:
1997 installation in the machine
- Bad welding joint on tuner ports, scraping the piston
2007 Leak developed on 1 tuner port: 300 mA tests had to be stopped
2008 Replaced with spare cavity, however: bad conditioning with beam due to a previous accidental venting during storage ⇒ no 300 mA test
2010 Re-installation of repaired cavity 5 but still problem with 1 coupler:
  • Degassing
  • Glow discharges
- Nevertheless: successful resuming of 300 mA tests
- Exchange of coupler in August 2010 solved vacuum problems

Since 2008: several window failures with existing LEP type coupler
RF upgrade project

1. 18 new single cell HOM damped cavities
2. Solid State Amplifiers
   - 4 x 150 kW SSA for the Booster
   - 18 x 150 kW SSA for the Storage Ring
   - Phase 1: 7 SSA manufactured by ELTA
3. In house development of SSA using a Cavity Combiner
4. Cavity Power couplers
   - New Spare couplers / existing design with improvements
   - Improved conditioning method
   - CERN/ESRF/SOLEIL collaboration for new couplers using LHC window design

RF upgrade Phase 1

- 4 SSA in fabrication: commissioning early 2012
- 3 SSA ordered: commissioning mid 2012
- 3 prototype cavities in fabrication: delivery in 2010-11
1. Single cell NC HOM damped cavity prototypes

DESIGN, checked with aluminum model

All the longitudinal HOM impedances are well below the threshold of 1A / 18 cavities

3 power prototypes in fabrication:

- validate the design
- validate 2 different manufacturing procedures
- qualify 3 companies: RI, SDMS, CINEL
- obtain 3 operational cavities for ID23

• 9 MV with 12 to 18 cavities
• Planned operation at 300 mA
• Power capability to sustain up to 500 mA

Details presented by V. Serrière

* This work, carried out within the framework of the ESRFUP project, has received research funding from the EU Seventh Framework Programme, FP7.
2. Contract for 7 SSA of phase 1 with ELTA

- Offer essentially along the initial SOLEIL design
- New 6th generation LDMOS-FET transistors allow for a more compact design with only 2 towers to obtain 150 kW:
  
  315 W → 650 W per module
  
  Coaxial combiners: 650 kW x 8 x 8 x 2 – losses = 75 kW / tower
- November 2009, contract with ELTA for:
  - 4 x 150 kW SSA for the booster (10 Hz pulsed operation)
  - 3 x 150 kW SSA for the SR (CW operation)
- First 75 kW tower built in close collaboration between SOLEIL and ELTA (transfer of technology)

**Schedule:**

- February 2010: Successful test of the first RF module, validation of the design:
  \[ \eta_{\text{module}} > 72\% \text{ (measured)} \]
  \[ \Rightarrow \text{expected total } \eta_{\text{SSA}} > 55\% \text{ (> spec)} \]
- July 2010: Successful test of the first combination of 16 RF modules, including 500 hours ON/OFF fatigue test (7500 x 4 min on/off cycles)
- February 2011: Acceptance test of the first 75 kW tower at ESRF
- January 2012: Commissioning of the 4 x 150 kW SSA connected to the ESRF booster cavities
- August 2012: Commissioning of 3 x 150 kW SSA connected to the first 3 single cell HOM damped cavities in cell 23 of the Storage Ring
400 V ac / 280 V dc power supply for the booster SSA

- Constant power: 250…350 kW
- Reduced power consumption
- Peak DC power: 1000…1200 kW
- Mains 400 V ac
- Constant current
- 280 V dc
- Anti-flicker: \( C \approx 3 \, \text{F} \)
- 10 Hz
- 2 booster cavities x 2 couplers
- Driver: 1 W

400 kW average

600 kW RF
Booster RF: 4
150 kW amplifiers

Existing transmitter room SYRF

2 five-cell cavities
x-2 couplers

Directional couplers

75 kW tower

4 Waveguide switches to 4 water loads

SY: Booster Synchrotron
Booster RF : 4
150 kW amplifiers

400kW PS
Good-access room
SYRF

Local control cubicles
4 x capacitances: 0.75 F per cubicle

Good Access
Wall
PS 400kVA
Condemnation Key system

SSA #1
SSA #2
SSA #3
SSA #4

Caniveaux
2000
CB14
Control
Control
Control
Control
500
2000
2000
Switch 2
Switch 2
1000
Switch 2
Switch ...

Water Load 300kW
Water Load 300kW
Water Load 300kW
7.4
1500
1000
1000
1000
1000
1121.9
Good-access
400kW PS

Booster RF : 4
150 kW amplifiers
3. R&D – SSA using a Cavity Combiner

[ M. Langlois, ESRF RF Group]

**ALBA Cavity Combiner:**
- MWS design / ALBA
- 100% match for 2 IOTs
- One IOT off and detuned:
  - Adjust tuning plunger in output waveguide
  - Re-establish match > 99%

**For ESRF application:**
- 6 rows x 22 Columns x [600 … 800 W per transistor module]
  - 75 … 100 kW
- More compact than SOLEIL type coaxial combiners
- Coupling: $\beta_{\text{waveguide}} \approx n_{\text{module}} \times \beta_{\text{module}} >> 1$
- Easy to tune if $n_{\text{module}}$ is varied
- Substantial reduction of losses $\Rightarrow$ higher $\eta$
Strongly loaded $E_{010}$ resonance

- Modest field strength
- Cavity at atmospheric pressure
- 1 dB - Bandwidth $\approx 500$ kHz

- SSA with Cavity Combiner
  - Mechanical design almost ready to build a 12 kW prototype (18 modules)
  - Main goal: develop an adequate electrical & mechanical interface between RF modules & cavity

- In parallel:
  - In house development of amplifier modules,
  - Using latest LDMOS-FETs
  - Goal:
    - Acquire expertise in SSA design,
    - Contribute to the design improvement
    - Prepare the future operation follow up
    - Set reference for coming procurements

- Prepare next step:
  - Full scale prototype at 75…100 kW

H field
Homogenous magnetic coupling of all input loops

E field
Strong capacitive coupling to the output waveguide
4. Cavity Power Coupler

**Brief history** see [J. Jacob & E. Montesinos, 12th ELS RF meeting’2008]

1. **2008:** after 17 years of quiet operation, suddenly
   - 5 leaks the booster cavity windows
   - 1 ceramic metallization on SR cavity 5
   - Fortunately: 6 pre-conditioned couplers in house but critical situation!

2. **With support from CERN**
   - Application of improved RF conditioning algorithm developed for LHC
   - 20 times thicker anti-multipactor Ti-coating on 12 spare windows

3. **Repair damaged couplers**
   - 4 times: welding a new window (new coating)
   - 2 times: brazing a new window (also new coating)

4. **Improve Vacuum on the booster cavities**
   - Add NEG inserts on the ion pumps
   - Bake out applied for the first time during summer (so far only done on SR)

5. **Since 2008:**
   - 24 new LEP type windows from PMB
   - Order of 2 x 10 new LEP type couplers from FMB and RIAL, respectively
We learnt so far:

- Ceramic chemistry had to be re-established, know how gets lost with time
  - finally bare ceramics from Wesgo

- Brazing of kovar rings on windows:
  - brazing material preventing correct welding
  - 1st series: repair by hand milling
  - Then: brazing specification refined

- Problem of cleanliness during manufacturing

- Apply correct pressure during assembly weld

- We are now testing:
  - Removal of Copper oxide from a “dirty couplers” that was arcing by sulfamic acid: it conditioned well
  - Waiting for one coupler with electro-polished inner conductor: to be tested soon

- Conditioning further improved:

- CERN Conditioning set up [Eric Montesinos] now rebuilt at ESRF using today’s technology

Essentially standing wave

Essentially traveling wave

LEP type coupler
New conditioning set up (new ESRF hardware implementation of LHC system)

LabView control

design available to other labs, if interested.

PIN attenuator: 48 dB dynamic, to set the power

2 RF MOS switches (50 dB) in series, to set the pulse width 20 µs to cw

PIN attenuator: 48 dB dynamic, to feed back fast vacuum response
New coupler using LHC window - CERN-ESRF-SOLEIL collaboration

see also [J. Jacob & E. Montesinos, 12th ESLS RF meeting’2008]

Reminder: LHC window directly brazed into copper collars:
◊ No sharp edges
◊ Well defined current paths
◊ Sustains very high power: tested at 575 kW full reflection without damage

1. Develop couplers for ESRF and SOLEIL using LHC window to
◊ Increase the power capability and improve the reliability
◊ Obtain a new standard and high performance platform for high power couplers
◊ Electrical & mechanical compatibility with existing LEP coupler for both NC and SC applications
◊ ESRF: 1 prototype for high power tests + 2 production prototypes
◊ SOLEIL: 2 production prototypes
◊ Including waveguide transformers

2. CERN’s interest
◊ Re-develop the brazing and subsequent electron beam welding in the CERN workshops
◊ Safeguard specialized know-how and guarantee durability of this strategic component

3. Status
◊ Successful ceramic / copper brazing at CERN (inspection of a cut sample)
◊ Prototype expected in December 2010
◊ Production prototypes for ESRF and SOLEIL in June 2011
Thank you for your attention!

ESRF Linac/Injection-Extraction/RF Group