RF Power Station and High Power Test Program at FREIA

Rutambhara Yogi and FREIA Group
• Maximum RF power coupled to beam = 320 kW

• Considering LLRF overhead = 15% (12.5% power overhead: Simulink model) (planning to use excursions of gain curve to reduce this overhead)

• RF loss in distribution system = 5%
  Power of RF source = 390 kW ≈ 400 kW

• Beam pulse width = 2.86 ms, repetition rate = 14 Hz,
  Natural fill time = $t_f = 2Q_L / (\bar{\omega}) = 135 \mu s$, ($Q_L = 1.5 \times 10^6$)
  RF pulse width = 3.1 ms
  Duty factor of the amplifier $\approx 4.28 \%$

• Spoke cavity band-width = 2.34 kHz
  system band-width $\approx 100$ times larger than spoke resonator band-width for tuning and regulation delay.
  $3 \text{ dB bandwidth} > 250$ kHz.

FREIA:
• Development of ESS Spoke Linac amplifier
• High power test of Spoke cavities.

Targets:
• Beam reliability 95 %
• Reliable operation - Beam will be lost if more than one Spoke Amplifier fails
• RF system reliability 99 %

Challenges:
• RF Amplifier doesn’t exist at ESS specifications
• FREIA: Developing amplifier at ESS specifications
• Testing to confirm specifications and reliability

10 Sept 2013 LLRF meeting in Uppsala
Compared all the possible RF Transmitters like Tetrode, Klystron, IOT, Solid state amplifier and selected **Tetrode** for the first RF power station (availability, price, footprint). [Reported in SLHiPP2012, Katania]

**Expected delivery: Dec 2013**

High power RF Power Station using solid state technology under development by Siemens Research centre.

**Expected delivery Jan / Feb 2014**

ESS Amplifier technology will be proposed after testing tetrode and solid state RF power stations.
 Specifications:

- Frequency = 352 MHz
- Peak power = 400 kW
- Average power = 20 kW
- Pulse width = 3.5 ms
- Pulse repetition frequency = 14 Hz

- Tetrode TH595 is selected as HPA [Reported in SLHiPP2013, Belgium]

- Conservative gain for TH595 = 13 dB

- Preamplifier (Solid state amplifier):
  - Peak power = 10 kW
  - Average power = 0.5 kW

TH595 (tested at Thales) for 200 kW output power.
(for double pulse width, with half pulse repetition rate)
High power tests at FREIA

RF power station test on load
- Test of preamplifier (10 kW peak / 0.5 kW avg)
- Test of amplifier (200 kW peak / 10 kW avg)
- Test of Tetrode RF power station (400 kW peak / 20 kW avg)
- Test of Solid state RF power station (400 kW peak / 20 kW avg)

Solid state RF power station test on Mismatch load
- Test with variable short with all phases
- Test with mismatched load
- Test with arc: Eric Montesinos(CERN) will provide the device.
  (Transmission line section in which arc will be created by a RF short circuit device)

<table>
<thead>
<tr>
<th>Lstub (mm)</th>
<th>Reflection coefficient</th>
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<tr>
<td>20</td>
<td>0.95</td>
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<tr>
<td>40</td>
<td>0.85</td>
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<td>160</td>
<td>0.20</td>
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<tr>
<td>200</td>
<td>0.04</td>
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</table>
Tetrode RF power station test on Mismatch load

- Circulatorless operation of tetrode: Under study. Collaboration with Eric Montesions (CERN). Test it at FREIA and then propose for ESS.

- Test with variable short with all phases for total peak power 200 kW.

Coupler Conditioning (400 kW)

- Detune the cavity (by few kHz)
- Start from low power and small pulse width and then slowly reach full power (352 MHz, 400 kW, 3.5 ms)

RF test of cavity

- Apply RF power needed to build maximum Eacc = 9 MV/m
- Start from low power and small pulse width and then slowly reach full power (352 MHz, 400 kW, 3.5 ms)
- Maximum Power = 100-200 kW, pulse width = 3.5 ms
Tetrodes can provide more than 1.5 times the nominal power for short time. Can be used to decrease LLRF overhead for Amplifier power calculation.

Courtesy: Eric Montesinos (CERN)
Lorentz detuning compensation of cavity

Special pulse shape needed
Due to absence of beam.

- Instead of power sweep, pulses of power can be given i.e. excursion of gain curve can be used.
- Feed-forward can be used to decrease the reflected power at the start of the pulse.
- To confirm experimentally in FREIA and then propose to ESS

Courtesy: Report from Vitaliy Goryashko, FREIA, UU
Schematic of RF Distribution layout at FREIA laboratory.

- Solid State RF power station
- Load 400 kWp
- Coaxial switch
- Circulator
- Load 400 kWp
- Tetrode RF power station
- FREIA Bunker
- Coax to wg adapter
- Spoke cavity

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6-1/8 Inch 50 Ohm coaxial line

- Dual directional coupler (DDC)

For first chain:
Inside FREIA bunker: 6-1/8 inch coaxial line with ceramic supports is used
Outside FREIA bunker: 6-1/8 inch coaxial line with teflon supports is used

For second chain:
WR2300 (half-height) waveguide to be used.
Signals for RF Amplifier and RF Distribution

Water Flow
Water Pressure
Water Temp. Out
Water Temp. In
Status
Drain current
Output VSWR
Interlocks
Monitoring

Air Flow
Air Pressure
Air Temp.
Water Flow
Water Pressure
Water Temp. Out
Water Temp. in
water σ
Cavity temperature
Interlocks
Monitoring

Control (phase shifter)
Control (stub)

Power Supplies

Power Supplies

Solid state RF power Station

Switch

EM current
Water Temp. Out
Water flow
Field
Control (EM current)

Arc det

Green colour: Signals handled by local controller of RF power station

10 Sept 2013
LLRF meeting in Uppsala
Thank you!