UPPSALA HIGH POWER TEST STAND FOR ESS SPOKE CAVITIES

R.A. Yogi, A. Rydberg, D. Dancila, K. Gajewski, L. Hermansson, M. Noor, R. Wedberg, R. Santiago-Kern, T. Ekelöf, T. Lofnes, V. Ziemann, V. Goryashko, R. Ruber,
Uppsala University, Uppsala, Sweden

Abstract

The European Spallation Source (ESS) is one of the world's most powerful neutron source. The ESS linac will accelerate 50mA pulse current of protons to 2.5GeV in 2.86 ms long pulses at a repetition rate of 14 Hz. It produces a beam with 5MW average power and 125MW peak power. ESS Spoke Linac consist of 28 superconducting spoke cavities, which will be developed by IPN Orsay, France. These Spoke Cavities will be tested at low power at IPN Orsay and high power testing will be performed in a high power test stand at Uppsala University.

The test stand consists of tetrode based RF amplifier chain (352MHz, 350 kW) power and related RF distribution. Outputs of two tetrodes shall be combined with the hybrid coupler to produce 350 kW power. Preamplifier for a tetrode shall be solid state amplifier. As the spoke cavities are superconducting, the test stand also includes horizontal cryostat, Helium liquefier, test bunker etc. The paper describes features of the test stand in details.

INTRODUCTION

The European Spallation Source (ESS) is the world's most powerful neutron source. The ESS linac will accelerate 50mA pulse current of protons to 2.5GeV in 2.86ms long pulses at a repetition rate of 14 Hz [1].

ESS Linac has twenty eight superconducting Spoke cavities. The power coupled to the beam ranges from 162 kW to 239 kW per coupler for beam current of 50mA. The RF amplifier for Spoke will power the spoke cavities via RF distribution system. Considering 5% loss overhead in RF distribution system and 25% power overhead for LLRF, the power for RF amplifier will range from 225 kW upto 350 kW.

ESS Specifications for Spoke Linac amplifier:

Frequency = 352.21 MHz
Power = 350 kW
3 dB Band-width = 200 kHz.
Pulse width = 3.5 ms
Pulse repetition rate = 14 Hz

RF amplifier at ESS specifications doesn't exist. Hence there is a need for prototyping it.

Also the superconducting spoke cavity for ESS Spoke Linac is being developed at IPN Orsay. It needs to be tested for high power.

Hence there is a need for High Power Test Stand. The ESS spoke cryomodule consists of two spoke cavities. Hence the test stand shall consist of two high power RF chains. A facility called FREIA is being built at Uppsala University to serve these purposes.

FREIA FACILITIES RELATED TO ESS

FREIA (Facility for Research and Instrumentation for Accelerators) is a facility being developed at Uppsala. First project of FREIA is High Power Test Stand for ESS superconducting Spoke Cavities (fig.1).

High Power Amplifier:

The various technologies of RF sources like tetrodes, solid state, IOTs and klystrons are compared [2] and Tetrode is finalized as the first high power amplifier for the first chain at FREIA.

Three Thales tetrodes TH781, TH391 and TH595 can serve the purpose.

Table 1: Comparison of Tetrodes

Specification	TH781	TH391	TH595
Maximum power at 352MHz	350kW	200kW	200kW
Efficiency	50 – 55%	> 65 %	> 65 %
Gain	11 dB	15 dB	15 dB
Cavity	Doesn't exist	Exist	Exist
Cooling	Water	Air	Water

The calculations show that TH781 can produce 350 kW at 352 MHz but at reduced gain and efficiency. Though TH391 offers improved gain and efficiency, it is air cooled, which allows anode dissipation of only 12 kW. Type of cooling will also affect the size of the system. Air cooling my lead to system with bigger size. TH595 is water cooled and hence it has higher anode dissipation of 40 kW, in addition the system will also be compact.

So 350kW power will be generated by combining outputs from the two tetrodes (TH595) which produce 175 kW each. Power combining will be achieved with help with the 3dB Hybrid coupler.

The specifications for Tetrode amplifier are:

Frequency = 352.21 MHz
Power = 175 kW
3 dB Band-width = 200 kHz.
Pulse width = 3.5 ms
Pulse repetition rate = 14 Hz
Gain > 15 dB
Efficiency > 65%

It is well known that gain of the tetrode reduces with aging. While calculating power needed from the pre-driver, this fact was taken into consideration, so gain of 13 dB is assumed and output power of predriver is 10 kW.

ISBN 978-3-95450-122-9

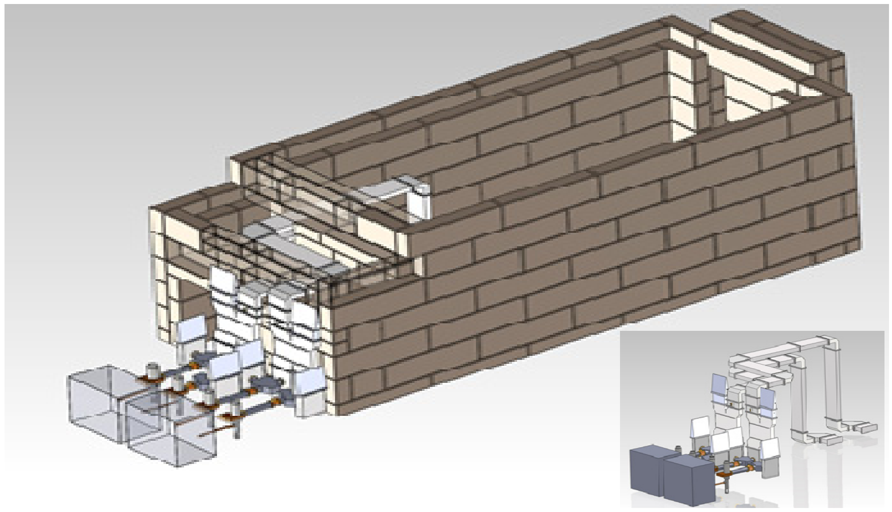

Figure 1: Model of bunker and high power RF chain for ESS spoke cryomodule with inset containing high power RF amplifier and RF distribution at FREIA.

TH595 characteristics [3] show that anode current more than 45 A is not permissible. Hence the tetrode can't be operated in deep class C mode. Hence the design suggests to operate it in class B, thus achieving low harmonic distortion than class C as well as more efficiency than class A.

The calculations show that there will be quicent current of 2 A flowing through the tetrode, which will lead to dissipation and hence decreased efficiency. To avoid this, control grid power supply will be modulated ie. it should be made more negative before and after the RF pulse to get nearly zero quicent current.

Power Supplies for Tetrode Amplifier

The Tetrode amplifier will need four power-supplies. Anode power supply (18kV, 18 A, average output power = 31 kW), screen-grid power-supply (1.3 kV, 0.7 A), control-grid power-supply (400 V, 0.7 A), filament power supply (8.8 V, 190 A rms). As there are two tetrodes in the first chain, it will need two sets of power-supplies.

Instead of using two anode power-supplies, a single anode power-supply powering both the tetrodes will be used, thus achieving lower cost and size [4]. Instead of crow-bar, series switch will be used for protection, thus increasing reliability of the system.

Pre-Amplifier

Solid state topology is chosen for the preamplifier. The amplifier will be modular. Each module provides more than 700W power. Each module has its own circulator. To avoid non-linearity, each module will be driven in class AB. To avoid power dissipation and hence to have high efficiency, a blanking signal is applied to the amplifier during absence of RF pulse. Power input to the preamplifier is given by signal generator.

Thus specifications of pre-driver are:

Frequency = 352.21 MHz
Power = 10 kW
3 dB Band-width = 200 kHz.
Pulse width = 3.5 ms
Pulse repetition rate = 14 Hz
Gain > 73 dB
Efficiency ≥ 50-55 %

RF Distribution

Basic layout of RF distribution is as shown in fig. 2.

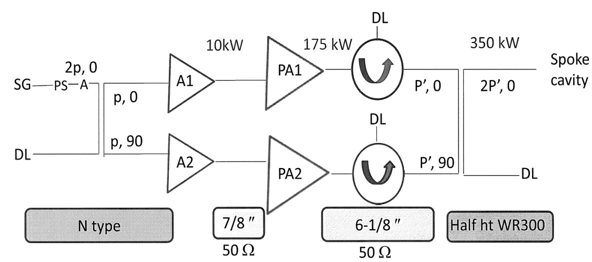

Figure 2: Schematic for high power RF layout for FREIA. SG: Signal generator, PS: Phase shifter, A:Attenuator DL: Dummy load, A1, A2: Preamplifier (352 MHz, 10 kW), PA1, PA2: High Power Amplifier (352 MHz, 175 kW)

Various types of RF distributions are studied. The RF distribution shown in (fig.2) is finalized considering space requirements, ease of handling and cost. Mainly three types of RF distribution are needed depending upon power level (fig. 1, fig. 2).

Peak power = 350 kW: Half height WR2300
Peak power = 175 kW: 6-1/8 inch, 50 Ω coaxial line
Peak power = 10 kW: 7/8 inch, 50 Ω coaxial line

He Liquifier and Cryostat

As the ESS spoke cavities are superconducting, it needs to be cooled down to 2 K . To achieve this, FREIA will have He liquefier with capacity of 100 lit./hour. It will also have horizontal cryostat for holding the Spoke cavities.

ISBN 978-3-95450-122-9

FREIA Bunker

Particles will not be injected in the spoke cavities during testing in the test stand. But cavities will be operated at high electric gradients, capable of generating X-rays. Thus there is requirement for the bunker. The bunker will be made up of Concrete blocks with iron. Simulations have been done to optimise thickness of the concrete block. Fig. 1 shows layout of the bunker.

FREIA hall will also have other facilities described in the next section.

FEATURES OF FREIA HALL

Following are the features of FREIA hall.

- $1000m^2$ hall
- Electrical input power = 1.2 MW
- Cooling capacity = 800 kW power
- Helium liquefier (> 70 l/h) with LN_2 precooling
- Distribution box to users
- Impure gas recovery from users
- RF amplifiers (two chains): 352 MHz, 350 kW
- RF distribution system
- Test cryostat vertical and horizontal
- Test bunkers.

SUMMARY

FREIA facility is being developed at Uppsala. The first project of FREIA is High Power Test Stand for ESS superconducting Spoke Cavities. It will serve two purposes i.e. prototyping of RF amplifier at ESS specifications and high power testing of superconducting spoke cavities of ESS. As cryomodule consists of two spoke cavities, the test stand will have two chains of RF amplifier (352 MHz, 350kW peak) and RF distribution. As the cavities are superconducting, He liquefier is needed.

Construction of FREIA hall will be completed by Q2 of 2013. The target is to complete installation of first amplifier chain, related RF distribution and liquefier by Q4 of 2013

REFERENCES

[1] S. Pegg, “Conceptual Design Report,” ESS-2012-001, 2012.
[2] R.Yogi et al, “Selection of RF power source and distribution scheme at 352 MHz for spoke cavities for ESS and at FREIA,” FREIA Report 2012/1, May 2012.
[3] Thales data sheet for TH595
[4] R.Wedberg et al., ‘Technical design report on power supplies for spoke cavities at FREIA’, FREIA Report 2012/2, May 2012.

ISBN 978-3-95450-122-9