Uppsala Test Facility Project Plan

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Abstract

Uppsala University and ESS AB are creating a test facility for the ESS spoke cavities and their RF systems at the FREIA laboratory, Uppsala. The test facility will serve for the prototyping of the RF power generation systems for the ESS single spoke cavities and for the high power testing of the prototype single spoke cavities and their cryomodule. This report describes the project plan for the Uppsala test facility.

1 Introduction

Uppsala University is currently creating the FREIA laboratory, a Facility for Research Instrumentation and Accelerator Development [1]. The laboratory is located in the new 1100 m² FREIA hall next to the Ångström laboratory. The FREIA laboratory will have a helium and nitrogen cryogenic facility, a horizontal and vertical test cryostat, RF power stations and concrete bunkers.

The first project for which the FREIA laboratory will be used is the high power testing of the RF source and prototype spoke cavity followed by the high power testing of a prototype spoke cryomodule for ESS. This project can be split in three phases: (1) test of the first RF source, (2) test of the prototype cavity and (3) test of the prototype cryomodule. Phase (3) requires the availability of a second RF source. During the ESS construction phase, the FREIA laboratory is available for the acceptance testing of the series spoke cryomodules before their installation into the accelerator.

The first RF power source with control and distribution equipment is scheduled to arrive begin 2014. The RF source will first be commissioned and tested using a water cooled load. The first prototype spoke cavity is expected to arrive mid 2014. It will be installed in the horizontal test cryostat and tested with an RF source at full power during the second half of 2014 and first half of 2015. The prototype spoke cryomodule is scheduled to arrive in mid 2015. It will be tested at high power during the second half of 2015 and the first half of 2016.
Thereafter FREIA is available for the acceptance testing of the series spoke cryomodules as they get delivered from the production line.

Below are given technical descriptions of the major components required for the ESS test program in Uppsala: the general infrastructure, RF equipment, the cryogenics and cryostat.

2 General Infrastructure

The new hall for the FREIA laboratory is available from 15th June 2013. The laboratory hall contains a separate compressor hall, a small workshop, a control room and several offices which are located at a mezzanine. Electric power, gas and fluid distribution systems are located around the walls. A sketch of the FREIA laboratory is shown in Figure 1.

The required test bunker will be built up from concrete blocks loaded with Magnetite to increase their weight density to 3900 kg/m$^3$ with increased stopping power for ionizing radiation. The bunker will have an internal volume 4 m wide by 9.6 m long and 4.8 m high. This will enable simultaneous installation of both the horizontal test cryostat and the prototype spoke cryomodule. The bunker will be constructed of a double layer of blocks. The required concrete blocks have been ordered and will be delivered starting August 2013. A delivery schedule is under discussion with the manufacturer to ensure that blocks are delivered according to the construction need.

3 RF Equipment

For the design and construction of the ESS linac there is a double interest in prototyping an RF power station for the spoke cavities and for prototyping the spoke cavities themselves at high power. Testing of the first prototype spoke cavity requires one single RF power station while testing of the prototype spoke cryomodule requires two RF power station. In addition there is an interest to prototype an RF power station based on existing and proven technology and an RF power station based on new state-of-the-art technology.

A tetrode based RF power station has been designed and subsequently ordered from a commercial supplier to be delivered begin 2014. The station will comply to the ESS parameters according to the 2012 baseline [2, 3]. Discussions with the supplier are ongoing to ensure that the RF power station can comply with the new 2013 parameters which are being studied by ESS.

A solid-state transistor based RF power station will be made available by another commercial partner and delivered end 2013. The station will comply to the ESS parameters according the 2012 baseline. In addition the supplier will try to ensure that the RF power station can comply with the new 2013 parameters which are being studied by ESS [3].

Both RF power stations will be commissioned in stand-alone operation to ensure correct operation and to verify that they comply with the ESS requirements. In addition soak testing is planned to study their long time reliability and understand their need and ease of maintenance. Then, both RF power stations will be tested with the prototype spoke cavity connected.

The RF testing requires a complete RF system consisting of LLRF controls, a high power RF station, RF distribution system and an RF load which is either a spoke cavity as shown
in Figure 2 or a water cooled load. The LLRF system generates the low power RF signal and adjusts the individual amplitude and phase to the spoke cavities. The LLRF also measures the field in the cavities and tunes the cavity frequency to adjust for the so-called Lorentz force detuning caused when the high power RF pulse starts filling the cavity volume. The LLRF system will be supplied by ESS together with the prototype spoke cavity.

Prototype and acceptance testing of the spoke cryomodules require addition of a second RF power amplifier and distribution chain. This will make it possible to power both cavities in a cryomodule simultaneously. The technology of the second chain will be decided upon after testing of the tetrode and solid-state based RF power stations.

4 Cryogenics and Cryostat

The cryogenic facility includes a helium liquefier, liquid and gas helium storage, liquid helium distribution valve box, impure helium gas recovery system and a liquid nitrogen distribution system. The layout of the facility is shown in figure 3. The requirement for the cryogenic facility is to deliver enough cooling power for testing two ESS cavities at the ESS parameters (full power, duty factory etc). The helium liquefier will have a peak power of 140 l/h LHe production. In addition there is a 2000 l storage dewar which is used as a buffer between

Figure 1: Interior layout of the FREIA hall.
Table 1: Maximum heat load capacity for which the horizontal test cryostat is designed. Note: LN\(_2\) = liquid nitrogen; LHe = liquid helium; GHe = gas helium; SHe = supercritical helium.

<table>
<thead>
<tr>
<th>T</th>
<th>Medium</th>
<th>4 K mode</th>
<th>2 K mode</th>
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<tr>
<td>80 K</td>
<td>LN(_2)</td>
<td>400 W</td>
<td>400 W</td>
</tr>
<tr>
<td>4 K</td>
<td>LHe</td>
<td>120 W</td>
<td>15 W</td>
</tr>
<tr>
<td>2 K</td>
<td>LHe</td>
<td>0</td>
<td>90 W</td>
</tr>
<tr>
<td>5–210 K</td>
<td>SHe</td>
<td>1050 W</td>
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liquefier and experiment. Thus, if a higher peak cooling power is required this can be delivered by the intermediate buffer.

The horizontal test cryostat, HNOSS (Horizontal Nugget for Operation of Superconducting Systems, in nordic mythology Hnoss is the daughter of Freia), is designed to fit two superconducting cavities of either ESS double spoke or ESS elliptical type. HNOSS consists of a horizontal vacuum vessel with a cryogenic valve box on top. The design aims to handle a peak heat load of 120 W at 4 K or 90 W at 2 K operation, see table 1 [4]. The thermal radiation screens are cooled by liquid nitrogen.

It is expected that an ESS double spoke cavity will have a dynamic heat load of 15 W at 2 K and an ESS elliptical high-beta cavity a dynamic heat load of 5.2 W at 2 K. The 2 K liquid helium flow is created inside the test cryostat. To provide 30 W cooling power for two spoke cavities requires a 1.5 g/s 2 K liquid helium flow. Including losses and accounting for

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**Figure 2:** Possible configuration option of RF equipment to power a superconducting spoke cavity.
Figure 3: Layout of the cryogenic facility including horizontal and vertical test cryostats.
gas helium in the 2-phase flow, we estimate that this requires a 2 times larger 2-phase flow from the 2 K cold box and a 1.5 times larger 2-phase flow from the 4 K liquefier cold box. The required liquefaction capacity is therefore 4.6 g/s at 4.4 K which is equivalent to 140 l/h. The 2000 l volume of the liquid helium storage dewar can serve as buffer to temporarily provide any additional required flow above the liquefier capacity. The storage dewar is replenished during periods with lower cooling flow requirements, e.g. when operating with only static thermal load or reduced dynamic load.

Prototype and acceptance testing of spoke cavities and cryomodules will require the measurement of static and dynamic heat load for future ESS reference. The dynamic heat load measurement can be used to determine the cavity Q-value.

5 Test Facility Project Plan

During the Fall 2013 and Spring 2014, the FREIA infrastructure will be installed and commissioned. Simultaneously the first two RF power stations, one based on tetrode and one based on solid-state technology, will be received and commissioned. Then by Summer 2014 the first prototype spoke cavity will arrive to be installed into the horizontal test cryostat. A one year time window is available for the installation of the cavity, commissioning of the

![Figure 4: Time line view of the project plan.](image)
test facility with cavity and testing of the prototype cavity. This includes testing of the first prototype LLRF system to be received together with the cavity. Then by Summer 2015 the facility will be ready to receive, install and start testing the first prototype spoke cryomodule.

At present (June 2013) 18 full and part time staff of Uppsala University are working for the FREIA laboratory and ESS project. This includes 2 professors, 6 researchers, 1 post-doc, 7 engineers and 2 administrative staff (economy and procurement). A cryogenics engineer will join during the Fall. The recruitment of additional staff is ongoing: contracts are soon to be signed with a post-doc, an RF engineer and a technician. Positions for two PhD students have been advertised.

During the ESS construction phase the FREIA facility is available for test of the complete spoke cryomodules. Testing of the prototype spoke cryomodule has already prepared the facility for the acceptance testing: RF systems have been extensively tested and the staff is familiar with installation and testing of a spoke cryomodule. The bunker is designed such that a cryomodule can be installed simultaneous with the horizontal cryostat leaving the possibility to continue tests on RF systems or a cavity. Cryomodules can enter the FREIA hall through the access door and work space between bunker and cryogenic plant. The bunker wall on that side can be opened to install the cryomodule.

References


