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THE NEW FREIA LABORATORY FOR ACCELERATOR DEVELOPMENT

R. Ruber, A.K. Bhattacharyya, D. Dancila, T. Ekelöf, K. Fransson, K. Gajewski, V.A. Goryashko, L. Hermansson, M. Jacewicz, T. Lofnes, M. Olvegaard, A. Rydberg, R. Santiago Kern, R. Wedberg, R. Yogi *, V. Ziemann
Uppsala University, Sweden

Abstract

The FREIA laboratory is a Facility for REsearch Instrumentation and Accelerator Development at Uppsala University, Sweden, constructed recently to develop and test accelerator components. Initially it will develop the RF system for the spoke cavities of the ESS linac and test prototype spoke cavities at nominal RF power. For this purpose we installed a helium liquefaction plant and will soon recieve a versatile horizontal test cryostat and two 352 MHz RF power stations, one based on two tetrodes and the other on solid state technology. Beyond these developments FREIA will house a neutron generator and plans for a THz FEL are under discussion. FREIA is embedded in the Ångström physics, chemistry and engineering campus at Uppsala in close proximity to mechanical workshops, clean room with electron microscopes, tandem accelerator and the biomedical center.

INTRODUCTION

Uppsala University has a long standing history of physics research with well known names as Anders Celsius and Anders Ångström in the 18th and 19th century and several Nobel Laureates in Physics during the 20th century. Theodore Svedberg, Nobel Laureate in 1926, initiated accelerator based research in Uppsala during the 1940s and construction of a 185 MeV cyclotron was completed in the early 1950s. During the 1980s the cyclotron was upgraded and a 1.36 GeV proton accelerator and storage ring, CELSIUS was constructed. The CELSIUS ring was closed down in 2006 while the cyclotron was kept open but is now mainly used for proton therapy and as irradiation facility for electronics testing.

Since 2006, the accelerator physics group at Uppsala University has been participating in the development of the CTF3/CLIC electron-positron collider, the FLASH and XFEL free-electron lasers and the European Spallation Source (ESS), concentrating on microwave (RF) power and instrumentation projects. With the 2009 decision to construct the ESS in Sweden, it was proposed to build a test stand for high power RF and superconducting cavities in Uppsala: The new FREIA Laboratory for accelerator and instrumentation development.

The new FREIA Laboratory has been designed and built around it first task to provide a test facility for superconducting spoke cavities and their high power RF systems. In addition it provides cryogenic fluids such as liquid helium and nitrogen to experimental groups at the university. The layout of FREIA is shown in Figure 1. The main equipment consists of HNOSS, a horizontal test cryostat, a helium liquefier, high power RF transmitters and several concrete bunkers. The infrastructure of FREIA has been designed to accomodate modest future extensions for other test facilities and experiments.

MAIN EQUIPMENT

The main resources of the FREIA Laboratory are its competent staff and a new set of state-of-the art equipment required for a superconducting accelerating cavity test stand: helium cryogenic system, test cryostat and RF power station.

Cryogenics

A Linde L140 liquefier has been installed delivering over 140 l/h of liquid helium into a 2000 l storage dewar. The storage dewar has 4 connections: one to fill mobile dewars and three with integrated cold valves to connect transfer lines to experiments. The helium gas recovery system includes a 100 m^3 gas balloon and three 27 m^3/h recovery compressors. A 20,000 l liquid nitrogen storage dewar, outside the building, provides the liquid nitrogen for the liquefier pre-cooling and also for the filling of mobile dewars. These installations were commissioned in March and since then the FREIA Laboratory has taken up the task to provide the cryogenics need for experiments all over the university. Details are described elsewhere [1].

Test Cryostats

FREIA has designed a versatile horizontal cryostat called HNOSS (Horizontal Nugget for operation of Superconduct-

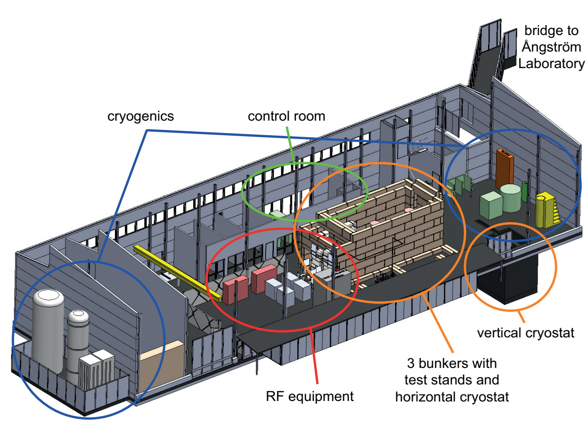

Figure 1: Layout of the FREIA Laboratory.

* presently at ESS

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ing Systems[1]) for test of superconducting accelerator cavities, magnets or other devices [1, 2]. The idea of HNOSS is based on HoBiCat and likewise it can accept two superconducting accelerating cavities simultaneously. Its dimensions, 3.2 m internal length by 1.3 m diameter, and access ports are designed to accomodate both TESLA type 1.3 GHz and ESS type 704 MHz elliptical cavities as well as ESS type 352 MHz double spoke resonators. HNOSS has an integrated internal magnetic shield and a valve box located on top as shown in Figure 2. The temperature operation range is down to 1.8 K with up to 100 W heat load. HNOSS is under construction in industry with delivery foreseen in August.

FREIA is planning to design and acquire a vertical cryostat in the near future.

To operate the test cryostats below the 4 K range of helium provided by the liquefier, a sub-atmospheric pumping station will be connected. To this end an integrated station with a set of roots and dry-pumps has been ordered with a flow capacity of 10 g/s at 200 mbar down to 3.2 g/s at 10 mbar (room temperature).

RF Equipment

As has been reported earlier [3], the technology and layout of the RF power stations have been chosen based on the requirements to test ESS type 352 MHz double spoke resonators: 400 kW peak power with 3.5 ms pulse length and 14 Hz repetition rate. Two stations are needed to power two spoke resonators inside a single cryostat simultaneously and individually. The first transmitter is ordered from industry [4]. Final integration has unfortunately been delayed due to external factors but delivery is still foreseen this year. The second transmitter will be ordered after commissioning of the first.

Both coaxial $6\frac{1}{8}$ inch and WR2300 half height waveguide lines will be used for the RF distribution. The coaxial line has enough margin for 400 kW peak power and is smaller than a waveguide line, but both are installed in order to test equipment for the ESS RF distribution.

[1] In Norse mythology, Hnoss is one of Freia's daughters.

Figure 2: The HNOSS horizontal test cryostat.

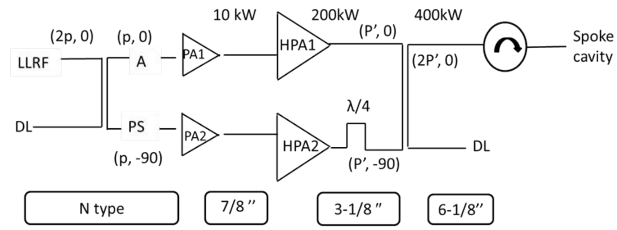

Figure 3: Layout of the RF power station.

Bunkers

Three concrete bunkers have been constructed for experiments producing ionizing radiation. The largest bunker has inner dimensions of 10.4 m length by 4 m width and 4.8 m height. It will be equipped with HNOSS. The walls are made of a double layer of 0.4 m thick magnetite-concrete blocks with a density of 3.9 ton/m^3 to prevent ionizing radiation in the public areas around the bunker. Of the two smaller bunkers, 4 m by 2.7 m internal dimensions, one will be equipped with a 14 MeV neutron generator, based on DT-reactions with a flux of 10^{10} neutrons/second, for instrument development and educational purposes. The second bunker is available for future experiment proposals.

MAIN PROJECTS

At present the main projects in the FREIA Laboratory are centered around the delopment of the ESS accelerator while a THz-FEL study has been started for the longer term future. Among the critical elements of the ESS proton accelerator are the superconducting accelerating cavities and their RF power stations. FREIA is concentrating on the spoke linac part of the accelerator and specifically on the development of the RF power station and high power test of the spoke resonators.

RF Power Station Development

A study has been done to investigate the technology choice for the spoke RF power stations. Considering the required RF power levels, reliability and availability in time for the FREIA test stand and ESS construction, a choice was made for tetrode vacuum tube amplifiers. The final choice was made for a TH595 type tetrode that can provide 200 kW peak power at 5% duty cycle [4]. A set of two tetrodes with individual solid-state pre-amplifiers is combined in a single RF power station, see Figure 3.

The FREIA RF power stations are prototypes and preseries for the ESS accelerator. After experience from the first RF power station has been gained during operation with superconducting spoke cavities, the design will be further optimized for use at ESS before ordering the second RF power station.

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Solid-state Amplifier and Combiner Development

In view of the increasing capabilities of solid-state transistors, we are working in-house to enhance the development of the technology for solid-state based RF power stations. We are optimizing the design of single transistor amplifier modules [5] and in addition developing methods for the RF power combination at the tens to hundreds of kW level [6].

With industry we are collaborating to develop and test a complete 352 MHz 400 kW peak solid-state based RF power station compatible with the needs for the ESS spoke linac. This includes volume size limitations which are important due to the need to install 26 RF power stations in the ESS RF gallery. A prototype station is being developed by industry based on commercial transistors with 1 kW peak power output and a three level RF power combination scheme.

Spoke Cavity and Cryomodule Development

The ESS accelerator will contain 26 double spoke resonators which are being developed by IPN Orsay [7]. The prototype spoke resonators will be tested first at the SupraTech vertical test stand at IPN Orsay. One resonator will be brought to FREIA where it will be tested in HNOSS. First at low power with a high-Q antenna to replicate vertical test stand results, then fully dressed with the high power coupler and tuning systems at nominal power. This testing programme will start towards the end of 2014.

The spoke resonators will be housed in pairs inside the spoke cryomodules also developed by IPN Orsay [8]. FREIA will test the prototype spoke cryomodule and valve box at nominal RF power. Both spoke resonators of the cryomodule will be powered simultaneously to investigate any cross talk, hence the need for multiple RF power stations. Figure 4 shows the installation of HNOSS and a cryomodule at FREIA.

Having the facilities and experience for the prototype spoke cryomodule testing, it is planned that the series spoke cryomodules for the ESS accelerator also will be tested at FREIA.

Accelerator and Test Stand Controls

Both FREIA and ESS have the need to develop control systems for their test stands and for the ESS accelerator.

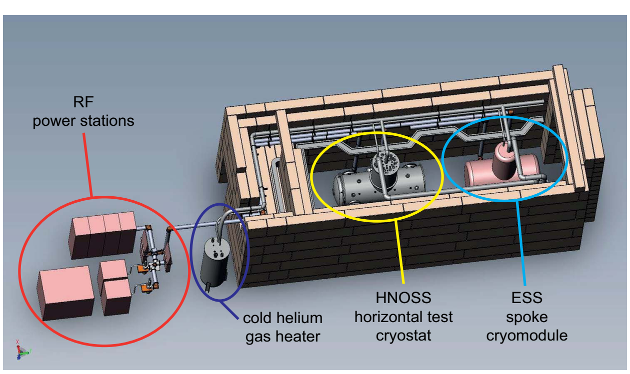

Figure 4: Layout of the spoke cavities test stand.

The FREIA controls are based on the EPICS standards with industrial PLCs, PXI and cRIO systems on the hardware side. The system will be adapted to be compatible with the developing software and hardware standards for the ESS Integrated Control System. This provides an early test bed for the ESS controls and offers the possibility to copy parts of the FREIA controls to the future ESS test stand and accelerator.

THz-FEL Development

The development and construction of the ESS spoke linac shall be completed by 2019. The FREIA facilities could then be used to accommodate a small CW electron accelerator based on two 352 MHz (spoke) superconducting accelerator cavities. Such an accelerator could reach 15 MeV sufficient to power a THz-FEL in combination with an X-ray source. Powerful THz pulses can excite low-frequency vibrations in biomolecules and induce charge carrier dynamics in nanoscale structures. A preliminary conceptual design has been studied [9] based on which a funding application has been submitted for a full conceptual design study.

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