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ScienceDirect

Physics Procedia 67 (2015) 791 – 795

Physics Procedia

25th International Cryogenic Engineering Conference and the International Cryogenic Materials Conference in 2014, ICEC 25–ICMC 2014

The ESS cryomodule test stand

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Abstract

The European Spallation Source (ESS) is an intergovernmental project building a multidisciplinary research laboratory based upon the world's most powerful neutron source to be built in Lund, Sweden. The ESS will use a linear accelerator which will deliver protons with 5 MW of power to the target at 2.0 GeV with a nominal current of 62.5 mA. The superconducting part of the linac consists of around 150 niobium cavities cooled with superfluid helium at 2 K. The majority of these cavities are of the elliptical type. They are grouped in cryomodules that hold 4 cavities each, with beam correction optics located between the cryomodules. A dedicated cryoplant will supply the cryomodules with single phase helium through an external cryogenic distribution line. Each of the 30 cryomodules containing elliptical cavities will undergo their site acceptance tests at the ESS cryomodule test stand in Lund. This test stand will use a dedicated 4.5 K cryoplant and warm sub-atmospheric compression to supply the 2 K helium as well as the 40/50 K shield cooling. A test bunker will accommodate one elliptical cavity cryomodule at a time and provide test capacities during both the installation phase as well as later during operation.

Peer-review under responsibility of the organizing committee of ICEC 25-ICMC 2014

Keywords: Helium, refrigeration; cryomodule; test stand; site acceptance test

1. Introduction

The European Spallation Source (ESS) is a world class neutron science facility currently under construction in Lund, Sweden, and will be the most powerful neutron source in the world, Eshraqi (2014). ESS is driven by a linear accelerator that produces a 5 MW beam of 2 GeV protons. Most of the acceleration is carried out by a

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Peer-review under responsibility of the organizing committee of ICEC 25-ICMC 2014
doi:10.1016/j.phpro.2015.06.134

superconducting linac that uses RF cavities operating at 2 K. The superconducting part of the linac consists of 146 niobium cavities cooled with superfluid helium at 2 K.

120 of the cavities are of the elliptical type and are grouped in cryomodules that hold 4 cavities each. Another 26 cavities are of the spoke type and are grouped in cryomodules that hold 2 cavities each. A dedicated cryoplant supplies the cryomodules with single-phase helium through an external cryogenic transfer line. Approximately 30 cryomodules containing elliptical cavities undergo their site acceptance tests (SAT) at the ESS cryomodule test stand in Lund. This test stand uses a 4.5 K cryoplant and warm sub-atmospheric compression to supply the 2 K helium. The test bunker and its RF equipment is suited for all elliptical-cavity cryomodules, providing testing capacity during both the installation phase and operation. The spoke cavity cryomodules will be tested at another test stand located at the University of Uppsala, Ruber et al. (2014).

2. The cryogenic supply for the test stand

The cryogenic system of ESS comprises three separate cryoplants, see Fig. 1 and Weisend et al. (2014). One plant for cooling of the superconducting cavities in the linac, one for cooling of the hydrogen in the neutron moderators of the target and one, named TICP, for the cooling of the cryomodules on the test stand as described here. The TICP will also provide liquid helium for neutron instruments and sample environments when ESS goes into operation as well as recover and purify the returned helium.

Although the use of the TICP for cryomodule testing is limited to a few years, this mode of operation dominates the capacity requirement and defines the plant design, see Table 1. The TICP will have the possibility to boost performance with liquid nitrogen pre-cooling but will probably be designed and optimized to reach the required performance without pre-cooling.

When used for testing cryomodules, the TICP coldbox is connected to the test stand by means of a helium shielded and vacuum insulated transfer line containing 4 process pipes. Furthermore, the coldbox will be connected to a liquid helium storage tank that can be used to support the cool-down of the cryomodules as well as buffering a reserve for the liquid helium delivery.

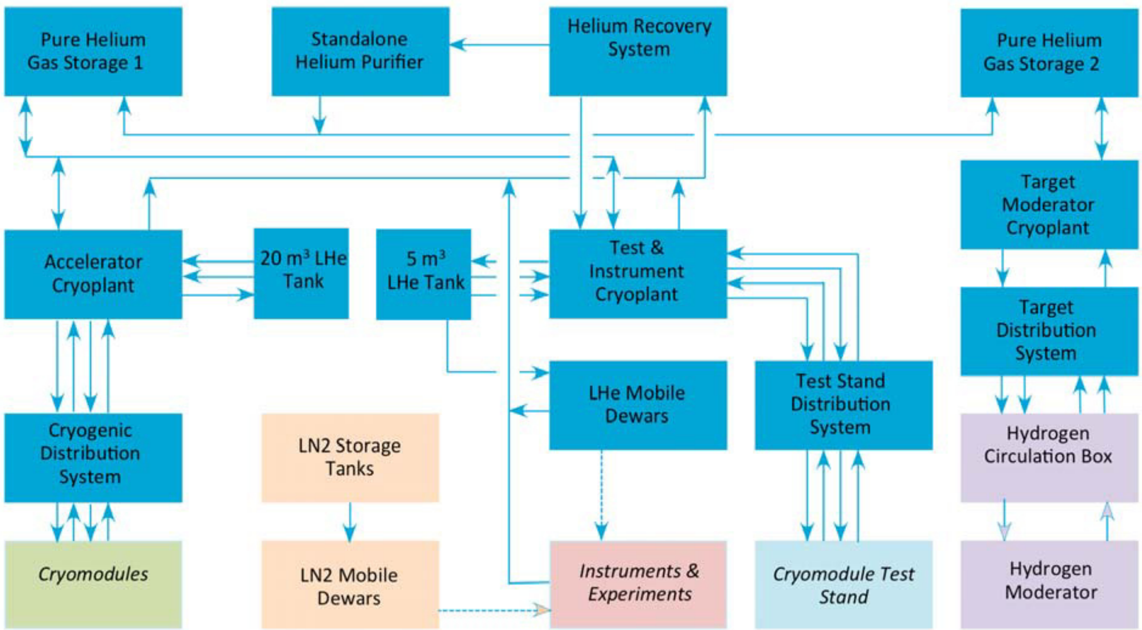

Fig. 1. Block diagram of the ESS cryogenic system, Arnold et al. (2014).

TABLE 1: Summary of heat loads for the test stand cryoplant. Values are based on predicted values for heat loads in the final tunnel installation, with the exception of the contribution of the proton beam, which is not present in the test stand. Safety- and operational margins are different from the linac cryoplant. The helium mass flow through the thermal shield (TS) as well as the exact temperature levels will be chosen by the cryoplant manufacturer, assuring an average shield temperature of ≤ 43 K.

Level	Heat load, W	Mass flow, g/s		Pressure, bar		Temperature, K	
		Supply	Return	Supply	Return	Supply	Return
2 K	76	**4.0**	**3.8**	**≥ 3**	**≤ 0.027**	**4.5**	6.0
4.5 K Liqu.	-		**0.2**	**≥ 3**	**1.05**	**4.5**	300
TS	**422**	tbd	tbd	**12.8**	**12.3**	**≥ 33**	**≤ 53**

Based on these requirements, the cryoplant is sized to provide 76 W at 2 K, 422 W at 40 K and 6 l/hr of liquefaction when it's operated in a mixed refrigeration/liquefaction mode. The plant is able to provide more than the required 7500 liters per month when operated in pure liquefaction mode. Due to the small 2 K load, sub-atmospheric pumping of the return helium from the cryomodule will be done by warm vacuum pumps rather than cold compressors.

The order for the TICP will be placed in May of 2015 which means that the plant will be fully commissioned in summer 2017 in time for the commissioning of the test stand and the first cryomodule tests by the end of 2017.

3. The ESS cryomodules

The elliptical cavity cryomodules come in two variants: medium-β and high-β with respective values for their geometrical β of 0.67 and 0.86, where beta is the ratio of the proton speed to the speed of light. The geometrical parameters have been set so that both types of elliptical cavity cryomodules are interchangeable. This reduces flexibility requirements for the test stand which now can be built to accommodate both medium-β and high-β cryomodules without major changes in waveguide arrangement and installations of other services.

The ESS elliptical cavity cryomodules are described in detail by Darve et al. (2014).

4. Test stand functions

The cryomodule test stand is a facility dedicated to the performance of the SAT of the elliptical cavity cryomodules. During these acceptance tests, a number of preparatory operations will be performed on the cryomodules as well. These operations include RF power coupler and cavity conditioning.

The test stand will also be used during operation of ESS to test cryomodules that have to undergo repair or maintenance outside the tunnel. The test stand also serves as part of an envisaged cryomodule R&D facility, at the disposal of colleagues from both within the organization as well as external labs.

The main purpose of the elliptical cavity cryomodule SATs is to verify the proper functioning of the series production cryomodules, to assess their performances and to condition their RF equipment in situ. Thus, both cryogenic and RF operability will be evaluated and key parameters of the cryomodules' subsystems, such as heat loads of the cryogenic components and resonant efficiencies of the RF components will be measured.

The test program includes the following steps:

- reception of the cryomodules at the ESS site & preparation for the test bench;
- installation on the test bench & initial testing;
- warm main power coupler conditioning & RF tests;
- cool down & cold main power coupler conditioning;
- cold low level RF tests & cold high power RF tests;
- cryogenic heat load measurements;
- warm up & disconnection from the test bench;
- preparation for storage and/or tunnel installation.

The RF tests at warm and cold conditions will go through a number of test sequences:

- Test of the main power coupler including re-conditioning of the coupler at full pulse length, measurement of RF properties of the coupler including external Q-factor and impedance as well as measurement of the thermal dynamics of the coupler and its static and dynamic heat losses;
- Basic RF tests of the cavities including measurement of the maximum accelerating gradient, X-ray emissions, dynamic RF losses, the cavities' quality factors, the Lorentz detuning and checking of the detuning compensation system, the piezo tuner's action on the cavity, such as adjustment of the cavity frequency and excitation of mechanical modes as well as the feed-forward system for compensation of the Lorentz detuning.

5. Test stand layout and test schedule

The cryomodule SATs are conducted in a bunker with walls that are designed to reduce radiation levels outside to an acceptable level. X-ray radiation produced during the tests originates in field emissions, which are in turn caused by the RF power fed to the cavities reacting to the presence of imperfections in and on the niobium cavity walls.

The tests require a constant flow of cold helium in order to maintain the cryomodules at their operating temperature. The test stand is therefore connected to TICP helium cryoplant through a transfer line. Fig. 2 shows the proposed layout of the test stand with the RF sources on the left and the bunker on the right. The TICP coldbox is located about 100 m from the test stand in the coldbox hall where all three ESS coldboxes are located. The TICP compressor is located in the compressor building, which is located about 50 m behind the coldbox hall.

A control room for both TICP and test stand operation is located in a building directly adjacent to the test stand area of the klystron hall. The cryomodules will arrive at ESS by truck and will be unloaded in a loading area next to the test stand area. The loading area, but not the test stand, is equipped with an overhead crane for handling the cryomodules.

The production schedule foresees delivery of the cryomodules at a rate of one per month for both the medium-β and the high-β variants. Testing will start in late 2017 with the arrival of the first medium-β cryomodule. There will be prolonged windows of 5 months for the first and 3 months for the second cryomodule, time needed for starting up of the test procedures and for devising adjustments of the production and testing of the cryomodules.

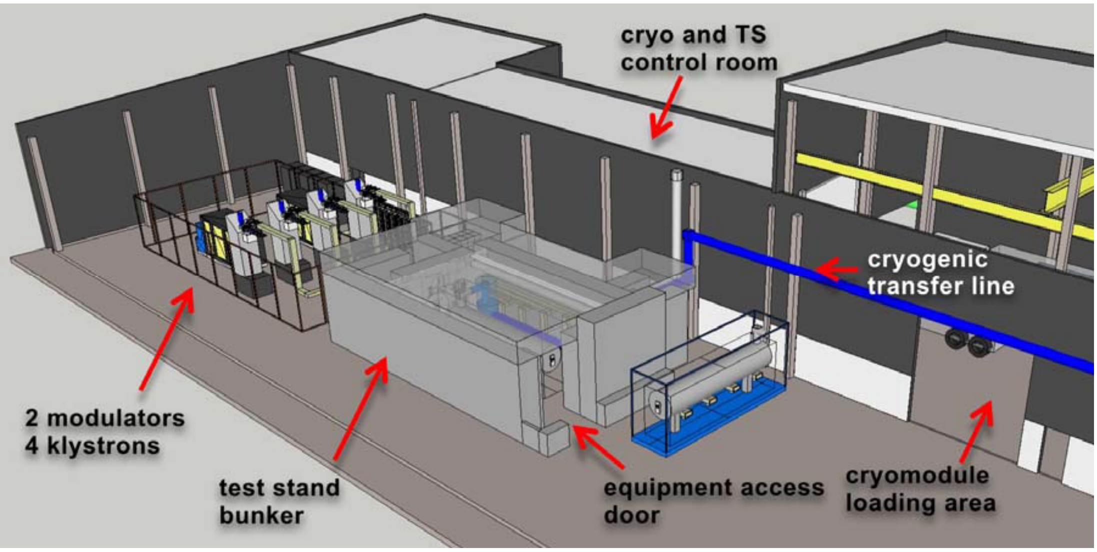

Figure 2. Proposed layout of the test stand, located in the contingency space of the ESS klystron building.

6. Outlook

The operation phase of ESS is scheduled to last for about 40 years. During this time, the test stand will be used for acceptance tests when a cryomodule needs to be replaced, or when new cryomodules are added. This should not happen with a significant frequency. So, during most of the time, the test stand will be available for other activities.

The vision is to make the test stand part of an SRF R&D facility which will be needed for repair and maintenance but can also serve the community to develop new, more efficient and possibly cheaper superconducting acceleration equipment. Such a facility is important for an facility of the size and importance of ESS, because the availability of third party labs cannot be guaranteed over its lifetime. Without on-site repair and maintenance facilities, downtimes can easily be prolonged significantly while waiting for access to the facilities of another lab.

Such an R&D facility is at this point, however, neither planned nor financed.

7. Conclusion

The ESS cryomodule test stand in Lund will be designed to accommodate the site acceptance tests of the elliptical cavity cryomodules of the ESS linac. The TICP cryoplant will supply the test stand with cryogenic cooling and adequate RF equipment will deliver the necessary power. During ESS operation, the test stand will be available for the repair and maintenance of cryomodules as well as occasional R&D activities.

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