THE ESS CRYOGENIC SYSTEM

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Abstract

The European Spallation Source (ESS) is a neutron science facility funded by a collaboration of 17 European countries currently under design and construction in Lund, Sweden. Cryogenic cooling is vital for large sections at ESS. Mainly there is a 2.0 GeV proton linac using superconducting RF cavities operating at 2 K.

In addition to cooling the SRF cavities, cryogenics is also used for the cold hydrogen moderator surrounding the target. ESS furthermore uses both liquid helium and liquid nitrogen in a number of the neutron instruments. There is also a cryogenic installation associated with the site acceptance testing of the ESS cryomodules [1].

This paper describes the conceptual design of the ESS cryogenic system including the expected heat loads and cryoplant features. Challenges associated with the required high reliability and turn-down capability will also be discussed.

OVERVIEW

The system comprises three independent helium refrigeration/liquefaction plants [2]: the Accelerator Cryoplant - ACCP, the Target Moderator Cryoplant – TMCP and the Test and Instruments Cryoplant - TICP. Fig. 1 is a block diagram of the ESS Cryogenic System. As the cryogenic consumers have very different technical requirements and schedule demands it was decided at an early stage to provide cryogenic cooling with three separate plants. Furthermore there will be an extensive cryogenic distribution system (CDS) connecting the cryoplants with their consumers.

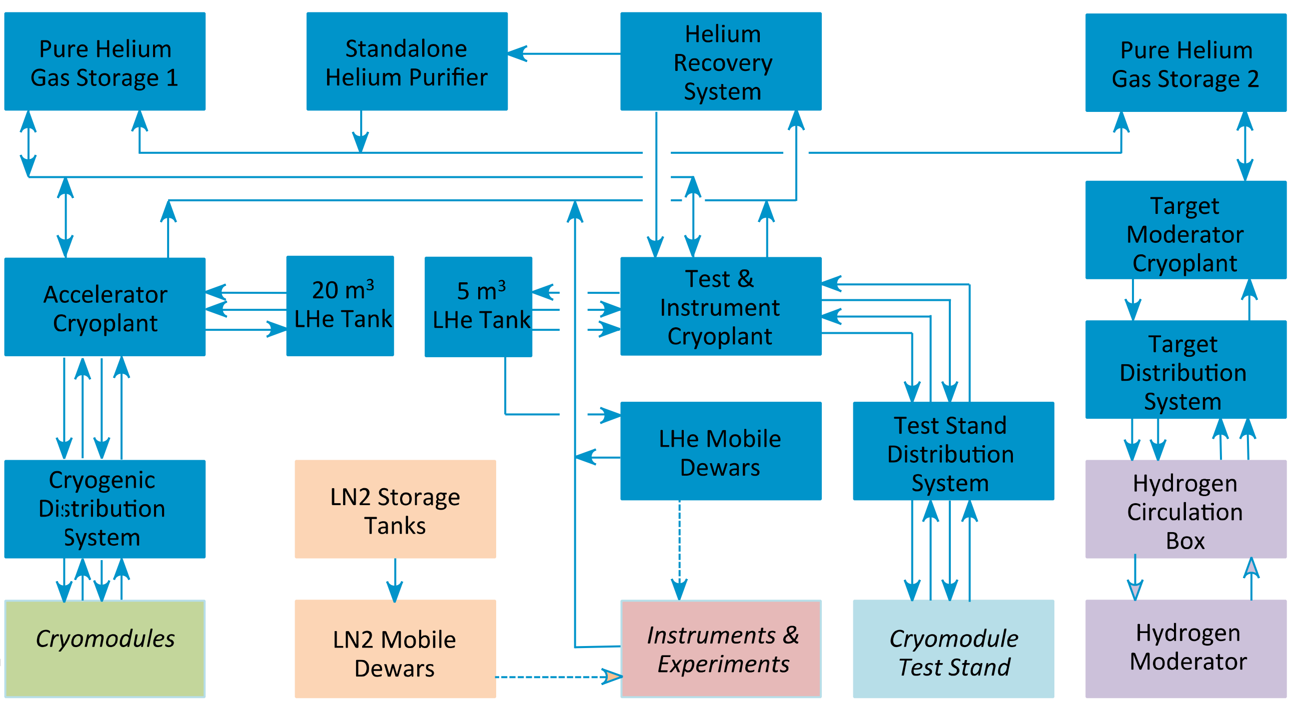

Figure 1: ESS Cryogenic System Block Diagram.

ACCELERATOR CRYOPLANT

The ACCP will provide cooling to the cryomodules in the linac. In the optimus+ design configuration the cold linac will contain 13 spoke cryomodules, 9 medium beta elliptical and 21 high beta elliptical cryomodules (Stage 1) [3]. In case the beam energy produced by these cryomodules turns out to be insufficient, up to 14 additional high beta cryomodules can be installed in the contingency space (Stage 2). The cryoplant will be designed to meet the heat load requirements of all 57 cryomodules, i.e. including the contingency modules, and the respective distribution system. It will also be designed to operate with high efficiency in other operation modes, particularly the nominal operation in the optimus+ design configuration. This will be achieved by preparing the cryoplant to operate in two configurations, namely stage 1 and stage 2. This is achieved by means of two sets of flow parts for cold rotating equipment and variable frequency drives in the warm compressor system. The heat loads that the ACCP shall be designed for are listed in Table 1.

Table 1: Accelerator Cryoplant Heat Loads

Operation modes		2 K Load, W Isothermal	2 K Load, W Non-isothermal	2 K Load, W Total	4.5 K Load 4.5 K, W Total	4.5 K Load Liquefaction, g/s	40-50 K, W Total
Stage 1 2019-2023	Nominal	1860	627	2478		6.8	8140
	Turndown	845	627	1472		6.8	8140
	Standby				1472	6.8	8140
	TS Standby	-	-	-	-	-	8140
	Maximal Liquefaction	Loads in standby mode plus maximum liquefaction rate at rising level into the storage tank					
Stage 2 2023-…	Nominal	2226	824	3050		9.0	10819
	Turndown	1166	824	1990		9.0	10819
	Standby				1990	9.0	10819
	TS Standby	-	-	-	-		10819
	Maximal Liquefaction	Loads in standby mode plus maximum liquefaction rate at rising level into the storage tank					

The cryogenic system will provide 4.5 K helium at a pressure of 0.3 MPa to each cryomodule. The actual production of 2 K helium will occur in the tunnel by means of a combination of a 2 K heat exchanger and a subsequent Joule-Thomson valve, which can be found in each of the cryomodule–valve box assemblies. The cavities will sit in a bath of saturated 2 K He II. The helium vapor with the corresponding saturation pressure of 3.1 kPa is warmed in the 2 K heat exchanger and by the static heat load in the transfer line before returning to the cryoplant. There, it will eventually be compressed by a combination of cold and warm compression stages in order to re-enter the main refrigeration process.

The other two cryogenic loads that the cryoplant has to supply – thermal shield cooling and liquefaction load for the cooling of the RF main power coupler – represent only 11% and 10% respectively of the plants total exergy. This load combination makes the use of liquid nitrogen pre-cooling less attractive. Hence only expansion turbines will provide the cryogenic refrigeration in the ACCP.

ESS has committed itself to be a green facility and the cryogenic system, being one of the heavy energy users, supports the approach of serious energy consciousness. The most important measure in this regard is to match the cryoplants refrigeration capacity optimally with the linacs load requirements. Load adaption will be managed by means of medium and high pressure adjustment, impacting the plants helium inventory and thus compressor and turbine power, as well as by means of the variable frequency drive(s) in the low pressure stage. A second approach for using energy efficiently is to recover heat from the cooling water. For this purpose the compressors oil and helium coolers shall be designed to minimize the temperature differences between cooling and warming flows, i.e. a possibly high temperature spread with consequentially lower cooling water flows.

High reliability is another central requirement, demanding thorough examination of the process design concept, installed components, redundancies and spares.

TEST AND INSTRUMENTS CRYOPLANT

The TICP comprises, besides coldbox and compressor system, also the infrastructure for filling liquid helium in mobile dewars, recovering warm helium from the consumers, re-compress, purify and store helium, i.e. to operate as liquefaction and recovery plant in an open loop. The neutron instruments and sample environments are expected to consume about 5000 litres of liquid helium per month.

For the first couple of years the TICP will almost exclusively operate to support the elliptical cryomodule test stand. The load requirements in this operation mode – 76 W isothermal at 2 K for the cavity cooling, 422 W at 40-50 K for the thermal shield and 0.2 g/s liquefaction load for the power coupler cooling – define the design of the system. The safety factors for the specified heat loads are substantially higher for the TICP compared to the ACCP as by definition this plant is a test plant and higher loads on some of the cryomodules can be expected in contrast to the average load of all cryomodules in the linac. Nevertheless, the returning sub-atmospheric vapor flow is not high enough to justify cryogenic compression as in the ACCP. Warm process vacuum pumps will compress the vapor after electrical heating to the suction pressure of the recycle compressor. During most of the test periods the TICP will operate in a closed loop. For the given functionality and loads the TICP is expected to fit in the standard series of the typical cryoplant vendors but needs nevertheless to be customized.

The TICP recycle compressor has the additional function of recovering helium from the cryomodules in the linac in case of a longer power shutdown. This

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compressor will hence be connected to the power backup system.

TARGET MODERATOR CRYOPLANT

The majority of ESS' users require lower energy neutrons than those created by the spallation process. For this purpose the neutrons will be slowed down by means of a supercritical hydrogen moderator. This supercritical hydrogen will be re-cooled via heat exchangers in the hydrogen circulator coldbox against supercritical helium, which warms up from 16.5 K to 19.5 K. The actual heat load is not yet defined but expected to be in the range of 20 kW. This significant load at a rather small temperature difference translates to a high helium mass flow. In order to enable a compact and efficient plant design the helium shall be looped through the helium– hydrogen heat exchangers as illustrated in Fig. 2. In this way the helium flow is cut in half and processed most efficiently. The second expansion turbine shall be situated either in the hydrogen circulator box or in a helium satellite box just next to the hydrogen box in the target building.

For optimal energy conservation the load adaption and compressor cooling system will follow the same approaches as the ACCP.

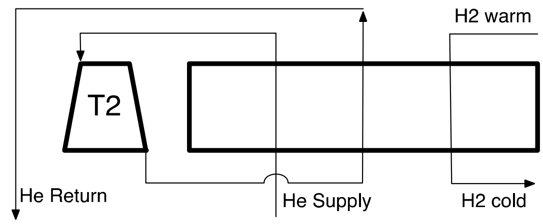

Figure 2: He-H2 Heat exchanger arrangement.

CRYODISTRIBUTION SYSTEM

All coldboxes, liquid helium storage tank, mobile dewar filling station and some auxiliary cryogenic equipment will be located in the ESS coldbox building as shown in a conceptual sketch in Fig. 3. As the cryogenic consumers are located several hundred meters away from the providers they have to be connected by means of an extensive cryodistribution system. While the distribution system may consist of rather simple transfer lines in the case of the target moderator cooling, it consists of a transfer line studded with a number of sophisticated valves boxes, one for each cryomodule, in case of the cold linac. A conceptual design drawing of one valve box – transfer line section can be found in [4]. The valve box-cryomodule assembly design permits equipment standardization and individual as well as integrated cool-down / warm-up of single cryomodules.

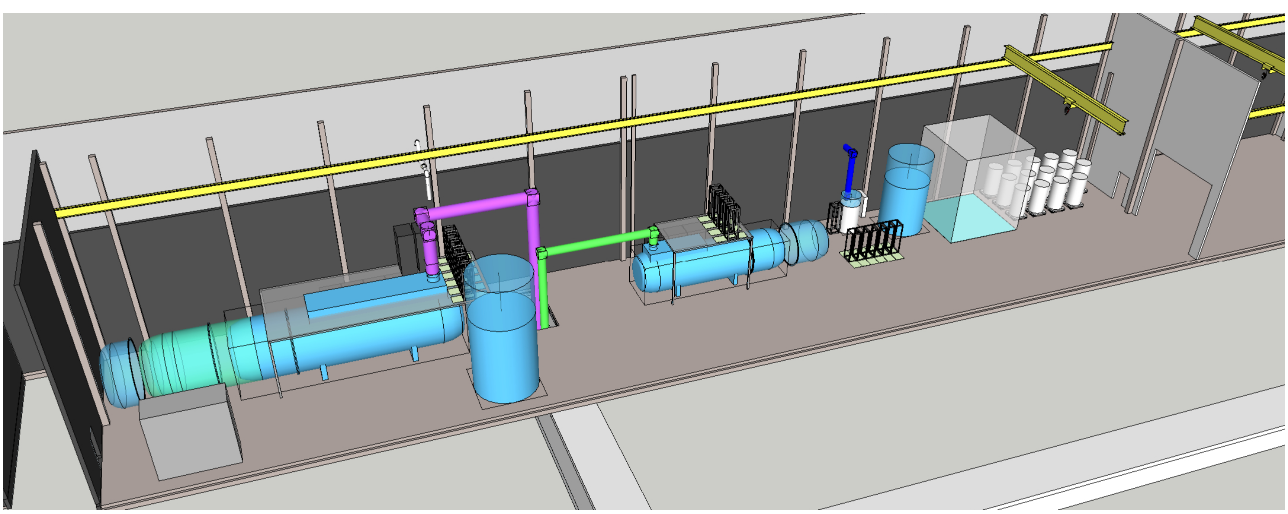

Figure 3: Conceptual layout of ESS' coldbox building; from left to right: ACCP, 20m^3 LHe tank, TMCP, TICP, 5m^3 LHe tank, LHe dewar filling station.

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