THE ACCELERATOR CRYOPLANT AT ESS

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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 particularly for the linear accelerator, producing a 5 MW beam of 2.0 GeV protons to strike a rotating tungsten target. [1] The cryogenic section of the linac comprises cryomodules with superconducting RF cavities that require helium cooling at 2.0 K, shield cooling at ~40 K and liquid helium for power coupler cooling. An extensive cryogenic distribution system connects the cryomodules with the linac cryoplant. With estimated electricity consumption of up to 3 MW this plant will be one of the major power consumers at ESS. Turndown modes and the intrinsic uncertainties regarding heat loads drive the need for high plant efficiency not only during full load operation but also at reduced performance. Together with flexibility and reliability over a long operation period these are the key challenges that will be addressed in this paper.

CRYOPLANT SET-UP

The Accelerator Cryoplant (ACCP) is split into a warm and a cold section, located in the ACCP compressor building and the coldbox building respectively. The ACCP interfaces an extensive cryodistribution system (CDS) that comprises one valve box including a 2K heat exchanger per connected cryomodule.

The simplified block diagram in Figure 1 shows the main components of the ACCP, consisting primarily of

- The warm compressor station circulating helium at the flows and pressures required by the ACCP cold section,
- Helium gas treatment comprising bulk and final oil removal and a gas dryer,
- Gas management panel for process control,
- One coldbox containing all required equipment to provide the specified cooling,
- An ambient heater to assist warm-up of the system or the cool-down of single cryomodules.

The above-mentioned equipment forms part of one single procurement by ESS. All other equipment required to run the ACCP, particularly warm helium storage, a liquid helium (LHe) storage tank, the CDS or the recovery system will be separate procurements or in-kind contributions to ESS.

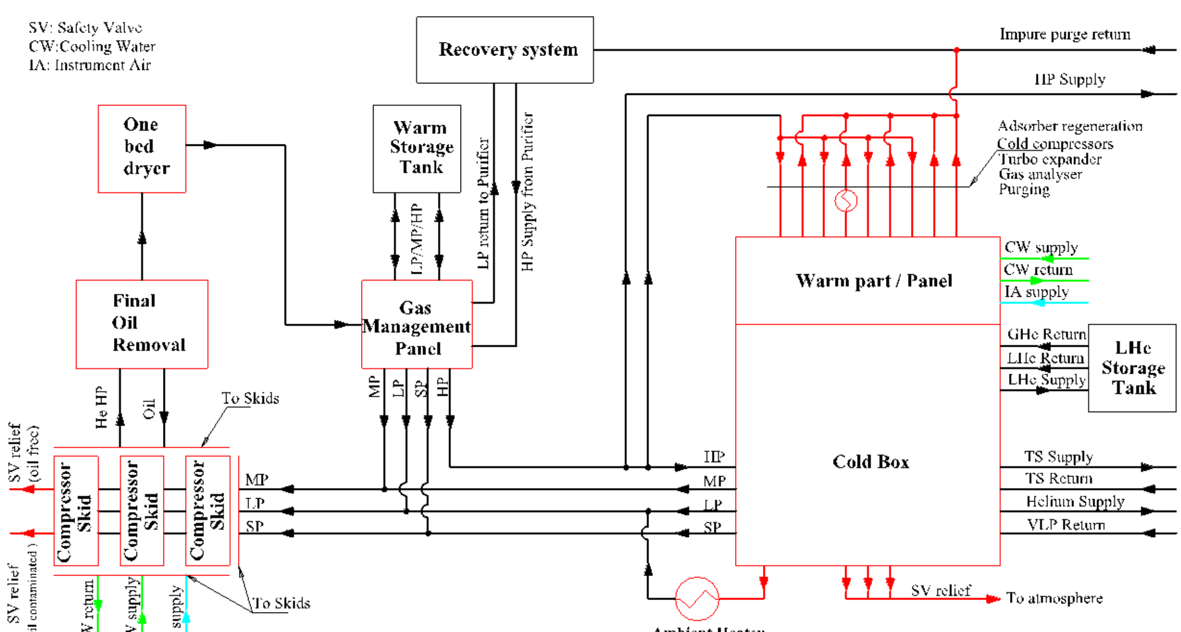

Figure 1: Simplified Block Diagram of the ACCP

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CRYOGENIC LOAD REQUIREMENTS

The ACCP provides cooling for the cryomodules (CMs) and the CDS. The predicted heat loads are multiplied by a set of safety factors [2] for specifying the ACCP load requirements according to the equation

$$Q = F_o(F_{ud}Q_d + F_{us}Q_s), \text{ where}$$

Q is the helium liquefaction capacity or heat load in the respective temperature level

F_o =1.15 is operational safety factor for plant degradation

F_{ud} = 1 is the safety factor for the dynamic load of the cavities (Q_d was determined sufficiently conservative to permit the safety factor to be 1 only)

Q_d is the dynamic load of the cavities and the beam losses

F_{us} =1.5 for the cryomodules and 1.3 for the CDS respectively, the safety factor for the static heat load

Q_s is the static heat load, i.e. heat conduction and radiation from the warm to the cold parts of the system

In the current design configuration, called optimus+, the cold linac will contain 13 spoke CMs, 9 medium beta elliptical and 21 high beta elliptical CMs (Stage 1) [3]. In case the beam energy produced by these CMs turns out to be insufficient, up to 14 additional high beta CMs can be installed in the contingency space (Stage 2). The cryoplant will be designed to meet the heat load requirements of all 57 CMs, i.e. including the contingency modules, and the respective distribution system.

The ACCP shall also be designed to operate efficiently when there is no beam, i.e. only the static heat load is imposed on the system. This operation is defined as Turndown. Furthermore there shall be a Standby mode, when the ACCP provides the static 2K loads at 4.5K, a mode when only the thermal shield is activated and a mode that provides 4.5K standby load plus maximal liquefaction. These operation modes shall be used for different intermediate operation, maintenance or failure scenarios and provide maximal operational flexibility. 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			4.5 K Load		40-50 K, W
		Isothermal	Non-isothermal	Total	4.5 K, W Total	Liquefaction, g/s	Total
Stage 1 2019-2023	Nominal	1860	627	2478		6.8	8551
	Turndown	845	627	1472		6.8	8551
	Standby				1472	6.8	8551
	TS Standby	-	-	-	-	-	8551
	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	11380
	Turndown	1166	824	1990		9.0	11380
	Standby				1990	9.0	11380
	TS Standby	-	-	-	-		11380
	Maximal Liquefaction	Loads in standby mode plus maximum liquefaction rate at rising level into the storage tank					

PROJECT STAGES

The different groups of CMs, spoke, medium beta and high beta CMs, will be installed and commissioned stepwise in the tunnel, starting with the first group in 2019. Not before 2023 all CMs of the optimus+ design configuration shall be installed which translates to a more or less extreme part-load requirement for the ACCP over several years.

In order to achieve stable and efficient operation the cryoplant shall be prepared to operate in two configurations, namely stage 1 and stage 2. This is realized by means of two sets of flow parts for cold rotating equipment, turbine expanders and cold turbo compressors, and variable frequency drives in the warm compressor system. The ratio between the stage 2 installed 2K load and stage 1 turndown 2K load is 48%. In case not all safety factors are required the ratio reduces even to 30%. As this turndown ratio can hardly be handled by the cryoplant in an efficient manner the relatively simple configuration with two sets of flow parts provides a good additional load adjustment possibility and has advantages in the spare strategy. The variable frequency control for one or more low pressure (LP) compressor, for one or more sub-atmospheric pressure (SP) compressor and the cold compressors provide efficient plant adaption also in all intermediate modes.

DESIGN CHOICES

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. This kind of set-up permits independent warm-up / maintenance /

cool-down of single cryomodules while the rest of the system is maintained in cold condition. The helium vapor with the corresponding saturation pressure of 3.1 kPa is warmed in the 2 K heat exchanger and by static heat load in the CDS before returning to the cryoplant. There, a combination of cold and warm compression stages ensures high flexibility regarding load adaption at optimal efficiency. Industry studies have shown that this concept and the decision to use one integrated coldbox for all cold ACCP components provide highest space and investment cost saving.

The ACCP shall be designed for operating without using liquid nitrogen pre-cooling as the load is dominated by 2K refrigeration. The other two cryogenic loads that the cryoplant has to supply – thermal shield cooling and liquefaction load for cooling 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 as performance boosting with LN2 pre-cooling is very moderate in this load regime. The very thin walled cavities result in a relatively low cold mass of only 20 tons for the whole accelerator [4]. Hence cool-down is not a big issue and LN2 support not required. Only expansion turbines will provide the cryogenic refrigeration in the ACCP, increasing reliability, capital cost saving and traffic reduction.

The ACCP control system will be based on local PLCs for internal, time critical and deterministic control loops and safety functions. Supervisory controls and high level batch operations shall run in the EPICS process controller. The HMI on local screens as well as in the control room, alarm handling and data archiving will all be based on EPICS. This functional split between local PLCs and EPICS IOC provides safe operation even in case the EPICS IOC shuts down, while the ACCP control system is compatible with the other linac control, providing all advantages of an open control system.

The ACCP compressor system is one of the heavy energy users at ESS. Apart from the already mentioned focus on matching the cryoplants refrigeration capacity optimally with the linacs load requirements a second approach for using energy efficiently is to recover heat from the cooling water [5]. For this purpose the compressors oil and helium coolers shall be designed to minimize the temperature differences between cooling and warming flows. The cooling water flow to the single coolers will be controlled primarily to achieve the required helium and oil outlet temperatures but secondary also to achieve a preferably high temperature spread between inlet and outlet of the cooling water. Besides reducing the required cooling water flow the water returns at elevated temperatures, enabling efficient heat recovery to serve Lunds district heating system and other potential greenhouse applications.

EVALUATION CRITERIA

The ESS will award the contract to the bidder presenting the economically most advantageous tender, which includes considerations of capital cost (30 scores), operational cost (30 scores) and qualitative aspects (40 scores).

The operational cost is calculated using the indicated electrical power consumption of the warm compression system in a pre-defined operational regime, comprising a mix of full and part load cases. The indicated consumption will be subject to a bonus and penalty regulation in the future site acceptance tests to prevent over-optimistic energy consumption estimates in the bidding phase.

In the qualitative tender evaluation scores are distributed to a number of well-defined criteria as compliance to the technical specification, simplicity of design and plant layout, control strategy. Also the plants liquefaction capacity and offered additional features are taken into account.

A very important issue for ESS is the availability of the ACCP. By assessing the plant concept, layout and equipment and the number of cold and hot spares ESS engineers estimate the plants availability of the different offers. An essential role plays also the recovery time from a trip of rotating machinery. The bidders are therefore requested to submit preliminary descriptions of failure scenarios and mitigation strategies along with assumptions on how long it takes to resume normal operation after a trip of rotating machinery without damage.

SUMMARY

The ACCP specification has been released in June 2014 including the requirements, design decisions and evaluation criteria as described in this paper. Contract award is expected in the beginning of 2015.

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