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CRYOGENIC INFRASTRUCTURE FOR THE MAINZ ENERGY-RECOVERING SUPERCONDUCTING ACCELERATOR (MESA)*

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Abstract

The 'Mainz Energy-Recovering Superconducting Accelerator' (MESA), currently under construction at the Institute of Nuclear Physics, Johannes Gutenberg University Mainz, Germany, requires a cryogenic infrastructure for its superconducting components. Prior to the start of the project, a helium liquefier was purchased that is capable of supplying the existing infrastructure of the Institute for Nuclear Physics, as well as the SRF test facility of the Helmholtz Institute. The liquefier has already been purchased in such a way that nitrogen pre-cooling can be integrated and can be upgraded for the operation of MESA. In addition to the superconducting accelerator modules, all components of the P2 experiment, i.e. solenoid, target and polarimeter (Hydromøller), must also be supplied with liquid helium. Therefore, besides the upgrade of the liquefier, it is necessary to extend the system with a dedicated cryogenic supply for the P2 target. This paper presents the current status of the cryogenic supply of the MESA accelerator, the future modifications and additions.

GENERAL OVERVIEW OVER THE CRYOGENIC INFRASTRUCTURE FOR MESA

The MESA accelerator ('Mainz Energy-Recovering Superconducting Accelerator'), which is currently under construction, has several cryogenic components that need to be integrated into an existing cryogenic circuit. The existing circuit previously served experiments by Dewar filling and the test stand for SRF research at the Helmholtz-Insititut Mainz by a 200 m transfer line [1]. These consumers, as well as the new MESA components, must continue to be supplied after the upgrade.

General Layout of MESA

Figure 1 illustrates the MESA layout. The cryogenic elements to be supplied are marked. MESA is designed as an energy-recovering linear accelerator. A normal conducting pre-accelerator injects a 5 MeV electron beam into the main accelerator. Two superconducting accelerator modules of the ELBE/Rossendorf type [2] provide the acceleration and deceleration in the recirculating main accelerator. MESA serves three experiments to precisely measure the limits of the standard model, MAGIX [3], darkMESA (BDX) [4] and P2 [5]. From these, only the P2-experiment needs to to be integrated into the cryogenic cycle containing three elements to be cooled.

First, the superconducting solenoid of the experiment will be cooled by liquid Helium, which comes from the MESA cryoplant. In addition, since the measurement uncertainty of the experiment includes the measurement uncertainty of the spin polarisation of the electron beam, a high-precision cryogenic Møller polarimeter (Hydromøller) [6] was forseen, which demands liquid Helium for cooling as well. Due to the sanctions imposed by the Federal Republic of Germany on Russian suppliers, it is currently impossible to continue the project. Therefore, a conventional Møller polarimeter that does not require a cryogenic supply is to be provided in the first expansion stage of the accelerator. For later upgrades, however, the possibility to upgrade the circuit to supply the Hydromøller with liquid helium has to be considered.

The third device of P2 to be cooled is the liquid Hydrogen target. This target will be cooled by gaseous Helium of a temperature of 15 K coming from an additional cryoplant which does not affect the amount of liquid Helium needed for the accelerator. Nevertheless, this additional circuit needs to be taken into account for the planning of the cryogenic piping under limited space constraints.

MESA can be operated in two modes. In the energy-recovering mode, the electron beam is recirculated up to two times to a beam energy of up to 105 MeV and then sent into the internal target MAGIX. After the interaction with the experiment, the non-interacted part of the electron beam will return to the main accelerator and decelerated via a phase shift of 180° in order to recuperate the energy for the accelerating beam.

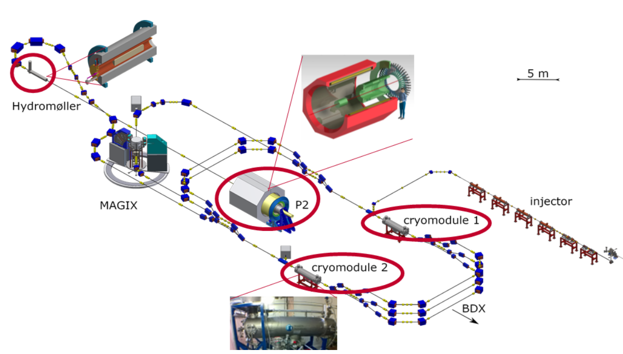

Figure 1: Lattice of MESA. The recirculating main linac is fed by a normal conducting injector. The main accelerator is driven by two superconducting ELBE-/Rossendorf-type cryomodules. The accelerator will serve three experiments, MAGIX, P2 and BDX (darkMESA). Only P2 will have cryogenic components, namely a solenoid and a hydrogen target.

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In the external mode, the beam is recirculated up tothree times in the main accelerator to a beam energy of up to 155 MeV and then directed to the P2- and darkMESA-experiments. The darkMESA-experiment is a beam dump experiment and uses the beam of the P2-experiment to collect data; it does not need exclusive beam time of the accelerator. Details of the accelerator and its experiments can be found in [3–8].

CRYOGENIC CIRCUIT

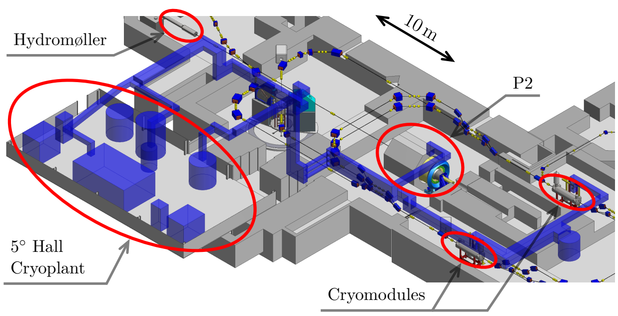

Figure 2: Layout of the cryogenic infrastructure of the accelerator. The envelopes of the cryogenic components are shown in transparent blue. The cryoplant hall with the two cryoplants, the subatmospheric compressor and the distribution is located at ground level. The components that have to be cooled are in the accelerator hall ten meters below [7].

MESA's cryogenic cycle is distributed over two halls. The cryoplant hall is located ten meters above the accelerator on ground floor level. Figure 2 shows the positioning of the individual components. The envelopes of the individual components and the lines are shown in blue. The total demand of liquid Helium and Nitrogen mass flows for cooling the devices have been evaluated mainly through measurements on the cryomodule performance [2] and adds up to at least 207.1 L h^{-1} and 16.6 L h^{-1} respectively. An additional margin of these quantities needs to be considered for the distribution system including valve boxes described in this paper. The existing distribution valve box alone needs an additional 35 L h^{-1} of liquid helium, which drives the consumption of the whole system close to the 250 L h^{-1} limit of the existing cryoplant. Table 1 sums up the required coolant mass flows.

Table 1: The estimated cooling demand of the MESA components. The existing valve box for the LHe-distribution needs an additional 35 L h^{-1} of liquid Helium.

Component	**Massflow LHe at 4.5 K**	**Massflow LN2 at 77 K**
cryomodule system	187.1 L h^{-1}	12.5 L h^{-1}
Hydromøller	9.0 L h^{-1}	unkown
P2-Solenoid	11.0 L h^{-1}	4.1 L h^{-1}
Total	207.1 L h^{-1}	16.6 L h^{-1}

Since parts of the previous halls of the MAMI accelerator are used for MESA, both the pipe routing and the positioning of the individual components have to be adapted to existing structural conditions. For example, the transfer lines have to be routed through the existing halls and intake shaft without impeding the usability of these. In addition, due to the statics of the existing building, limitations on the size and the position of the intake holes have to be considered.

Figure 3 shows the process flow diagram for the circuit of the accelerator. The helium liquefier supplies the already existing infrastructure of the Helmholtz Institute Mainz (HIM) and MESA with a distribution valve box from a 5000 L dewar. Since the cryomodules are operated at 1.8 K, a subatmospheric compressor system will be installed in the cryoplant hall to generate the necessary helium pressure of 16 mbar.

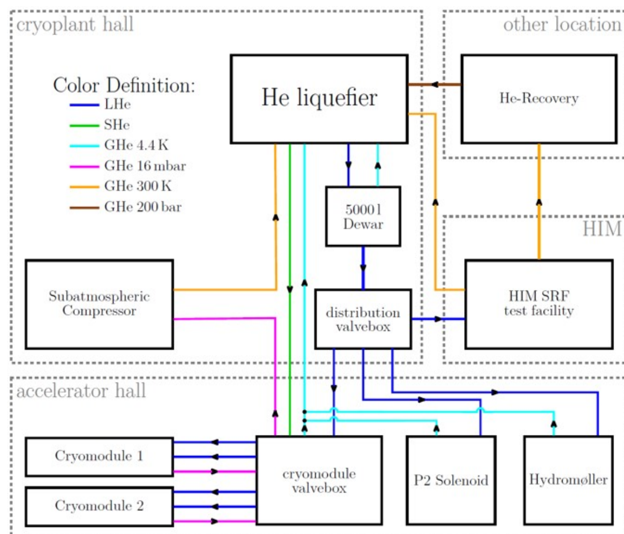

Figure 3: Process flow diagram of the cryogenic circuit for MESA. While the liquefier has also to serve other users, e. g. the HIM SRF test facility, MESA will be the main user. The cryogenic components in the accelerator hall will be fed by the existing but modfied helium liquefier. The 16 mbar pressure for the 1.8 K circuit in the cryomodules will be generated by the subatmospheric compressor system.

CRYOGENIC COMPONENTS

Helium Liquefier MESA

The existing helium liquefier is a L280 liquefier by Linde with an integrated helium purifier, which has been prepared for nitrogen pre-cooling. Currently, the liquefier produces 140 L h^{-1} of 4.5 K helium without nitrogen pre-cooling. To enable nitrogen pre-cooling in the L280, the necessary liquid nitrogen infrastructure has to be installed and the turbines liquefier has to be exchanged. To meet the MESA requirements of at least 210 L h^{-1}, the liquefier needs to be upgraded to an output of 250 L h^{-1}. In addition the liquefier has to be upgraded for closed loop operation. For this purpose, an internal 80 K-adsorber and nitrogen pre-cooling will be

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retrofitted and the turbines will be adapted for the new working point.

Helium Refrigerator P2-Target

The refrigerator for the P2-target is designed for a Helium temperature of 15 K and is a stand-alone system. A combination system for MESA and the P2-target was reviewed and could not be implemented due to administrative issues. The refrigerator is used to cool the Hydrogen target of the experiment and is designed for a cooling capacity of 4200 W at a mass flow of up to 250 g s^{-1}; it is currently under procurement [5].

Distribution Valve Box

The distribution valve box supplies the SRF test facility, the cryomodule valve box, the P2 solenoid and the Hydrømøller with liquid helium. The currently existing valve box with three cold valves has too few branches to supply the MESA accelerator and the existing infrastructures. Since the heat loss in the distribution valve box is rather high with 23 W, a new distribution valve box with more branches and less heat influx has to be procured to free up additional liquid helium capacity and supply the existing infrastructure.

Subatmospheric Compressor

The subatmospheric compressor station consists of two strings, each with four dry Root pumps and a screw compressor with a total pumping capacity of 8 g s^{-1} at 16 mbar. An identical single string system was successfully tested at the HIM SRF test facility which was used for the acceptance tests of the MESA cryomodules [1]. The system is already ordered and will be installed by the end of 2022.

Cryogenic Lines

Due to the limited margin in the condensing capacity and the length of the transfer lines of up to 80 m, the heat input into the transfer lines must be minimized. A maximum heat input of 0.01 W m^{-1} is specified. To achieve this, well insulated multi-channel transfer lines with an LN2 shield, a vacuum shield and multi-layer insulation are planned. Figure 4 shows the pathway of the piping system.

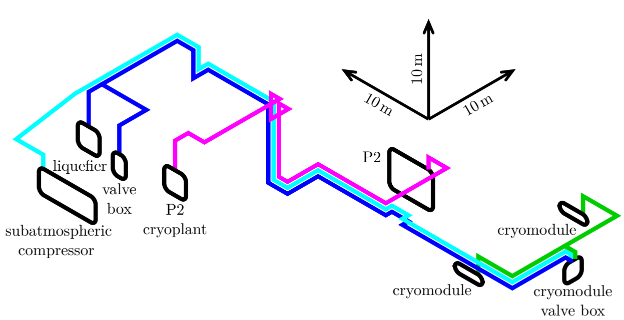

Figure 4: Layout of the cryogenic pipes leading from the liquefier at ground level down into the accelerator halls, to supply the P2-experiment and the cryomodules. The 4.5 K supply line is marked in dark blue, the cryomodule distribution in green, the 16 mbar return line in light blue and the P2-target line in magenta [7].

CONCLUSION

The integration of the existing infrastructure into the new facility presents the biggest challenge for the construction of the cryogenic cycle. This results in restrictions in terms of space as well as performance. Due to the rejection of a new acquisition of a combined refrigerator for the P2-target and the MESA accelerator, the existing helium liquefier has to be upgraded. Since the liquefaction capacity does not have much excess capacity, unnecessary heat input must be avoided under any circumstances, especially in the design of the transfer lines. In order to free up further capacity, a new distribution valve box with a lower heat input than the current model will be purchased.

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