ISBN: 978-3-95450-233-2 ISSN: 2673-5504 doi:10.18429/JACoW-SRF2021-WEPFAV004

STATUS OF THE CRYOGENIC INFRASTRUCTURE FOR MESA*

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Abstract

The Institute of Nuclear Physics at the Johannes Gutenberg University Mainz, Germany is currently constructing the Mainz Energy-recovering Superconducting Accelerator (MESA). The centerpiece of the MESA consists of two superconducting cryomodules of the ELBE/Rossendorf type, which are operated at 1.8 K. Furthermore, accelerator elements for polarimetry, a 10 T solenoid, and the external SRF test facility of the Helmholtz Institute Mainz have to be supplied with 4 K helium. One challenge here is to supply the components located throughout the accelerator according to their requirements and to establish a 16 mbar system for 1.8 K operation. To ensure the required supply of helium at the different temperature levels, the existing helium liquefier has to be upgraded. The cryogenic infrastructure has to be adapted to the accelerator. The concept of the future cryogenic distribution network is presented in this paper and the design of the cryogenic facilities including the modifications is described in detail.

INTRODUCTION

In the moment, the energy recovery linac MESA (Mainz Energy Recovering Superconducting Accelerator) is under construction at the Institute of Nuclear Physics, Johannes Gutenberg-Univerität Mainz, Germany [1]. Its recirculating design, shown in Figure 1, has as its centerpiece two cryomodules designed for continuous wave operation at a temperature of 1.8 K [2]. Each cryomodule consists of two TESLA cavities, operating at 1.3 GHz and a field gradient of 12.5 MeV. To operate both cryomodules, they must be supplied with liquid helium, brought to 16 mbar, and liquid nitrogen to power the LN2 shields.

MESA will be used for nuclear and particle physics research and will supply three experiments in its first phase. The P2 experiment is designed as a fixed target experiment and is used for high-precision measurement of the electroweak mixing angle (Weinberg angle) [3]. It is supplied by MESA in external beam mode with 150 µA spin-polarized electrons with an energy of 155 MeV. The experiment will be realized as a liquid helium target inside a superconducting solenoid that must be integrated into the cryogenic supply. In addition, P2 requires an accurate measurement of the beam polarization before the experiment. This is measured in the beamline before the experiment with the so-called hydromøller [4]. This also requires connection to the cryogenic supply.

The so-called beam dump experiment "Dark Mesa BDX" is operated in the same time as the P2 experiment and is looking for dark particles that can be created during the dumping of the electron beam in the P2 beam dump [5]. The experiment is located outside the accelerator halls to have a low background and does not need to be considered for cryogenic supply.

The third experiment is the MAGIX experiment that is supplied as an internal target in ERL mode with up to 105 MeV and a beam current of 1 mA. The MAGIX experiment is planned as a dual-arm multipurpose spectrometer and also does not need to be included in in the cryogenic supply [6]. As can be seen in Figure 1, the components to be supplied are distributed across the accelerator halls. The task of planning the cryogenic infrastructure is to design a distribution system that meets the different requirements of the components. Especially the requirements of the cryogenic modules demand an adaptation of the existing infrastructure. This paper is intended to give an overview of the components, as well as the current status of the planning and the required components.

HELIUM AND NITROGEN DEMANDS

The components have different liquid helium and nitrogen requirements, which are are shown in Table 1.

Table 1: Estimated demands of the MESA components to the cryogenic infrastructure. The existing valvebox for LHe-distribution needs additional 35 L h^{-1} LHe.

Component	LHe(4 K)	LN2 (77 K)
cryomodule system	187.1 L h^{-1}	12.5 L h^{-1}
hydromøller	9 L h^{-1}	TBD
P2-Solenoid	11 L h^{-1}	4.1 L h^{-1}
Total	207.1 L h^{-1}	16.6 L h^{-1}

The liquid helium demands of the cryomodules were measured during the horizontal tests [7]. While the hydromøller and P2-Solenoid will need 4 K for (pre-)cooling, the working temperature in the cryomodules is 1.8 K. A subatmospheric pumping stage (subatmospheric compressor) is needed to achieve this temperature by lowering the pressure of the return gas to 16 mbar. This has been taken into account in the Table 1. The existing LHe distribution valvebox needs additional 35 L h^{-1} LHe because of an inefficient design. The valvebox has to be changed before operation.

* This work is supported by the German Research Foundation (DFG) under the Cluster of Excellence "PRISMA+" EXC 2118/2019
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ISBN: 978-3-95450-233-2 ISSN: 2673-5504 doi:10.18429/JACoW-SRF2021-WEPFAV004

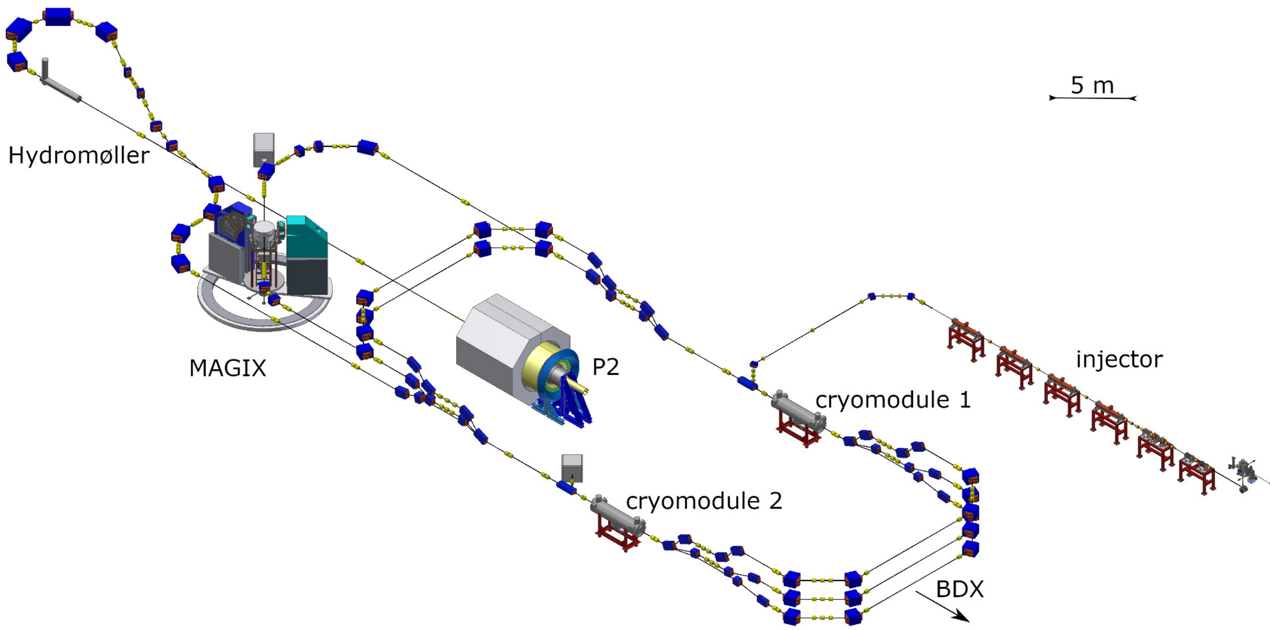

Figure 1: MESA lattice. Electrons are produced and pre-accelerated to 5 MeV in the injector before they are injected into the recirculating main-accelerator. The cryogenic components are the P2 experiment (solenoid and target), the hydromøller for polarization measurements, as well as the cryomodules. The BDX experiment is positioned outside of the accelerator hall, but in line with the P2 beam dump and not shown in this picture.

CRYOGENIC DISTRIBUTION

At the time of this paper, some parts of the cryogenic distribution are in place. First, the helium liquefier exists, but it is not optimized for the required helium flow and therefore needs to be modified. Second, a sub-atmospheric compressor for 16 mbar operation has already been extensively tested for cryogenic module acceptance [8]. The task is to supply all components with liquid helium and nitrogen. However, this consideration will neglect two aspects. First, the P2 target, since it is fed from its own refrigeration system, and second, the internal 3He-4He mixed cooling circuit of the hydromøller, since it is self-contained. However, the P2 solenoid must be supplied with liquid helium and nitrogen, as well as the pre-cooling of the hydromøller.

Process Flow Diagram

To enable the uninterrupted flow of operations, the cryogenic distribution system must be planned carefully. Detailed preliminary studies have already been carried out for this purpose [9]. On this basis, the design for a supply was developed. This is shown schematically in Fig. 2. As can be seen in Figure 2, three locations are foreseen for the cryogenic cycle. The helium liquefaction, storage and distribution is located in the ”cryoplant hall” on ground level. Centerpiece is the helium liquefier, that will be operated in two modes after its modification. In the first mode, the liquefier fills a 5000 L dewar and the liquid helium will be distributed in the ”distribution valvebox” to the SRF test facility at the Helmholtz Institute Mainz (HIM) and the accelerator components in the ”accelerator hall”. The HIM-SRF test facility is connected to the cryogenic system via a 200 m line and serves for cryomodule testing for MESA and HELIAC [10]. The accelerator componentes are located in the ”accelerator hall”, 10 m below the surface, and will be connected with to the distribution system in the cryoplant hall with approx. 80 m long pipes. This mode is shown in fig. 2 in orange and blue (dark blue for liquid, light blue for cold gas return and orange for warmed gas return). The second mode of operation will be possible after the upgrade of the helium liquefier. A supercritical line (shown in green) will be installed, that allows helium transport at 3 bar in such a way that the helium expansion will happen in the ”cryomodule valvebox”, circumventing dynamic effects of the two-phase flow in the pipeline. It will be internally connected to the different temperature stages and will allow a controlled temperature ramping. This will aid the cool down behavior of the cryomodules, that was investigated in [11]. The cryomodules themselves will be supplied with 4 K helium from the cryomodule valvebox. The Joule-Thomson expansion takes place directly at the module. The subatmospheric compressor in the cryoplant hall reduces the pressure of the return gas to 16 mbar, allowing 2 K operation.

CRYOGENIC COMPONENTS

Helium Liquefier L280

The existing helium liquefier L280 is not designed for the liquefaction capacity needed at MESA. For the adaption to the MESA specifications, extensive modifications are required. LN2 pre-cooling will be installed to achive the liquefaction capacity of $Q_{\mathrm{L280,\,LHe}} = 250\,\mathrm{L\,h^{-1}}$. For controlled

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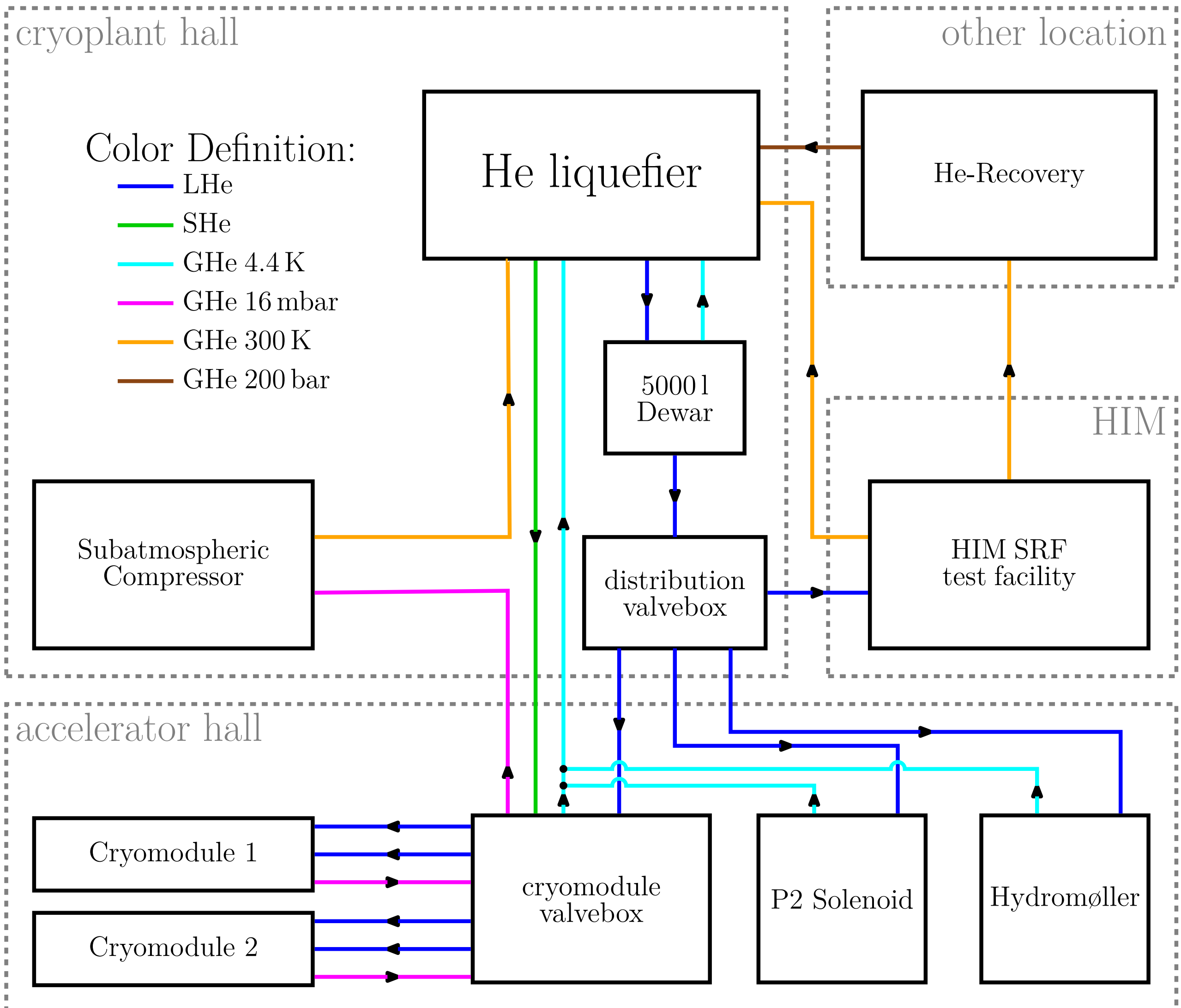

Figure 2: Process Flow Diagram (PFD) of the cryogenic distribution layout for MESA. The accelerator components to be supplied with liquid helium (LHe) are located in the accelerator hall. In addition, the SRF test area of the Helmholtz Institute Mainz must be supplied. A supercritical line (SHe) is foreseen, which also serves for a controlled cooldown. The gaseous phases (GHe) are color-coded according to their temperatures (light blue and orange) and pressures (magenta and brown).

cool down of the cryomodules and avoiding dynamic effects of two-phase flow in the pipes, the supercritical line will be installed. Additionally an internal 80 K adsorber will be installed. A more detailed discussion about the modification can be found in [12].

Helium Recovery

The helium recovery system will contain of three parts. The cold gas return, connected directly into the helium liquefier and will added into the internal return pipe behind the first heat exchanger. The warm return line will be given into the compressor circuit. Potentially contaminated gas is pressurized to 180 bar and added to the high-pressure reservoir. From here, it can be returned to the circuit via the gas purifier of the helium liquefier. The high-pressure return part is limited to 162 L h^{-1} due to the high-pressure compressor power.

Subatmospheric Compressor

Since the operating temperature of the cryomodules is 1.8 K, the pressure of the return gas must be lowered to 16 mbar. A subatmospheric compressor is provided for this purpose. The incoming helium is relaxed at a Joule-Thomson valve installed directly onto the cryomodule [2]. One requirement for the subatmospheric compressor is that it is hermitically sealed so that neither components from the air, nor oil vapors from the pumps, get into the helium. To test these requirements, a one-string system consisting of four Roots pumps connected in series with a screw pump as the backing pump was tested at the HIM SRF test facility. This

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system met our leakage requirements. However, one string only achieved the flow rate of up to 120 L h^{-1}. Currently, it is being investigated whether the existing subatmospheric compressor can be expanded with a second string, or whether it can be modified to meet the MESA requirements.

Piping Concepts

First concepts for the lines have been developed in [9]. The pipeline lay-out is limited by the existing structure of the building. In order to obtain a connection between the cryoplant hall and the accelerator hall, several bends have to be installed due to these external boundary conditions. For example, in the line between the distribution valvebox and the cryomodule valvebox on a distance of 77 m 18 bends must be installed. An overview of the possible piping path can be found in figure 3.

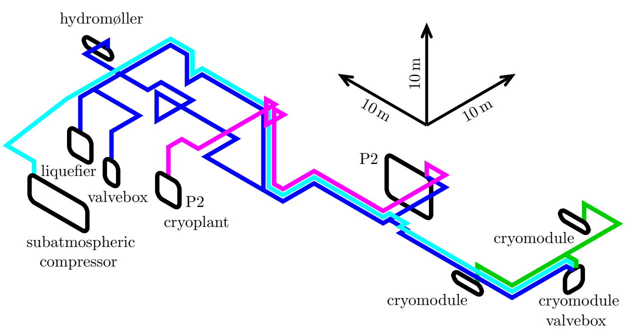

Figure 3: Piping path for connecting the cyoplant hall above ground with the accelerator hall below ground. The old building structure is limiting the possible paths [9]. Dark blue represents the liquefier connection to the cryomodules valve box and P2 solenoid, green the distribution from the cryomodule valve box to the modules, light blue the 16 mbar string and magenta the P2 target cooling circuit.

To ensure constant flow, a pressure cascade has to be obtained. Boundary conditions for this are given by the designs of the individual components. Considering the boundary conditions, the pressure ranges given in Table 2 result.

Currently, the design of the multi-channel transfer line has not yet been finalized. In particular, integration into the existing infrastructure while maintaining the specifications requires special attention.

CONCLUSION

It could be shown that the existing cryogenic components of the Institute of Nuclear Physics can be adapted for continuous operation of MESA. To meet the LHe demand of MESA, a comprehensive modification of the helium liquefier is necessary. The piping layout has to be finalized and an upgrading of the existing sub-atmospheric compressor has to be performed.

ACKNOWLEDGEMENTS

We like to thank W. Anders (HZB), Jens Conrad (TU Da), D. Pflückhahn (SLAC) and S. Rotterdam (HZB) for their advice in the design process, especially regarding to the liquefier modification.

Table 2: Pressure levels of the cryogenic compenents in mbar. These are dictated by the pressure guidelines of the individual components. The calculations were performed in [9].

Component	**operation** in mbar	**supercritical** in mbar	**Standby** in mbar
Liquefier out	-	2800	-
5000 L-Dewar	1350	-	1350
CM-Valvebox	1250	1300	1330
Cryomodules	16	16	1230
Liquefier cold return	1200	1200	1200
SAC	10	10	-

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