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CRYOMODULE FABRICATION AND MODIFICATION FOR HIGH CURRENT OPERATION AT THE MAINZ ENERGY RECOVERING SUPERCONDUCTING ACCELERATOR MESA*

T. Stengler[†1], K. Aulenbacher[12], F. Hug[1], T. Kürzeder[2], D. Simon[1]
[1] Johannes Gutenberg-Universität Mainz, Germany
[2] Helmholtz-Institute Mainz, Germany

Abstract

At Johannes Gutenberg-Universität Mainz, the Institute for Nuclear Physics is currently building the multiturn ERL 'Mainz Energy-Recovering Superconducting Accelerator' MESA. The 1.3 GHz cryomodules are based on the ELBE modules at Helmholtz Center Dresden-Rossendorf (HZDR) but are modified to suit the high current, energy recovering purposes of MESA. With two 9-cell TESLA cavities each, they shall provide 50 MeV energy gain per turn. The design and fabrication was done by Research Instruments GmbH, Bergisch Gladbach, Germany. The current status of the cryomodules, the test set up at the Helmholtz-Institute Mainz, the cavity properties and their tests will be discussed.

INTRODUCTION

At the Institute for Nuclear Physics of Johannes Gutenberg-Universität Mainz, Germany, a new Energy-Recovering Superconducting Accelerator is under construction. This accelerator will be the first superconducting accelerator at Mainz and will complement the existing, multiturn electron accelerator MAMI [1]. MESA will run at 1.3 GHz and serve two main experiments: P2 and MAGIX.

P2 will investigate the Weinberg angle with high precision [2,3], while MAGIX is planned as a multi purpose high resolution spectrometer [4] to measure the form factor of the proton and search for the dark photon [5].

To provide the required beam energy for the experiments, two cryomodules will be installed. The design is based on the ELBE cryomodules, which are in use at the Helmholtz Center Dresden-Rossendorf (HZDR), Germany [6]. Modifications had to be done, to satisfy the demands of a high current c. w. beam with a duty cycle of 100 %. The modules are currently in production at RI Research Instruments GmbH, Bergisch Gladbach, Germany and will be delivered soon (fourth quarter of 2017). The cavities are already manufactured by RI, and SRF tested at DESY, Germany [7]. This paper will show the results of the vertical SRF tests, the power coupler conditioning at HZDR and the cryomodule test set up at the Helmholtz-Institute Mainz.

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† stengler@kph.uni-mainz.de

MAINZ ENERGY-RECOVERING SUPERCONDUCTING ACCELERATOR

MESA is an multiturn electron accelerator with two different modes of operation to be conform with the different requirements of the experiments. It can be operated as a normal multiturn linac (external beam "EB" mode) or as an energy-recovery linac (energy recovery "ER" mode). An overview can be found in Fig. 1.

Two different kind of sources are currently under development to provide a polarized beam by photo emission (STEAM) [8] or a high intensity beam (SPOCK) [9]. Behind the low energy beam transportation, a normal conducting pre-accelerator (MAMBO) [10] pre-accelerates the electrons to 5 MeV. The main accelerator contains two cryomodules for acceleration and deceleration. One turn provides an energy gain of 50 MeV. The number of turns depends on the mode of operation.

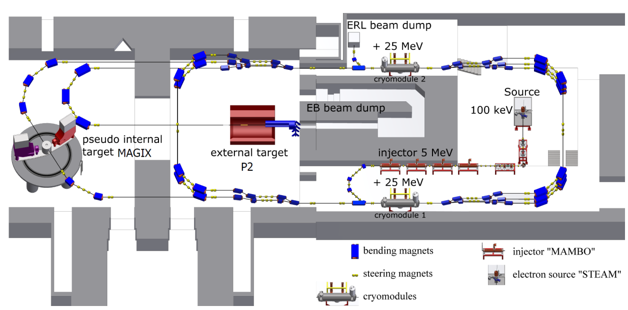

Figure 1: Current design of the MESA lattice. The accelerator is centred around the external beam (EB) mode beam dump. The fixed target experiment P2 is located in the accelerator hall, while the pseudo-internal target MAGIX is located in a separated hall.

At external beam (EB) mode, an energy of 155 MeV at a beam current of 150 µA [11] for polarized electrons is needed. Therefore the beam passes the cryomodules three times.

At energy-recovery (ER) mode, MESA accelerates a non-polarized 105 MeV beam with high currents between 1 mA up to 10 mA. After two turns through the main accelerator, the beam will interact with the pseudo-internal target MAGIX. In current simulations, 0.16 % of the beam is lost in the experiment [12]. The non-interacting part of the beam will be guided back into the accelerator with a phase shift of 180° and will be decelerated down to 5 MeV.

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The ER mode has the advantage to allow higher currents and to be more efficient compared to a conventional linac with the same energy and beam current.

MESA CRYOMODULE

The MESA cryomodules operates at 1.3 GHz at 1.8 K and contain two 9-cell TESLA/XFEL cavities. The modifications regarding the tuner and the HOM antenna, the helium supply are discussed in [13, 14]. A cross-section of the cryomodule is given in Fig. 2.

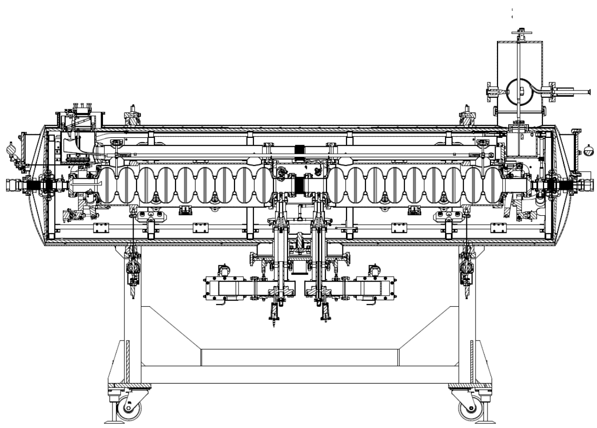

Figure 2: Design of the cryomodule based on the ELBE cryomodule. It contains two TESLA nine-cell-cavities. The overall length is 3.45 m. Courtesy of RI Research Instruments GmbH.

The specifications are defined by the helium system. Because of the dimensions of the existing refrigerator, the total thermal losses, have to be restricted to the values per module which can be found in Table 1.

Table 1: Specified Heat Load per Module. The dynamic losses correspond to a $Q_0 = 1.25 \cdot 10^{10}$ at 12.5 MV/m.

Heat Load per module		Watts
static heat load		
	module	15 W
	JT-valve	1 W
dynamic heat load		
	all cavities	25 W
	all HOM-Coupler	5 W
over all heat load	per module	46 W

The cavities are already produced by RI and tested at the accelerator module test facility (AMTF) at DESY, Hamburg, Germany. The test results will be discussed in the following section. The power coupler have been conditioned at the Helmholtz-Center Dresden Rossendorf (HZDR), Rossendorf, Germany. By now the critical parts are delivered and the assembly of the module 1 cold string starts soon.

The first cryomodule will be delivered in the fourth quarter of 2017. The module RF tests will be done within the same year at the test bench at the Helmholtz-Institute Mainz, which is located next to the Institute for Nuclear Physics at the campus of Mainz university.

VERTICAL TESTS OF THE CAVITIES AT DESY AMTF

To verify the performance of the cavities in compliance with the specification, the cavities were brought to the vertical cryo test stand at the AMTF.

Two cavities (CAV007 and CAV010) showed a satisfying behaviour with high quench limits ($E_{Acc} > 35$ MV/m) and high quality factor $Q_0 = 1.4 \cdot 10^{10}$ at 12.5 MeV. The results can be seen in Fig. 3 and Fig. 4.

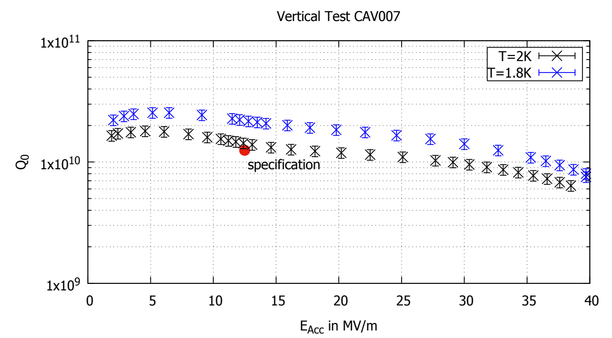

Figure 3: Results of the vertical cryo test of “Cavity 007”. $Q_0 = 1.4 \cdot 10^{10}$ at 12.5 MeV and 2 K was reached.

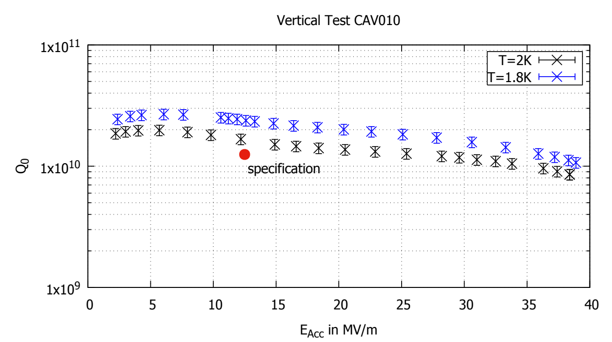

Figure 4: Results of the vertical cryo test of “Cavity 010”. $Q_0 = 1.6 \cdot 10^{10}$ at 12.5 MeV and 2 K was reached.

The achieved gradients of the remaining two cavities are above specifications as well, but have shown some unwanted behaviour. Cavity CAV008 (Fig. 5) has shown field emission (FE) above 26 MV/m. This behaviour is not a direct concern, because this gradient exceeds the required gradient for MESA a lot, but could be a problem, if the cavity behaviour gets worse after long term use. A high pressure rinsing (HPR) procedure could possibly push the start of FE up to higher gradients, but is a risk because of a increase of manufacturing steps.

The cavity with a rather remarkable behaviour is the cavity CAV009, which can be seen in Fig. 6. The cavity is limited at a gradient of 17.6 MV/m without any FE, but still within the specifications. After the first test, a HPR was done. The

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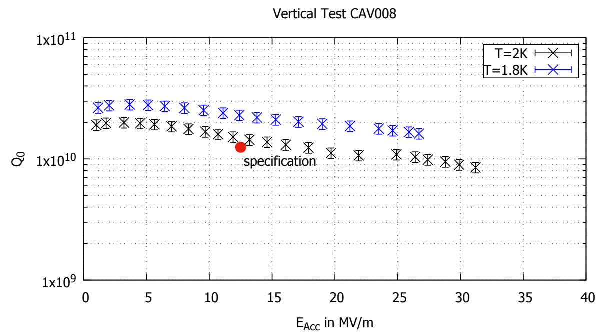

Figure 5: Results of the vertical cryo test of “Cavity 008”. Field emission was seen around 26 MV/m. $Q_0 = 1.3 \cdot 10^{10}$ at 12.5 MeV and 2 K was reached.

second test has not shown any major changes at the quench limit but a slight increase of the quality factor.

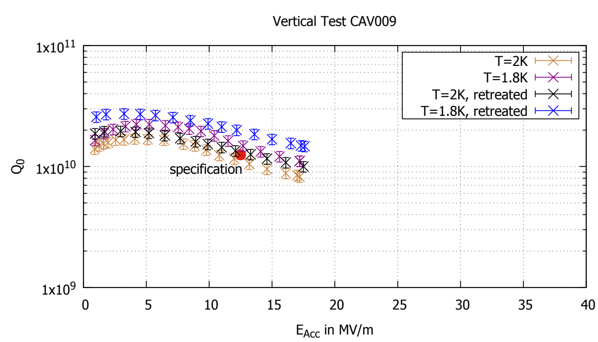

Figure 6: Results of the vertical cryo test of “Cavity 009”. Break down at 16.7 MV/m without Field emission.

To determine the reason of the early break down, a closer inspection and a retreatment would be necessary. Nevertheless the MESA specification still can be fulfilled if the cavity with the highest heat load (CAV009) will be combined with the cavity with the lowest heat load (CAV010) in one string, because the module requirements are defined by the over all static and dynamic losses.

COUPLER CONDITIONING AT HZDR

Because of the fixed length of the power coupler, the external coupling had to defined equally for both operation modes. The loaded quality factor was set to $Q_L = 1.38 \times 10^7$ which corresponds to a RF power consumption of the modules of $P_{EB} = 7.8$ kW and $P_{ER} = 4.5$ kW at $I_{EB} = 150$ µA and $I_{EB} = 1$ mA . Further calculations can be found in [11].

To determine if the couplers are capable to handle the required power level, the couplers were conditioned at the resonant ring test stand at the Helmholtz-Center Dresden-Rossendorf, Germany [15].

The resonant ring allowed a test of the couplers up to 20 kW c.w. In Fig. 7 the conditioning results of the couplers are shown. As one can see, a few vacuum events shows the conditioning. The long temperature stable operation at 20 kW was reached successfully.

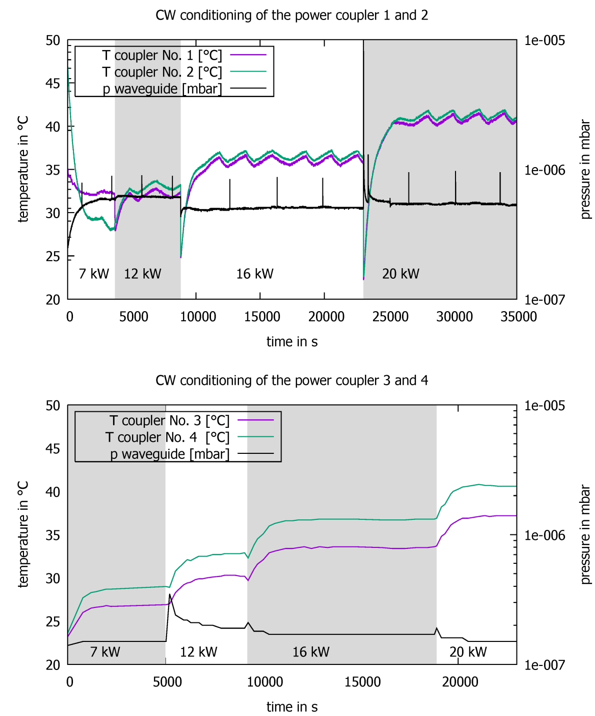

Figure 7: Conditioning of the four couplers at HZDR. A stable operation at 20 kW was achieved.

A SRF TEST BENCH AT THE HELMHOLTZ-INSTITUTE MAINZ

The first SRF tests of the cryomodules will be done in cooperation with the Helmholtz-Institute Mainz (HIM), Germany. In the new experimental hall of the HIM, a test bench bunker with 4 K liquid helium and 77 K liquid nitrogen supply was constructed. The helium refrigerator and the nitrogen supply is positioned at the Institute for Nuclear Physics, at Mainz University and is connected through a 200 m cryogenic line with the HIM.

First stress tests of the cryoline showed a liquid helium transport rate of 150 l/h (≅5 g/s) at a stable temperature of $T = (4.247 \pm 0.002)$ K and pressure of $p = (1.000 \pm 0.002)$ bar. For a single cavity test at 1.8 K, 71 l/h (≅2.5 g/s) helium are needed, if $Q_0 = 1.25 \cdot 10^{10}$ at 12.5 MV/m is reached. The Q-value corresponds to a total head load of 31 W if only one cavity is tested. At a run of the hole module, the total heat load is 46 W.

The test bench contains a valve box, which will be used as a phase separator. The valve box is designed to split the helium flow to the two cryomodules at MESA. At the cryomodule, a Joule-Thomson valve expands the helium to 16 mbar (≅ 1.8 K). The cold return of the module will precool the helium from the valve box, before it will be heated up to 300 K. After heating a sub-atmospheric compressor will compress it to 1 bar. It is designed to accept up to 119 l/h

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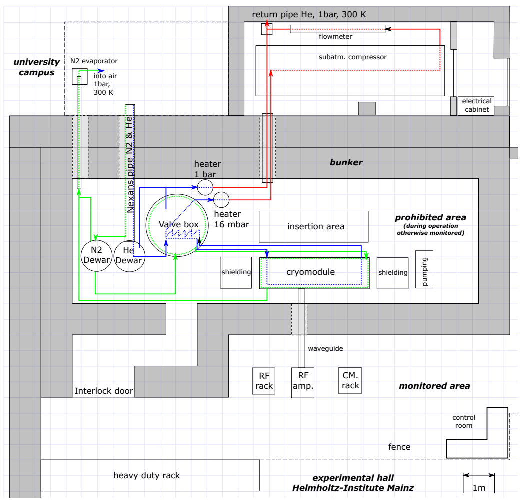

Figure 8: General layout of the SRF test bench at the Helmholtz-Institute Mainz.

($\cong$4 g/s) helium within a pressure range of 12 to 40 mbar. After compression a flow meter measures the flow of the gas to determine the dynamic losses of the cavities. This procedure is necessary, because of the fixed power coupling. The warm, compressed helium gas will be carried back to the refrigerator. An graphical overview of the cryo concept can be found in Fig. 9.

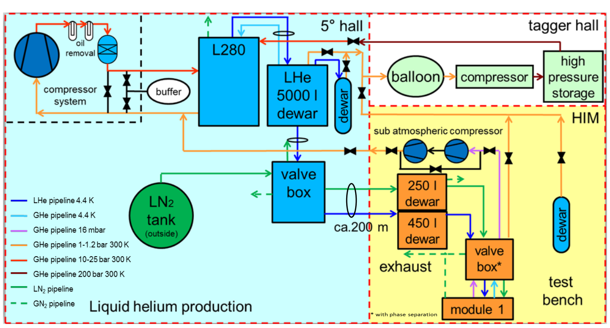

Figure 9: Concept of the cryogenic piping of the test bench at HIM.

CONCLUSION AND OUTLOOK

After testing the cavities three out of four showed a quite good behaviour. Only for cavity *CAV*009 it has to be considered to be retreated. The power couplers are successfully conditioned and showed a good behaviour up to 20 kW at c.w. . The cryomodule SRF tests will start in the fourth quarter of 2017.

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