

# STATUS OF THE SUPERCONDUCTING CRYOMODULES AND CRYOGENIC SYSTEM FOR THE MAINZ ENERGY-RECOVERING SUPERCONDUCTING ACCELERATOR MESA\*

T. Stengler<sup>†</sup>, K. Aulenbacher, F. Hug, D. Simon, P. Weber, N. Wiehl,  
Johannes Gutenberg-Universität Mainz, Germany  
F. Schlander, European Spallation Source, Lund, Sweden

## Abstract

SRF and the cryogenic system are mandatory for the operation of MESA at the Institut für Kernphysik at Johannes Gutenberg-Universität Mainz. The cryomodule production project is running for one year right now and the recent developments and measurements are presented. Further on the cryogenic concept required for the operation of MESA will be discussed.

## INTRODUCTION

The Mainz Energy-Recovering Superconducting Accelerator (MESA), which is under construction at Johannes Gutenberg-Universität Mainz, Germany, will be a energy recovery linac (ERL) with an maximum of three turns. MESA is shown in Fig. 1. The main acceleration will be realized with two superconducting radio frequency acceleration modules (SRF cryomodules). There will be two 9-cell TESLA/XFEL-type cavities per cryomodule with an energy gain of 12.5 MeV each.

Applying some modifications, the Mainz extended ELBE-type cryomodules are based on the cryomodules in the ELBE accelerator at the Helmholtz Zentrum Dresden-Rossendorf (HZDR), Germany [1]. Those modifications had to be done, to satisfy the demands for the high current c.w. beam operation of MESA. The modules are currently in production at RI Research Instruments GmbH, Bergisch Gladbach, Germany. One main modification is the change of the tuner, which is replaced by an XFEL/Saclay-type lever/piezo actuator system. To minimize the heating of higher order mode (HOM) extraction by RF losses, the heat transfer of the HOM will be optimized as well.

Another modification is the presence of the Joule Thomson valve and corresponding regulation systems for the Helium flow on top of the module. This modification allows for efficient integration of the modules into the closed helium circuit of MESA.

The niobium cavities are a key component for the accelerator. To make sure that the production cavities have the optimal material, different testing procedures were performed at Mainz university.

This paper will discuss the modifications of the cryomodules and the material testing of the RRR>300 niobium sheets.

\* Work supported by the German Research Foundation (DFG) under the Cluster of Excellence "PRISMA"

<sup>†</sup> stengler@kph.uni-mainz.de

## MAINZ ENERGY-RECOVERING SUPERCONDUCTING ACCELERATOR

MESA will be operated with a duty cycle of 100 % and two different modes: an energy recovering (ER) mode and an external beam (EB) mode.

Behind a normal conducting pre-accelerator (MAMBO) [2], fed by a photoemissive electron source (STEAM) [3], the electrons are injected into the main accelerator with 5 MeV.

The main accelerator has two cryomodules for acceleration and deceleration and a stacked beam line with two arcs similar to CEBAF [4]. One turn provides an energy gain of 50 MeV with an varying number of turns, depending on the operation mode.

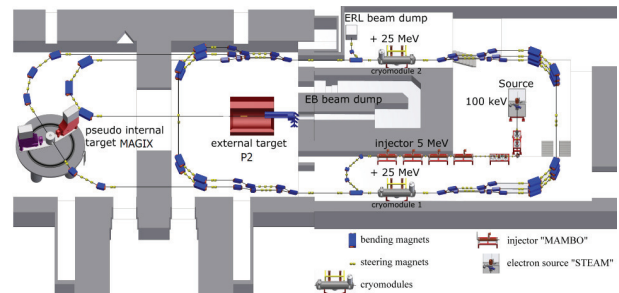


Figure 1: Current design of MESA. The beam pipe is allocated around an existing beam dump which will be used in external beam (EB) mode. The energy recovering (ER) mode will use the smaller 5 MeV beam dump.

At EB mode, MESA is used as a recirculating linac with external target. To achieve the end energy of 155 MeV at a beam current of 150  $\mu$ A [5] for polarized electrons, there will be three passes through the cryomodules. The fixed target experiment P2 investigates the Weinberg angle with high precision [6].

At ER mode, MESA will work as a Energy Recovery Linac (ERL) and shall accelerate non-polarized, high beam currents between 1 mA to 10 mA up to 105 MeV. This correlates to two turns through the main accelerator. The 105 MeV beam will interact with a pseudo internal target MAGIX. It is planned as a multi purpose high resolution spectrometer [7]. After interacting with the pseudo internal target the electron beam is guided back to the main accelerator with a phase shift of 180°. The phase shift leads to energy recovery and deceleration of the electrons within the cavities down to 5 MeV after two turns. Those decelerated electrons will be dumped in a separate beam dump. The ER mode has the

advantage to allow higher currents and to be more efficient in cost compared to a conventional linac with the same energy and beam current.

### MESA CRYOMODULE

The MESA extended ELBE-type cryomodules are modified ELBE-type cryomodules, which are in use at the Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Germany. Each module contains two 9-cell TESLA/XFEL cavities and operates at 1.8 K and will provide an energy gain of  $\Delta E \geq 25$  MeV. A cross-section of the cryomodule is given in Fig. 2.

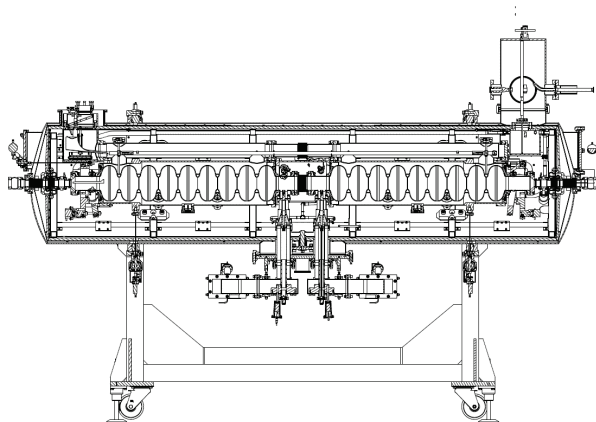


Figure 2: Design of the cryomodule based on the ELBE cryomodule. It contains two TESLA nine-cell-cavities. The overall length is 3.45 m. Courtesy of RI Research Instruments GmbH.

To suit the purposes and considering the beam parameters of MESA, there are some modifications of the ELBE-type cryomodules.

Because of multi turn ERL operation, it is necessary to have a faster control of the detuning by beam cavity interaction [8]. Instead of using the original ELBE tuner, the XFEL/Saclay tuner will be used, which combines a spindle-lever system for slow tuning with an additional piezo actuator support.

The c.w. operation at a duty cycle of 100% will produce higher order modes (HOM) and those have to be damped. This will be discussed in the next section.

In contrast to the ELBE-type cryomodule, the MESA cryomodule will be equipped with an internal helium subcooler stage to cool helium from 4 K to 1.8 K.

### HIGHER ORDER MODE (HOM) DAMPER

At ER mode, every cell is filled with two bunches, an accelerating and a decelerating bunch. Because of the recirculating design, the beam is sensitive to field disturbances, which can cause a beam break up. The interactions between the electrons and the RF field leads to higher order modes (dipole and higher) in the field. To stabilize the system, the HOMs have to be received by an antenna (notch filter) and will be taken out of the system by a feed-through.

RF losses in the HOM system causes heating, which could lead to quenching. The high thermal conductivity of sapphire will guarantee a good thermal connection between the HOM antenna and the copper piece. The copper piece is thermally coupled to parts of the cold mass. The connection to the 1.8 K helium vessel has an excellent heat transfer and is used as a heat-sink.

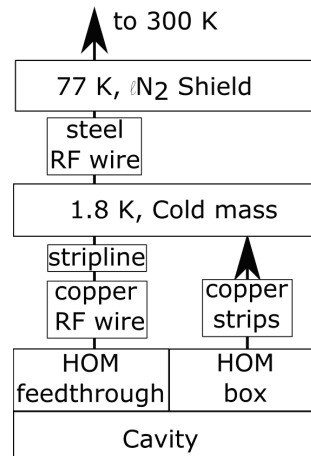


Figure 3: Schematic set up for the cooling of the HOM feedthrough and HOM box. The stripline is connected to the cold mass.

A CST particle studio simulation has shown, that the transition between inner conductor of the HOM feed-through and the steel hf wire to the load outside of the cryomodule could be a problematic area for heat accumulation. The steel wire is needed to minimize the heat load from outside the shielding.

To solve this dilemma while keeping the steel wire and optimizing the cooling for the inner conductor of the HOM feed-through, a slot-line at the liquid helium vessel is added. The slot-line will be the transition point between the steel wire from the outside and a copper wire connecting the HOM feed-through.

### ANALYSIS OF THE NIOBIUM SHEETS

In cooperation with the institute for nuclear chemistry of the Johannes Gutenberg-Universität Mainz a Neutron Activation Analysis (NAA) of niobium sheets for the cavity has been made at the TRIGA (Training, Research, Isotopes, General Atomics) reactor. Four different sheets have been examined with the preliminary results of found isotopes shown in table 1 and fig. 4. The numbers are calculated from the theoretical well known decay of the daughter nuclei created by the absorption of neutrons by mother nuclei.

Sodium is most likely a contamination due to ultrasonic rinsing, where the purified water had some sodium traces left. Tantalum and tungsten are traces caused by the manufacturing process of niobium sheets. Tantalum is chemically and physically hard to separate from niobium. Tungsten is most likely caused by the melting process of niobium, which

Table 1: Preliminary results of NAA with all shares of elements in parts per million (ppm) obtained from theoretical treatment.  $Ta_{stand.}$  stands for the amount of tantalum measured by a comparison of a irradiated tantalum standard, while  $Ta_{calc.}$  is the amount, by calculating the radioactive series. The numbers of Na and W have to be critically reviewed because of an unknown percentage of epithermal neutrons.

| Sheet/ Isotope | Na <sup>24</sup> | Ta <sup>182</sup> <sub>stand.</sub> | Ta <sup>182</sup> <sub>calc.</sub> | W <sup>187</sup> |
|----------------|------------------|-------------------------------------|------------------------------------|------------------|
| 58             | 0.15(1)          | 144                                 | 135(8)                             | 2.1(1)           |
| 69             | 0.13(1)          | 136                                 | 129(7)                             | 2.0(1)           |
| 84             | -                | 148                                 | 153(7)                             | 2.2(1)           |
| 95             | 0.14(1)          | 137                                 | 132(8)                             | 2.0(1)           |
| Mean           | 0.14(1)          | 141                                 | 137(7)                             | 2.0(1)           |

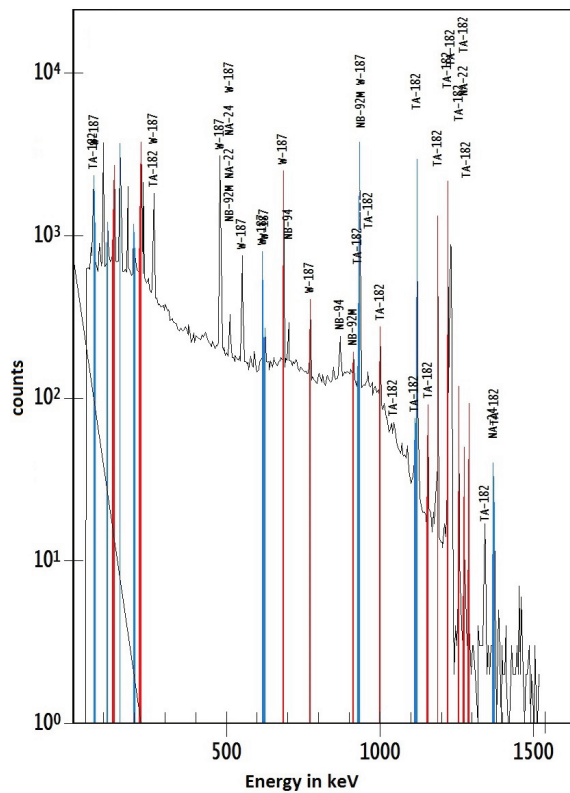


Figure 4: Parts of a gamma spectrum of the niobium sheet No. 69. Red peaks are single identified, blue are multiple identified isotopes in one peak.

is done with electron beams originating from tungsten electrodes.

Assuming a natural isotope distribution, the total impurity of tantalum is 137 ppm and 6.99 ppm for tungsten. These results lie below the concentrations given by the manufacturers, which amount to 500 ppm for tantalum and 70 ppm for tungsten. Comparing the tantalum amount in the different sheets shows, that sheet 84 has a 10 % higher content than the average. Because of the small samples which were used for NAA (1 cm<sup>2</sup> each), one can assume that the tantalum distribution is likely not homogeneous in the material. A

former eddy current scan shows a few located defects on sheets [9]. To resolve this issue, an additional X-ray fluorescence analysis at the Institut für Geowissenschaften at Johannes Gutenberg-Universität Mainz is ongoing. This measurement can locate impurities on a  $r = 16$  mm disk sample in sub micron range. Preliminary measurements, without a reference material lie also below the thresholds given by the manufacturer of niobium and confirm the inhomogeneous distribution of tantalum.

Since several sheets of niobium have been spared for cavity production due to impurities detected with an eddy current scan [9], it is planned to examine those impurities in a next step. To obtain an analysis for elements with low masses, additional mass spectroscopy analysis are carried out.

## MODIFICATIONS FOR THE HELIUM SUPPLY OF THE CRYOMODULES

The superconducting accelerator structures and superconducting parts of the experiments requires a constant and stable amount of liquid nitrogen and helium.

For now the demands of the main cryomodules for liquid Helium (LHe) are including a margin around  $7.2 \text{ g s}^{-1}$ . Since to all our knowledge systems require a safety margin for higher losses (e.g. due to  $Q_0$ -drop of the cavities at the desired field levels) we believe that  $8 \text{ g s}^{-1}$  is a reasonable estimate for the mass flow to be expected.

Therefore an existing type L280 liquefier from Linde Kryotechnik AG will be modified with nitrogen pre-cooling to provide a mass flow of  $280 \text{ L h}^{-1}$  liquid helium. The sub-cooling stage is currently in design phase at RI.

## STATUS OF THE PROJECT

The design of the cryomodules including the modification presented here is finished by now. The dumb bells are produced and within the end of may 2016, the 9-cell cavities will be completed and will be vertically tested in the third quarter of 2016. The cryomodules will be delivered mid 2017 and module RF tests will be done within the same year.

The availability of several analysis tools on our campus has proven to be expedient for quality surveillance. In particular the NAA results so far support the quotations given by the vendors of our Niobium material. The high resolution X-ray fluorescence analysis will be finalized soon.

The work on the cryogenic infrastructure is ongoing. The subcooler stage is currently in design phase at RI. At present the subcooler is not considered to define a critical path in the cryomodule project.

## ACKNOWLEDGMENT

We would like to thank the institute for nuclear chemistry at JGU Mainz for the possibility to do the NAA. We thank also RI Research Instruments GmbH, Bergisch-Gladbach, Germany for providing the niobium samples and DESY for the usage of the tuner design.

**REFERENCES**

- [1] J. Teichert et al., "RF status of superconducting module development suitable for CW operation: ELBE cryostats", ERL'05, Newport News, USA, (2005).
- [2] R. Heine et al., "Further Investigations on the MESA injector", TUPWA045, IPAC'15, Richmond, VA, USA (2015).
- [3] S. Friederich et al., "Test electron source for increased brightness emission by near band gap photoemission", TUPWA044, IPAC'15, Richmond, VA, USA (2015).
- [4] R. Legg et al., "Operating Experience at CEBAF", WEX01A, EPAC'96, Sitges, Spain (1996).
- [5] K. Aulenbacher et al., "Elementary design report of MESA", Internal Report, Mainz, Germany (2014).
- [6] K. Aulenbacher, "Opportunities for parity violating electron scattering experiments at the planned MESA facility", *Hyperfine Interactions*, Vol. 200, Issue 1-3 (2011), pp 3-7, ISSN: 0304-3843 (Print) 1572-9540 (Online).
- [7] S. Aulenbacher, "Design and simulation of the internal gas target for MAGIX", diploma thesis, Mainz, Germany, (2014).
- [8] J. R. Delayen et al., "Frequency tuning of the CEBAF upgrade cavities", MOP114, PAC'99, New York, NY, USA (1999).
- [9] T. Stengler et al., "Modified ELBE Type Cryomodules for the Mainz Energy-Recovering Superconducting Accelerator MESA", THPB116, SRF'15, Whistler, BC, Canada, (2015).