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THIN FILMS ON HOM ANTENNAS TO PUSH THE LIMITS FOR HIGHER BEAM CURRENTS AT MESA*

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Abstract

The Mainz Energy-Recovering Superconducting Accelerator (MESA), an energy-recovering (ER) LINAC, is currently under construction at the Institute for Nuclear physics at the Johannes Gutenberg-Universität Mainz, Germany. In the ER mode continues wave (CW) beam is accelerated from 5 MeV up to 105 MeV. The energy gain of the beam is provided through 2 enhanced ELBE-type cryomodules containing two 1.3 GHz 9-cell TESLA cavities each. By pushing the limits of the beam current up to 10 mA, a quench can occur at the HOM antennas. This is caused by an extensive power deposition within the antenna. Calculations have shown that a power transfer of 1 W must be assumed. However, tests of the 1.5 GHz version of the TESLA HOM coupler have shown a quench limit of 43 mW in CW. To prevent a quench of the HOM antennas by high beam currents without major modification of the design of the HOM antenna and F-part it is necessary to find suitable materials beyond pure Niobium. Nb_3Sn and NbTiN can be applied as a coating to the HOM antennas and have higher critical parameters than pure Nb which will lead to a higher power limit. As a further approach to improve the power transfer the material for the HOM antenna will be changed to oxygen-free high thermal conductive (OFHC) Copper. The limit of the coated antennas will be tested with the cavities of a cryomodule from the decommissioned Accelerator and Light In Combined Experiments (ALICE) accelerator from STFC Daresbury[1].

INTRODUCTION

The research on sufficient damping of HOMs in superconducting radio-frequency (SRF) cavities is a crucial part for future ERLs which push the limits in beam currents and energy. For MESA were developed the MESA Enhanced ELBE-type Cryomodule (MEEC) [1] by Research Instruments (RI). The MEEC is based on the commercial available ELBE/Rossendorf-type cryomodules but needed to be modified in three major parts: the tuner, HOM feedthrough and Helium supply. Through high beam currents of 10 mA, calculation have shown, that the power in the MEEC HOM dampers will exceed their limits. At the moment a cryomdule from the decommissioned ALICE ERL [2] is under refurbishment in Mainz. After the refurbishment of the cavities they will be used to test coated HOM antennas to improve the performance of the cavities at high beam currents. The reassembled and modified ALICE cryomodule can be used as a platform for SRF-research and spare cryomodule for MESA.

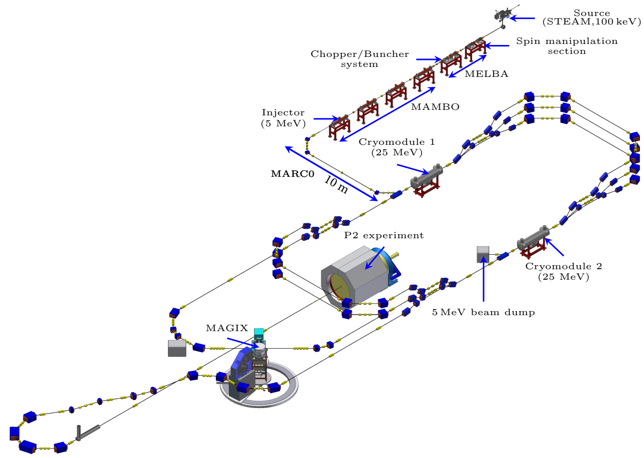

Figure 1: The MESA lattice

MESA Layout

In figure 1 is shown the lattice of MESA [3], which has an normal conduction pre-accelerator and a superconducting main accelerator. MESA is a continuous wave multiturn LINAC, which operates at a frequency of 1.3 GHz and can be operated in the Energy Recovering (ER)-mode or in the beam dump mode. MESA will have two electron sources: Small Thermalised Electron Source at Mainz (STEAM) [4], which provides polarised electrons at a beam current of 150 µA up to 1 mA. The MESA-Injector Source Two (MIST) [5] can provide an average beam current of 10 mA. MESA Low Energy Beam Apparatus (MELBA) [6] prepares the beam in bunches and MilliAMpere BOoster (MAMBO) accelerates the bunches up to the injection energy of 5 MeV. After MAMBO the electron bunches will be injected to the main accelerator, which is driven by two MEECs which provide an energy gain of 25 MeV each. For the P2 and BDX the electrons will recirculate for 3 turn and have an energy gain of 150 MeV and MESA is running in the beam dump mode at 150 µA. For MAGIX the electrons are in the main accelerator for two recirculations to have an energy gain of 100 MeV and MESA is running then in the ER-mode at 1(10) mA.

STATUS OF THE ALICE CRYOMODULE

The ALICE cryomodule needs to be refurbished and modified to fulfill the requirements for an operation in MESA. Ref. [7] describes the previous refurbishment steps. An unexpected and long maintenance phase of the clean room infrastructure of the Helmholtz Institute Mainz (HIM) post-

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poned the high pressure rinse (HPR) treatment. The clean room treatment of the cavities is planned in summer 2023. Because of an existing oil contamination of the Helium tank of the first cavity a pre clean room cleaning procedure was necessary which includes three cleaning steps. In the first step the tank was filled with a mixture of ultra pure water and Tickopur R33 to remove the oil residuals. The mixture included a total part 5% of Tickopur R33. This mixture was pumped in a circle for 24 hours and heated up to a temperature of 40 °C. Figure 2 shows a schmeatic of the setup. The pump speed was set to 100%, which were 180 L h^{-1}, so that the total volume of 35 L was exchanged over 100 times. Afterwards the tank was pumped with ultra pure water in a circle to remove oil and Tickopur residuals. For that was the pump speed reduced to 50%, 10 L h^{-1}, and reduced the volume exchanges to 7. This was done for 24 hours and after an inspection of the outflowing water a second rinse was needed to remove more residuals. After the second rinse cycle were noticeable oil spots left. So the next step is cleaning the inner surface of the Helium tank with Acetone to remove the last residuals of oil and Tickopur. This will be done to avoid a contamination of the ultra sonic bath in the clean room at HIM. Also the Helium tank of the second cavity will be cleaned before it will enter the clean room. This decision was made since the contamination of oil was heavier than expected. The cleaning of the Helium tank with Acetone started shortly before the conference. In figure 3 is the cavity mounted to the transportation cage, which can be mounted to a lifter. In the following the tank will be filled with 10 L of Acetone and then be rotated so that the whole surface in the Helium tank will be cleaned. Afterwards the cavities will be brought into the clean room at HIM, where the inner surface will be refurbished with a HPR. In the following the performance of the cavity will be measured by a vertical cold test.

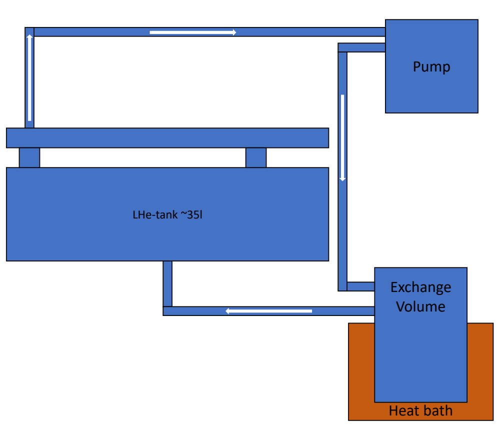

Figure 2: Schematic of the setup for cleaning the Helium tank. Including a pump, heat bath to heat up the circulating water in the exchange volume all connected with the Helium tank.

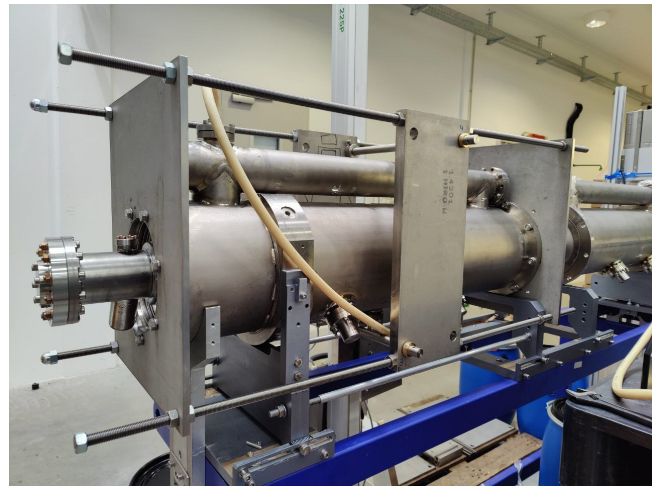

Figure 3: Cavity mounted to a transportation cage and hanging on the lifter. Ready for the Acetone treatment.

THIN FILMS ON HOM ANTENNAS TO INCREASE THE POWER LIMIT

Higher beam currents in ERL will lead the search for efficient HOM damping to new frontiers. One possible solution could be the application of a thin film on existing HOM feedthrough to have a minimal invasive change and an easy upgrade for existing accelrators.

Power Limit at the HOM Antenna Tip

One potential limit for the maximum beam current for MESA results from the heating of the HOM antenna tip. An improvement could be achieved by using an sapphire feedthrough which improved the thermal coupling of the antenna up to a heat load of 43 mW [8]. However, this will be not sufficient for the beam currents of 10 mA. A further modification of the MEEC was an installation of an stripline coupler for direct cooling of the inner conductor of the HOM feedthrough [9]. With the addition of the stripline coupler the power limit could be improved up to 95 mW in simulations. To achieve an estimation for the stored power from the beam in the fundamental and longitudinal mode [10] presents a formula:

$$P = NqkI_{average} \tag{1}$$

where N is the number of beams in the cavity which is 4 in total in the ER mode for MESA, q is the bunch charge, k = 10 V pC^{-1} the loss factor of the superconducting cavity and $I_{average}$ is the average beam current in the cavity. Table 1 presents beam induced HOM power. It is assumed that 30% of the stored power is transferred to the HOM antenna [10]. From that number it can be derived that 1000 mW will be present at the HOM antenna tip. This is more than a factor 10 larger than the value from the simulations. Nevertheless it is not fully understood if all of this power can be interpreted as pure heat load to the antenna tip.

A further approach to estimate the power limit of the HOM feedthrough is to calculate the dissipated heat loss

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Table 1: Calculated power limits for two beam currents at MESA. The step to 10 mA leads to an increase of a factor of 100 for power stored in HOMs. This will cause an extensive power deposition at the HOM antenna tip and heating.

$I_{average}$ [mA]	bunch charge [pC]	HOM power [mW]
1	0.77	30.8
10	7.7	3080

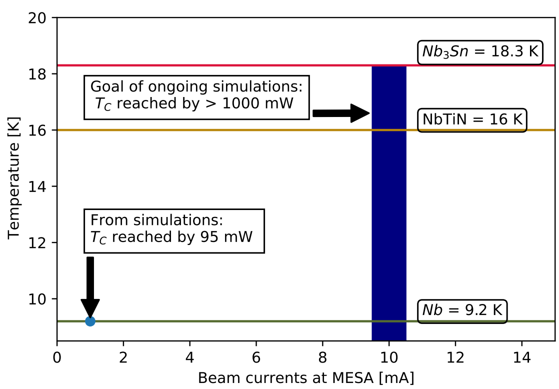

Figure 4: Simulation of power limits of HOM antenna tips. The currents DESY design fulfills the requirements for the ER mode at 1 mA. The quench is expected at 95 mW from simulations. The simulations are ongoing for the coated HOM antennas with Nb_3SN (T_C=18.3 K) and NbTiN (T_C=16 K). It is expected, that the coating will prevent a quench at beam currents of 10 mA.

from the magnetic field $H_\perp$ which is perpendicular to the HOM antenna surface:

$$W_{loss} = \frac{1}{2} R_{S(BCS)}(T) \int |H_\perp|^2 dS \quad (2)$$

and $R_{S(BCS)}(T)$ is the BCS resistance plus the residual resistance of the surface material and has a temperature dependency. It is growing exponentially for T getting closer to T_C of the material. In Ref. [11] calculated the heat loss of a Niobium and a Nb_3Sn tip. It shows that the tip with Nb_3Sn will be thermally more stable, so that the tip can tolerate an increased power load. Figure 4 shows that the current HOM feedthrough design from DESY fulfills the requirements for MESA at 1 mA. For the beam currents the design needs to modify. Since the geometrical constrains are not changeable a thin film of Nb_3SN/NbTiN could improve the power limit of the HOM feedthrough.

Coating of Nb_3Sn and NbTiN

Since the MEECs use the DESY HOM coupler design, geometrical changes are not possible without major redesign. One solution is to improve surface parameters like higher T_C and lower $R_{S(BCS)}$. This can be reached by coating the HOM antenna tip with Nb_3Sn or NbTiN. Since both materials have higher T_C than pure Niobium an improvement of HOM heating is to be expected. The coating will be done by our research collaboration partners at the University Hamburg and Technische Universität (TU) Darmstadt. In Hamburg the antennas can be coated with NbTiN through Plasma-enhanced Atomic Layer Deposition (PEALD) [12] and in Darmstadt can the antennas be coated with a thin film of Nb_3Sn through magnetron sputtering [13].

Copper as Core Material

A further possible solution could be to replace the Niobium antenna with an antenna made from Oxygen-Free High thermal Conductivity (OFHC) Copper. On the Copper antennas would be then applied a coating of Nb_3Sn or NbTiN. The superconducting thin film could handle the high induced surface currents at the antenna tip while the copper core provide a more efficient thermal coupling. At a temperature of 1.8 K is the thermal conductivity a of OFHC Copper a factor over 100 larger than the thermal conductivity from Niobium [14].

CONCLUSION & OUTLOOK

At the moment a cryomodule from the decommissioned ALICE ERL is in the process of refurbishment. The performance of the two cavities will be tested this summer. Also contact to Kyocera as a supplier for HOM feedthrough is established and the first antennas are expected to be ready for coating this year. The antenna tips made from copper are already produced from the workshop in house and the first antenna is at the TU Darmstadt and will be coated soon.

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