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SUPERCONDUCTING THIN FILMS FOR HIGHER ORDER MODE ANTENNAS TO INCREASE THE CW PERFORMANCE OF SRF CAVITIES 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 a 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 higher order mode (HOM) antennas. The quench is caused through the increased power deposition induced by the electron beam in ER mode. Calculations have shown that an upgrade from 1 mA to 10 mA can increase the deposited power in the HOMs up to 3080 mW. From this power approximately 30% will be present at the HOM feedthrough and can be used as a thermal input. Previous simulations have shown a power limit of 95 mW, which includes the power of a recirculating beam at 1 mA but is exceeded at 10 mA. A solution to increase the power limit are superconducting thin films which provides higher critical fields, temperature and currents. Nb_3Sn and NbTiN are the material candidates. Preliminary simulations shown an increased power limit, which includes the limits for MESA.

INTRODUCTION

Research on sufficient damping of HOMs in superconducting radio-frequency (SRF) cavities is a crucial part for future energy-recovering LINACs (ERLs) and high current accelerators, which are pushing the limits in beam currents and energy. For MESA, the MESA Enhanced ELBE-type Cryomodule (MEEC) [1] was developed and fabricated by RI Research Instruments GmbH. 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 [1]. At a high beam current of 10 mA, calculations have shown that the power in the MEEC HOM dampers will exceed their limits [2]. At the moment, a cryomodule from the decommissioned ALICE ERL [3] is under refurbishment at 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. First HOM antennas were coated at DESY to study the coating quality on the designed geometry of the antenna.

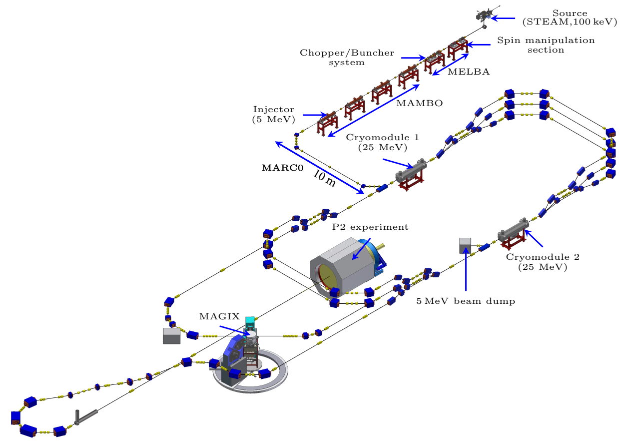

Figure 1: The MESA lattice.

MESA Layout

In Figure 1, the lattice of MESA [4] is shown. MESA has a 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) [5], which provides polarised electrons at a beam current of 150 µA up to 1 mA.

The MESA-Injector Source Two (MIST) [6] can provide an average beam current of 10 mA. MESA Low Energy Beam Apparatus (MELBA) [7] prepares the beam in bunches and the 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 and provides an energy gain of 25 MeV each. For the P2 and BDX experiments, the electrons will recirculate for three turns and gain an energy of 150 MeV at a beam current of 150 µA. This operational mode is called the beam dump mode. For MAGIX the electrons are in the main accelerator for two recirculations and have an energy gain of 100 MeV, this operational mode of MESA is called then the ER-mode. The ER-mode provides a beam current of 1 mA with a possible future upgrade up to 10 mA.

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

I_{avg}/mA	q_{bunch}/pC	$P_{HOM,C}$/mW	$P_{HOM,A}$/mW
1	0.77	30.8	10
10	7.7	3080	1000

POWER LIMITS OF HOM ANTENNA

One can calculate the stored power in the cavity from the passing beams by the following formula (from Ref. [8]):

$$P = NqkI_{avg}, \quad (1)$$

where N = 4 is the number of beams in the cavity 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_{avg} is the average beam current in the cavity. Table 1 presents beam induced HOM power. From these values, it is assumed that 30% of the stored power is transferred to the HOM antenna [8] and can be interpreted with as purely thermal loss in a worst case scenario. In Table 1 the HOM power values are shown. We see that increasing the beam current from 1 mA to 10 mA increases the power at the antenna from $P_{HOM,A,1}$ = 10 mW to $P_{HOM,A,10}$ = 1000 mW which is a factor of 100.

Since $P_{HOM,A,10}$ exceeds the power limit of the Nb antennas, which was at P_{Limit} = 95 mW [9]. Given that the geometrical constrains can't be changed and the cooling of the HOM was improved by installing a stripline cooler to cool RF cable of HOM antenna to 1.8 K, a possibility is to change the surface material. The top layer, which is in the order of magnitude of the London penetration depth λ_L, is important for superconductivity. Therefore, a coating with a thickness of λ_L could be sufficient. This approach has the advantage that no new design for the HOM antenna is necessary. But applying the coating on the antenna tip provides a new challenge. Since the superconducting thin film can be applied on various substrates, this leads to variety of different solutions. The material candidates of this work is to study coating of NbTiN on Nb and Nb_3Sn on Oxygen Free High Conductivity (OFHC) Cu.

THERMAL SIMULATION WITH CST

The goal of the CST simulations is to study the quench limit of the antenna tip. For that, the first study series is using a setup where the thermal load of the HOM antenna is depicted by a static thermal load. The cooling of the antenna is passive since it is located outside of the LHe bath. A stripline cooler, which is mounted on the helium-tank of the cavity, is cooling the RF cable to 1.8 K. A stainless steel cable, which has a low thermal conductivity, is connecting the stripline cooler to the connection port to the outside of the CM. A Cu cable is connecting the HOM feedthrough with the stripline cooler. The stripline cooler has the function of a thermal shield, so that, the thermal load of the stainless steel cable was neglected in the simulations. CST provides a feature to give materials a non linear thermal conductivity. This feature was used since the thermal conductivity of the materials, which are used in the HOM feedthrough are changing significantly in the range between 2 K to 30 K. In Fig. 2, the thermal conductivities of Nb, Mo, OFHC Cu and Sapphire are shown. In Fig. 3, the heating of the HOM antenna is shown for a thermal load of 330 mW. When the thermal load at the tip increases, it is noticeable that the antenna tip is heating significantly more than the rest of the HOM feedthrough.

In Fig. 4, the results of the thermal simulations of the antenna tip for different thermal loads are shown. The Nb antenna would quench with an NbTiN coating at ~1025 mW, while the Cu with a Nb_3Sn coating would quench at ~4700 mW.

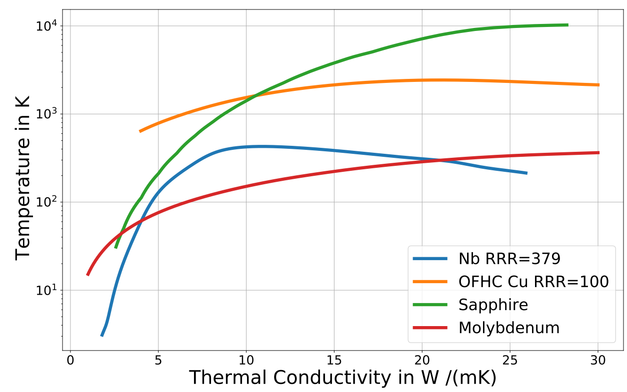

Figure 2: Logarithmic plot of thermal conductivities of the material of the HOM feedthrough: Mo [10], Nb [11], Sapphire [12], OFHC Cu [13]

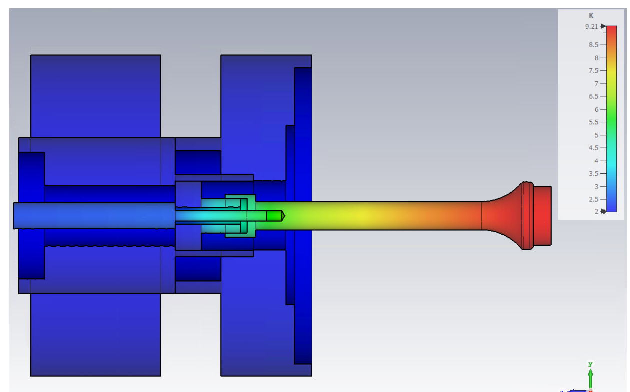

Figure 3: Thermal simulation with a static load of 330 mW at the antenna tip. The temperature at the tip is with 9.21 K, which is close to the the critical temperature of Nb.

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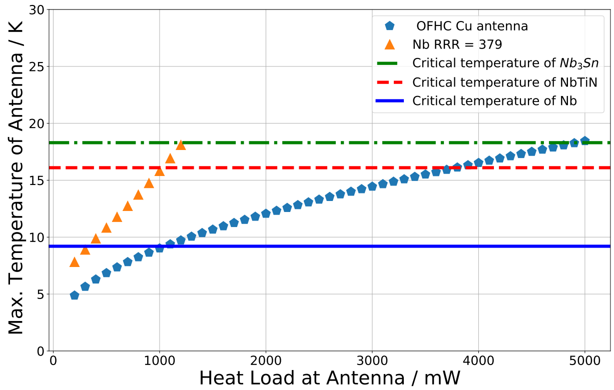

Figure 4: CST simulations of heating at the antenna tip for different thermal loads of Nb and OFHC Cu antennas. The quench limit of an Cu antenna is the factor of approximately four times larger than the Nb.

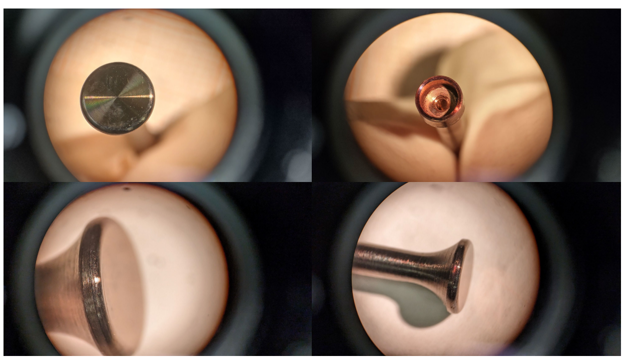

Figure 5: HOM antenna after a successful coating of a layer of 15 nm AlN and 20 nm NbTiN. The pictures are from an optical inspection and show good coating on the HOM antenna geometry. Top left: Flat side of the antenna tip; Top right: Connection to sapphire was successfully covered and not coated with NbTiN; Bottom left: Coated edge of the antenna tip; bottom right: The contact surface of the antenna with the plate was not coated.

STATUS OF ANTENNA COATING

NbTiN: Plasma Enhanced Atomic Layer Deposition (PEALD)

Due to technical constrains the HOM antenna tips have to be coated before they are brazed to the feedthrough. To study how the NbTiN is coated via PEALD [14] on the geometry of the tip, Cu antennas were coated at DESY in Hamburg. In Fig. 5, an antenna tip after being successfully coated is shown. The coating seems uniform at the whole antenna surface. From the inspection of the surface was observed that a small spot at the antenna tip, where it was in contact with the plate of the coating setup, was not coated. A new antenna holder was designed and is under fabrication to enable a complete coating of the antenna tip. It is planned to coat the Nb antenna in Q3 2024.

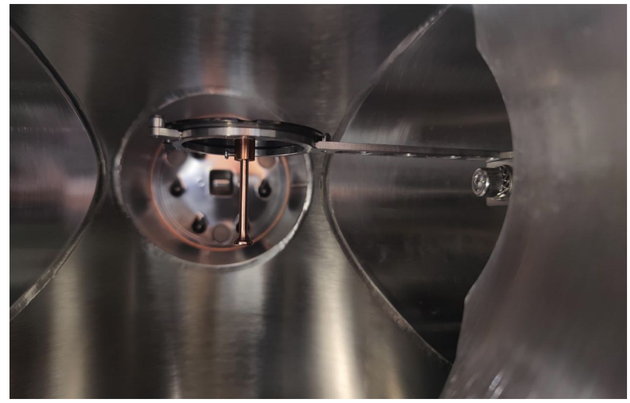

Figure 6: HOM antenna mounted on a Si-wafer in the gate before the sputtering oven.

Nb_3Sn: Magnetron Co-Sputtering

At the end of the last year, a first coating of Nb_3Sn on OFHC Cu was started at Technische Universität Darmstadt (TUDA). In Figure 6, the antenna is shown, which is mounted on a sample holder. During this test it was noticed that further modifications on the sample holder in the sputtering oven [15] are necessary to apply a coating on the antenna. The modification are in the moment ongoing and a first coating is planned during this summer.

CONCLUSION

The CST simulations have shown that a coating of NbTiN on a Nb antenna can increase the quench limit up to 1025 mW which is above the limit of 1000 mW. This limit could be further increased by applying the coating on OFHC Cu antennas, then the maximum quench limit would be 4700 mW. By using equation 1 to calculate a corresponding beam current, one would get that the the coated OFHC Cu HOM antenna quenches at of I_{avg} = 22.5 mA. However, further modifications are needed to increase the Beam Blow Up limit for the TESLA cavities, which is calculated up to I_{avg} = 12.5 mA [2]. For this reason, it is necessary to test the cavities with coated HOM-antennas in an environment where the beam current is an adjustable parameter.

OUTLOOK

The coating process of the antennas started at DESY this spring and two OFHC antennas were coated successfully with NbTiN to study the coating on the antenna geometry. From this study, an improved antenna holder was designed. Modifications at TUDA are ongoing at the moment to coat the antennas with Nb_3Sn this summer. A test stand to study the thermal properties of antennas is under development. A baseline measurement of the test cavities will be performed in Q3 2024.

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