COAXIAL HOM COUPLER DESIGNS TESTED ON A SINGLE CELL NIOBIUM CAVITY*

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Abstract

Coaxial higher order mode (HOM) couplers have been developed for HERA cavities and are used in TESLA, SNS and JLab upgrade cavities. The principle of operation is the rejection of the fundamental mode by the tunable filter of the coupler and the transmission of the HOMs. It has been recognized recently that inappropriate thermal designs of the feedthrough for the pick-up probe of the HOM coupler will not sufficiently carry away the heat generated in the probe tip by the fundamental mode fields, causing a built-up of the heating of the niobium probe tip and subsequently, a deterioration of the cavity quality factor has been observed in CW operation. An improvement of the situation has been realized by a better thermal design of the feedthrough incorporating a sapphire rf window [1]. An alternative is a modification of the coupler loop ("F" – part) with an extension towards the pick-up probe. This design has been tested on a single cell niobium cavity in comparison to a "standard TESLA" configuration by measuring the E_{acc} behavior at 2 K. The measurements clearly indicate that the modified version of the coupler loop is thermally much more stable than the standard version.

INTRODUCTION

The coaxial HOM coupler was originally developed for the 500 MHz HERA cavities in 1985. This coupler provided damping of dangerous modes to Q_{ext} values below 1000. Later, this coupler design as schematically shown in Figure 1 was adopted for the TESLA cavities after modifications to the frequency of 1300 MHz [2]. Because of its successful use in these two projects, it was later adopted for the SNS project and the CEBAF upgrade cavities. The principal of operation is as follows: the inductance of the coupling loop and the capacitance between endplate of the can together with coaxial line between endplate and the output form a tunable rejection filter. The notch of the filter can be tuned such that the fundamental mode frequency is rejected with ~ -100 dB, while the HOM frequencies can pass and are coupled out by the coupling probe to an external load. There is however quite some stored energy in the coupler with the maximum magnetic field near the pick-up probe tip, while the electric field in this area is minimized.

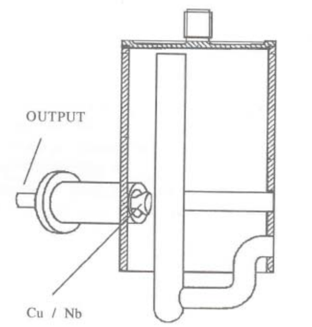

Figure 1: HOM coupler schematic (from Ref. [2]).

The induced currents in the probe tip associated with the magnetic field can lead to heating of the probe tip, if the surface resistance is high and if the generated heat cannot be transferred efficiently to the surrounding environment, e.g. heat sinking at cryogenic temperatures.

In a previous paper [3] we had reported about observations on a CEBAF upgrade cavity, which showed at very low gradients of ~ 3 MV/m already a rapid drop of the Q – value with increasing field in the cavity and the rf had to be switched off up to 1 hr, before the Q-value could be recovered. This was a clear indication that the feedthrough/probe tip configuration used in these tests (probe tip was made of copper) did not provide sufficient heat transfer. A significant improvement was gained by a newly designed rf feedthrough utilizing a sapphire window and a much improved thermal design [1]. We pursued an alternative approach by modifying the coupling loop of the HOM couplers as shown in Fig. 2. A short extension ("leg") towards the pick-up probe is welded onto the HOM loop ("F" – part).

Room temperature measurements carried out at DESY had shown that the damping of the dangerous higher order modes is not being affected by this modification. Simulation calculations of the coupler fields and especially the H-fields at the probe tip showed a significant reduction of the Joule heating at the probe tip as shown in Fig. 3.

In the following we report about the cryogenic measurements on a single cell niobium cavity, equipped with both HOM – coupler types ("standard" and modified).

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Figure 2: Modified HOM coupler configuration.

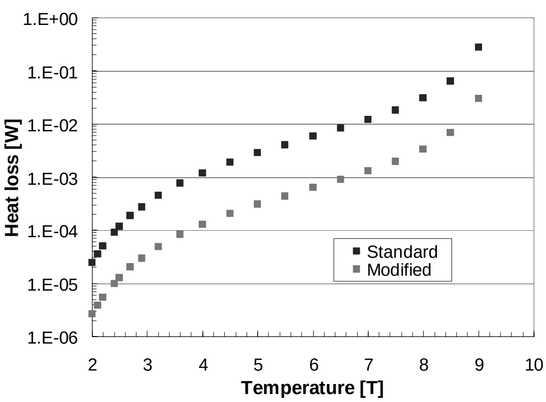

Figure 3: Simulation calculations for the probe heating.

HOM COUPLER TEST CAVITY

For the evaluation of the modified loop design we fabricated a single cell niobium cavity from RRR ~ 250 niobium of the old CEBAF shape with two HOM couplers attached to the beam pipes as shown in Fig. 4. One of the HOM coupler had the old loop configuration; the second coupler was modified as shown in Fig. 2.

In test sequence 1 the cavity and the couplers were fully immersed in the helium bath and the Q vs. E_{acc} performance of the cavity was measured at 2K in two separate tests, where the coupling port of the HOM coupler not under test was blanked off.

As feedthroughs we used in both cases “standard” Kyocera feedthroughs as used e.g. for the TESLA cavities. The probe tips were made from niobium, soldered onto the inner conductor of the feedthrough. The results from this test series are shown in Fig. 5, clearly indicating an improved performance of the modified HOM coupling loop. While in the standard configuration the probe tip heated up and the cavity switched into the normal conducting state at an accelerating gradient of E_{acc} ~ 15 MV/m, the modified coupler did not negatively influence the cavity performance and a gradient up to E_{acc} ~ 27 MV/m was measured, limited eventually by “Q-drop”.

Figure 4: HOM Test Cavity.

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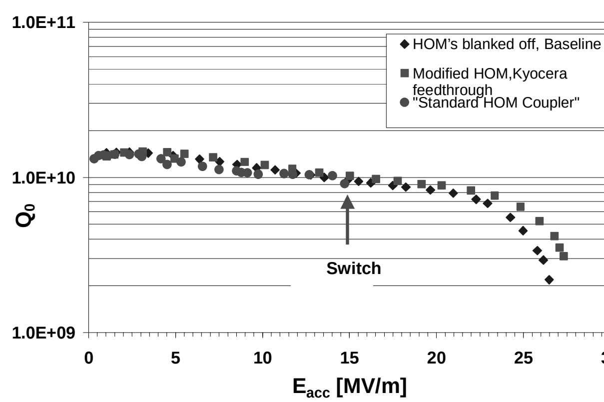

Figure 5: Comparison of the Q vs. E_{acc} performance of the test cavity with coupling probes attached to the “standard’ (red circles) and “modified” HOM couplers (green squares). Included is a baseline test with both HOM couplers blanked off (blue diamonds).

FUTURE TESTS

In the test sequence described above the cavity was immersed in the helium bath. In a cryomodule, the cavity is surrounded by a helium vessel, filled with 2 K helium, whereas the HOM couplers are located in the vacuum space, cooled by conduction from the beam pipes. To simulate this situation as closely as possible, we have modified the cavity such, that the modified HOM coupler can be isolated from the Helium bath by surrounding it with a stainless steel vacuum container, attached to a niobium plate, which has become part of the cavity. Indium gaskets are used for sealing. The new configuration is schematically shown in Fig. 6. The testing of this configuration has started, but no results are yet available for this contribution. A very similar test is in preparation at DESY [4], the only difference being a galvanic contact between the probe tip and the "leg" on the coupling loop, bridging the usual gap between probe tip and loop.

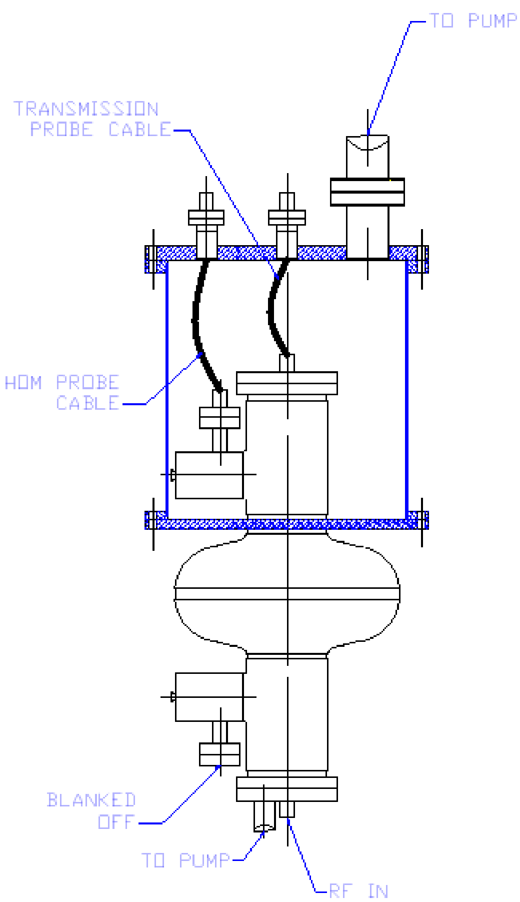

Figure 6: Schematic of isolated HOM coupler configuration.

We believe that further improvements of the thermal stabilization of the feedthrough can be achieved by replacing the niobium probe tip with one made from Nb_3Sn. The higher critical temperature of this material will provide a larger margin for heat load of the probe tip prior to going normal conducting. Simulation calculations have shown [3] that up to several orders of magnitude improvements could potentially be realized.

SUMMARY

A test cavity has been developed, which can be used to evaluate the thermal performance of feedthroughs, probe tip and coupler loop configurations in the coaxial HOM coupler. A comparison between "standard' and modified HOM loop configurations as shown in figure 2 showed significantly improved thermal performance of commercially available feedthroughs for the modified loop configuration, when the cavity was fully immersed in superfluid helium. Further tests are in progress to isolate the feedthrough from the helium bath simulating the situation in a cryomodule, where the HOM couplers are located in the vacuum space and are cooled by conduction from the beam pipes.

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