

Thermal Tests of HOM Couplers for Superconducting Cavities

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Abstract

In order to restrict the multi-bunch phenomena due to long-range wakefields in the TESLA linac, the higher order modes of the cavity must be damped down to the 10^4 - 10^5 level. For this purpose, HOM-couplers, mounted at both ends of the cavity, must couple strongly to the most dangerous modes, while rejecting by means of a filter the accelerating mode. Two versions have been developed [1], one is welded to the beam tube and the other one is demountable thanks to an intermediate flange. In this paper, we present the results of high power tests performed on the demountable version with a special test stand, including a single-cell cavity, a 5kW klystron and the coupler itself, as well as thermal simulations, which were initiated previously [2] with the help of a finite elements code. Accelerating field of 21 MV/m in cw mode, limited by cavity quenches and not by the coupler, was achieved, giving a comfortable safety margin if one keeps in mind that the duty cycle of the TESLA pulsed mode is lower than 2 %. Moreover, by intentional detuning of the filter, the coupler was capable to transmit a peak power of 1.75 kW for the TESLA beam pulse duration, higher than the maximum HOM power which could be resonantly excited by the beam.

on the beam tube, which was not in direct contact with the LHe bath, of a single-cell cavity.

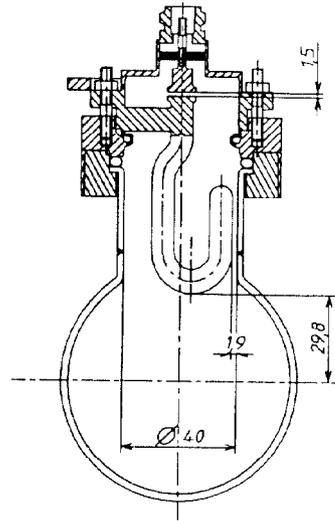


Fig. 1 : Drawing of the demountable HOM coupler

1. INTRODUCTION

The key component of the demountable coupler is a loop whose plane is orthogonal to the beam axis (see figure 1), which couples mainly to magnetic field for the dipole modes and mainly to electrical field for the longitudinal modes. The rejection filter of the fundamental mode is simply formed by the inductance of the loop itself and the capacity between the loop end and the outer conductor [3]. No stringent fabrication tolerances are required and the final tuning of the filter can be performed outside the clean room, once the coupler is mounted and the cavity is closed, with the help of the small bellow located above the Helicoflex gasket. The present design of the LHe-vessel of the TESLA cavity prevents from a direct cooling of the coupler by LHe. The loop is then simply cooled by conduction through the upper stub, which can be however linked to the LHe bath through a thermal shunt. Since the integrated filter has to sustain very high reactive power (the external Q of the coupler without filter with respect to the accelerating mode is only a few 10^6), the thermal behaviour of the device under high RF power must be carefully studied. We present and discuss the results of RF tests and calculations obtained with different couplers mounted

2. TEST STAND AND CALIBRATION

For the power tests, we used the existing 1497 MHz RF equipment. The cavity and coupler dimensions were then scaled from the 1300 MHz TESLA frequency to 1497 MHz. However, in order to push away limitations due to cavity quenches, the coupling of the scaled version to the accelerating mode was made on purpose five times higher than the final 1300 MHz TESLA version. The distance between the cavity iris and the HOM coupler was decreased, while the loop penetration in the beam tube was increased. With this test arrangement, the surface magnetic field at the filter location is about 3 Gauss/MV/m. We also used calibrated thermometers fixed around the coupler and the beam tube for temperature measurements. On the other hand, the important parameters which can be only deduced from experimental data, such as the thermal contact resistance at the sealings, were determined by means of a special arrangement using a heater. This arrangement looks like the real coupler (Fig. 2) and was also used to check the thermal simulations. A manganin wire heater, attached to the end of the loop, is used to simulate the RF losses and the resulting temperature distribution around the coupler and the uncooled beam tube is measured as function of the heater power (P_{heater}).

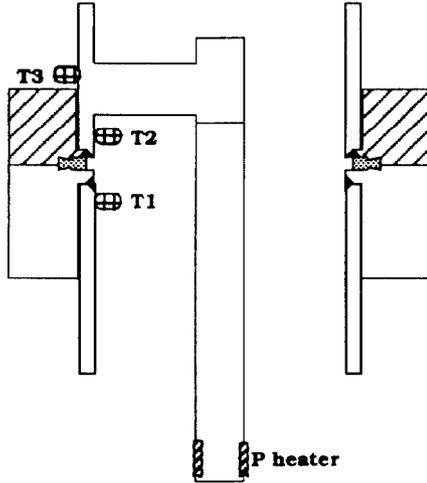


Fig. 2 : calibration test assembly

The results showed an important thermal contact resistance across the flanges. An overall equivalent thermal conductivity k_{eq} to this assembly can then be defined by :

$$\int_{T_1}^{T_2} k_{eq}(T) dT = P_{heater} \frac{L}{S}$$

where L and S are geometrical parameters. The value of this equivalent thermal conductivity at 4.2K is 720 times lower than that of the Nb used for the tests (RRR=270).

Furthermore, by introducing k_{eq} in the simulation model, the resulting temperature distribution is very close to the measured values (Fig. 3). Moreover, the Nb critical temperature is reached at the extremity of the inner conductor for a heater power of 60mW inducing a temperature difference across the flanges of 6.2K.

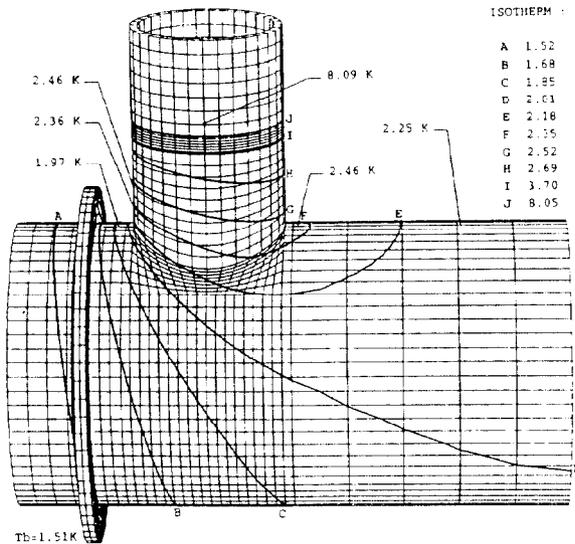


Fig. 3 : measured and computed temperature distributions for a heater power of 46mW

Consequently the thermal breakdown of the coupler will be mainly controlled by this thermal contact resistance, and only

a small gain on power capability (<10%) is obtained by using a loop made of sputtered niobium onto a copper substrate.

3. RESULTS OF THE RF TESTS

A. Without thermal shunt

Preliminary tests were performed without any thermal shunt in cw mode. Various configurations were used : different loop geometries (cylindrical and bean shaped capacitor), different construction materials (bulk Nb, Nb/Cu) and/or different tunings ($2 \cdot 10^{10} < Q_{ex\ fund.} < 6 \cdot 10^{12}$). For all these tests, the quench of the coupler occurred for cw accelerating fields in the range 11-14 MV/m and was always characterized by the same phenomena (Fig. 4) : Eacc jumps from the maximum field to ~2MV/m at the same incident power, the quality factor drops from $\sim 10^{10}$ to $\sim 10^9$, the $Q_{ex\ fund.}$ of the coupler decreases by ~30%, the maximum temperature measured during the RF test reaches values higher than 20K.

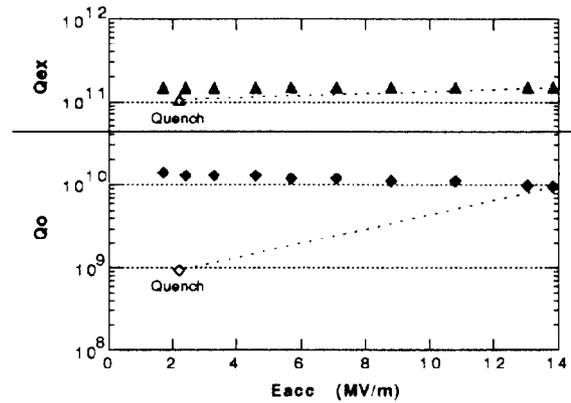


Fig. 4 : Q_o and Q_{ex} versus Eacc for a Nb HOM coupler without thermal shunt.

(Solid symbols : values before the coupler quench
Open symbols : values after the coupler quench).

From the test corresponding to Fig. 4, it is possible to evaluate the dissipated power of the HOM after the quench. Before the quench at a field of 2.1 MV/m the Q_o value gives a dissipated power in the cavity of 31mW (all the other dissipations are neglected at this very low field). After the quench of the HOM coupler and for the same field, the Q_o value is about ten times lower, leading to a dissipated power in the coupler of 430mW. The dissipating area is the region where the magnetic field is highest, i.e. the extremity of the loop. At this location, from the dissipated power and the value of the magnetic field, one can deduce a surface resistance of $5.3m\Omega$ which is consistent with the measured temperature of 26K. Once the quench of the coupler is reached ($T_{max} \sim 25K$), about 3 minutes are needed for recovering the s.c. state with a maximum temperature lower than 4K. It is worthwhile noting that even without thermal shunt, the quench of the coupler, which occurs at 14 MV/m in cw mode, will occur at a much higher field for the TESLA pulsed mode (2% d.c.). For example, the thermal breakdown was observed at 20.7 MV/m for a duty cycle of 40 %. However, since the coupler could be

exposed to intense field conditions if the cavity has to be processed in-situ with pulsed peak power, and in order to increase the safety margin in normal operation, a thermal shunt linking the upper stub to the LHe-vessel was added.

B. With thermal shunt

In order to by-pass the gasket, the stub of the HOM coupler was connected to the LHe tank by a thermal shunt (standard braided copper wires). The test with this arrangement was limited by a quench of the cavity at 21 MV/m, but up to this value the coupler did not show any abnormal behaviour (Fig. 5).

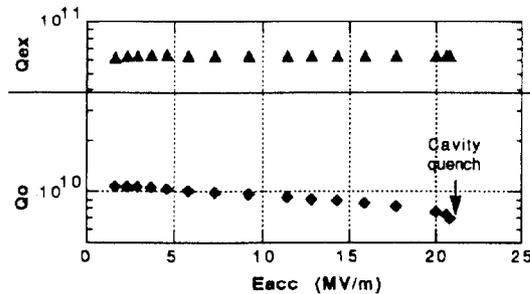


Fig. 5 : $Q_0=f(E_{acc})$ (Nb HOM with thermal shunt)

With a LHe bath temperature of 1.65K, the maximum temperature measured around the coupler (Fig. 6) is 4.06 K at the maximum field level. A test in pulsed mode with 18.6% duty cycle at the same field level (21 MV/m) showed oscillations of the maximum temperature between 1.94K and 2.22K, consistent with the curve of Fig. 6 obtained in cw mode if one considers the average squared field ($= E_{acc}^2 \cdot d.c.$). Using the calibration test assembly, the heater power needed to reach the Nb critical temperature was 285mW (as compared to 60mW without the thermal shunt).

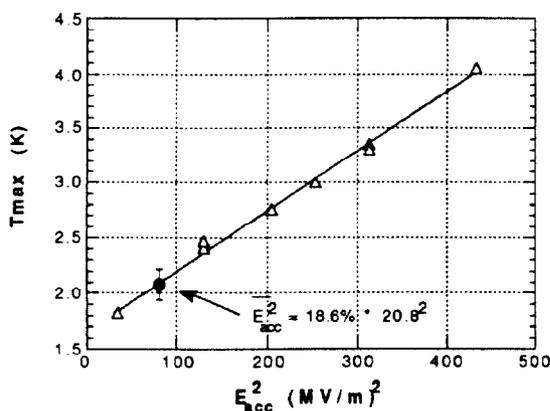


Fig. 6 : Maximum temperature measured in cw mode (triangles) and in pulsed mode (dot).
(Linear fit : $T_{max} = 1.65 + 5.47 \cdot 10^{-3} E_{acc}^2$)

In addition, the coupler was tested with the TESLA beam pulse (10Hz, 0.8ms) and a detuned filter to simulate the peak power which could be induced by resonantly excited HOMs. A peak power of 1.75 kW, higher than the expected HOM power

which could be extracted in the worst case, was transmitted before reaching the anomalous heating of the coupler. The hottest point during this test was located close to the N-SMA transition at the RF output of the coupler.

4. MULTIPACTOR AND FIELD EMISSION

No multipactor was detected with the final coupler whose filter capacitor is made of the end of the straight cylindrical inner conductor and the outer conductor. However, the multipactor was clearly identified with a coupler whose capacitor IC is bean shaped. Taking into account the capacitor gap variation due to a concentricity default between the bean shaped IC and the outer conductor, multipactor is expected to occur theoretically in the E_{acc} range 1.6-2.2MV/m. This is consistent with our observations among which : the high temperature values for $E_{acc} = 1.8\text{MV/m}$, the random strong and fast temperature increases in the vicinity of the capacitor during the field rise or fall of some pulses for 13.2MV/m (the maximum temperature is measured at this location while it is measured in front of the stub without multipactor), and the electronic current measured at the RF output of the coupler.

For each test, the computed and measured temperature distributions are in good agreement for all the thermometers excepted those located on the uncooled beam tube (systematically higher than the computed values by 0.3 K to 1.0K depending on E_{acc}). The emitted electrons from the cavity could dissipate a power of up to 1 W on the beam tube if we assume typical values for the involved parameters (electron kinetic energy, e^- current, ...). This additional heat load could explain the observed discrepancy.

5. CONCLUSION

The thermal behaviour of the demountable coupler has been still enhanced thanks to a thermal shunt. A cw accelerating field of 21 MV/m, limited by a cavity quench, was then reached. The maximum temperature measured in front of the stub is 4.0 K at this field level, and decreases to 2.1 K with a duty cycle of 18.6 %. The coupler should then operate with an important safety margin with TESLA parameters (1.4% d.c. and 25 MV/m). Moreover, the test with a detuned filter and the TESLA beam pulse showed that the coupler could handle a RF power of 1.75kW, higher than the maximum power extracted from HOMs when they are resonantly excited by the beam.

6. REFERENCES

- [1] Sekutowitz, "HOM coupler for TESLA", 6th Workshop on RF Superconductivity, CEBAF, 1993
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- [3] A. Mosnier, "Developments of HOM couplers for superconducting cavities", 4th Workshop on RF Superconductivity, Tsukuba, 1989.