TESLA TYPE 9-CELL CAVITIES CONTINUOUS WAVE TESTS

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Abstract

TESLA 9-cell cavity [1] was designed a decade ago for pulse operation at duty factor of a few percents and is successfully used for the FLASH linear accelerator at DESY [2], [3] and will be used for planned XFEL [4]. Recently, numerous coherent and synchrotron light sources projects base their driving superconducting linacs on this design assuming operation in a continuous wave (CW) mode at rather high gradients. We have performed CW tests of a standard 9-cell TESLA cavities installed in helium vessel and fully equipped with the standard TESLA-TTF auxiliaries, main coupler and both Higher Order Mode (HOM) couplers in the horizontal test cryostat to find out a limit in the CW operation.

INTRODUCTION

The lifecycle of a standard 9-cell TESLA-type cavity includes two types of high RF power cavity tests. One is a CW test of the cavity without liquid helium (LHe) tank fully immersed in LHe in the vertical test cryostat and most efficiently cooled. The second is a pulsed test with the cavity, welded in LHe tank and fully equipped with the standard TESLA-TTF auxiliaries, main coupler and both HOM couplers. The cavity is placed in the horizontal test cryostat without LHe end-groups cooling (fig.1,2). There are two limits for cavity-in-tank in the full CW mode: first, cryogenic power limit (tank and LHe supply line diameter) at about 35 W (2 K), second, the end groups cooling by thermal conduction. Two cavities were taken for such a test, S33 and AC128, last one equipped with a new HOM coupler feedthroughs with sapphire isolator, having much better thermal conductivity as a standard one (aluminum ceramics), see [5] and [6]. New feedthroughs allow for better inner conductor cooling through copper braid connection to the 2 K cooling circle (fig.3).

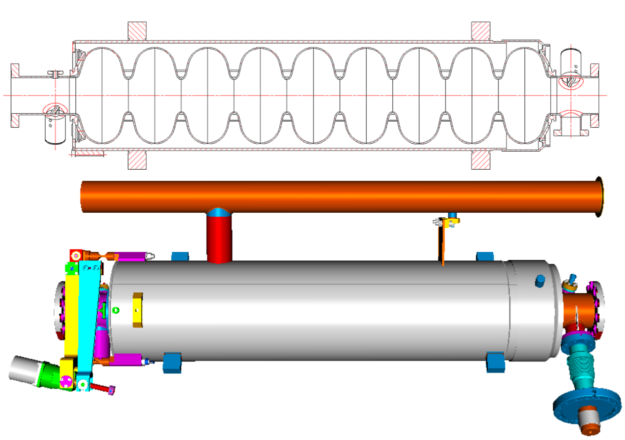

Figure 1: SRF cavity in LHe tank with auxiliaries.

EXPERIMENTAL SETUP

The CW cavity-in-tank test (usually named horizontal test after the horizontal test cryostat) is done with the same horizontal cryostat setup a pulsed RF test is done with, but instead of the 5 MW klystron the 1 kW CW amplifier together with analogue PLL low level RF system from the vertical cryostat CW test is used to power the cavity. To couple the CW RF power to the cavity a high-Q-antenna with a Q_{load} about 10^{10} is installed instead of a standard RF power input coupler ($Q_{load}=3x10^6$), see fig.2. Several Allen Bradley type thermometers are fixed at different locations at HOM couplers (HOM1, HOM2) for monitoring the temperature during the tests, see fig.3.

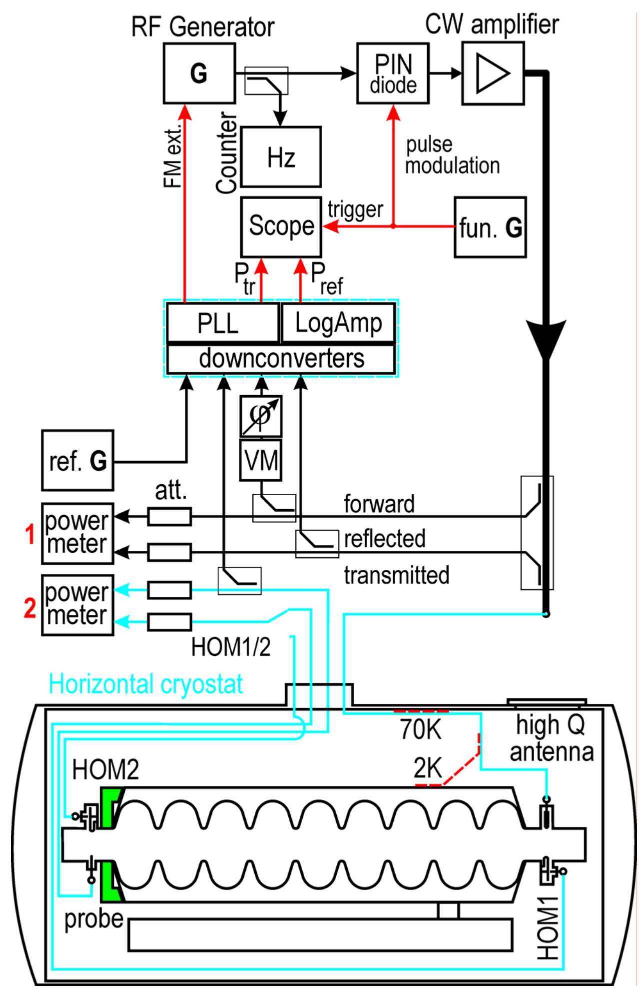

Figure 2: Superconducting cavity CW test in horizontal test cryostat.

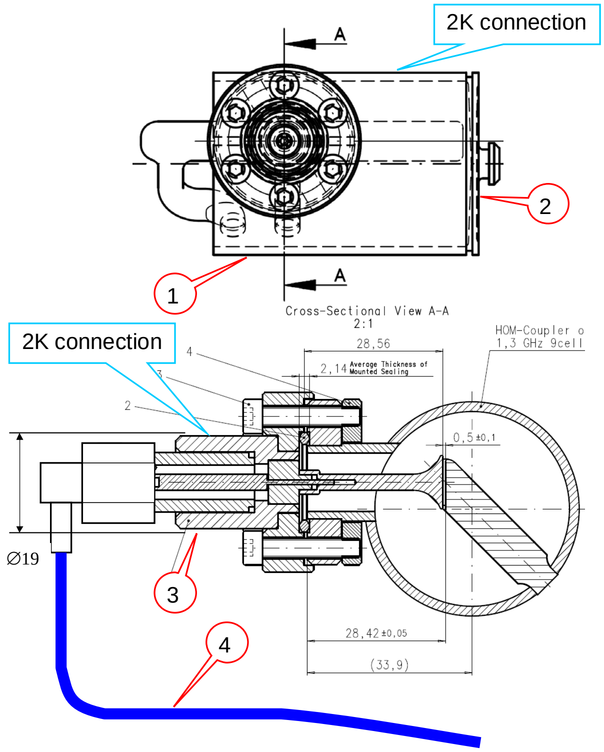

Figure 3: HOM coupler with a new feedthrough (JLAB design), with temperature sensors positions.

MEASUREMENT RESULTS

Cavity S33

This cavity reached 25 MV/m in the standard vertical CW test without HOM couplers feedthroughs (fig.4, test 7) and 24 MV/m with decreased Q_0 in the repeated vertical test with the feedthroughs (fig.4, test 15).

The horizontal CW test was done with terminated HOM couplers feedthroughs (fig.4 test 11) and with feedthroughs connected to the RF cable (fig.4, test 13).

Only with fast, large RF power step measurement reaching the vertical test performance was possible (fig.4 test 11/48), standard test performance was limited at 15 MV/m with strong Q_0 drop at the end (fig.4 test 11/49) resulting from the HOM1 (fig.2) coupler heating caused by small part of the operating mode RF power coupling (rejecting filter is tuned to Q_{load}~10^{11}). Fast test with connected feedthroughs gave the curve with decreased Q_0 and 20 MV/m limit (fig.4 test 13/63), now the additional heat load from cables also deteriorated the performance of the cavity and resulted for the even worst result, 7 MV/m limited, if measured slowly (fig.4 test 13/64). HOM1 coupler heat load was strongly limiting the performance.

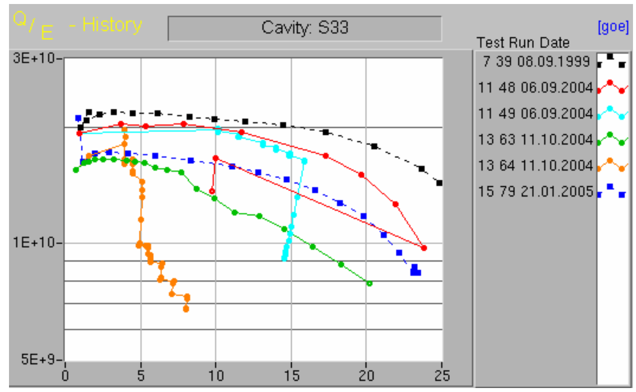

Figure 4: Cavity S33 tests (7 and 15 are vertical tests).

Cavity AC128

Vertical CW tests results are presented in fig.5.

Horizontal CW tests done with HOM coupler feedthroughs cables connected, first test without cooling of the feedthrough (fig.6,7, test 4), second one with cooling of the feedthroughs, connected through a copper braid to 2 K cooling circle (fig.6-8, test 5). Test was done for 1.8 and 2.0 K LHe bath temperatures, see fig.5-7.

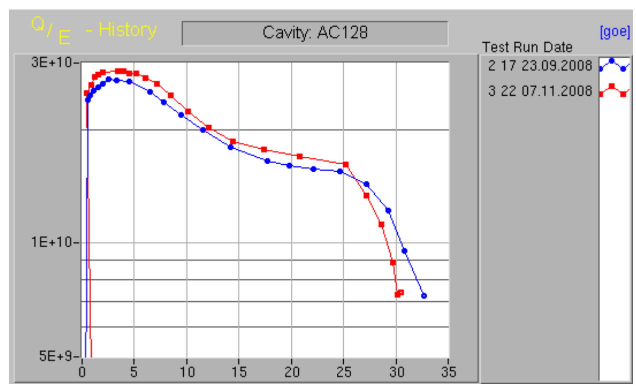

Figure 5: Cavity AC128 vertical tests.

Main points are:

- $E_{acc.max}$ = 32.2MV/m with Q_0 (low field) = $2.5x10^{10}$ (at 2 K), vertical cavity test performance (fig.5) reached (fast point measurement).
- Slow power-up with max.gradient of 25 MV/m (P_{diss} = 57 W), cryogenic cooling system limited.
- Measured at 1.8 K up to 32.8 MV/m (P_{diss} = 104 W) – fast point measurements with RF power off (cooling) in between (1 s RF ON / 10 s RF OFF).
- Q_{HOM1} = $3x10^{12}$, Q_{HOM2} = $2x10^{12}$, Q_{trans} = $2.7x10^{11}$.
- 6/9π and 5/9π modes used for the HOM couplers RF power heating test (HOM couplers rejecting RF filters are tuned to π-mode).
- $T_{feedthrough.max}$ = 70 K (fig.3, sensor 3), at 7..15 W HOM coupler RF power. No HOM coupler caused quenches.
- Some performance improvement through HOM couplers feedthroughs with sapphire isolator connection to 2 K circle, feedthrough temperature decreases from 100 to 70 K for 10 W HOM coupler long time operation at 6/9π mode.

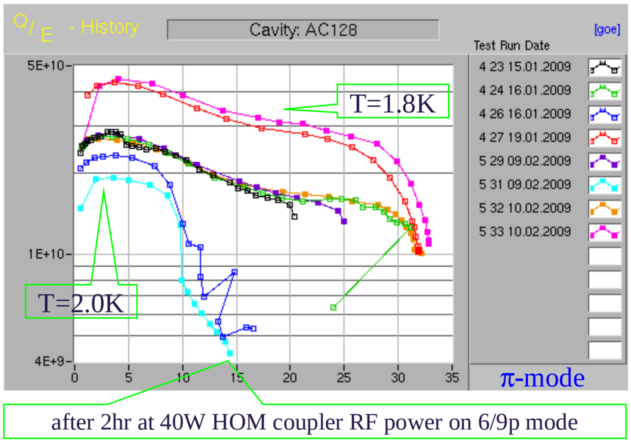

Figure 6: Cavity AC128 horizontal tests history.

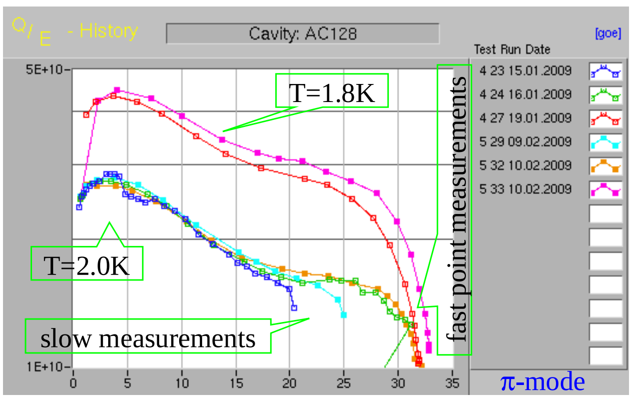

Figure 7: Cavity AC128 horizontal tests: cavity performance improvement with connection of HOM coupler feedthroughs to 2K.

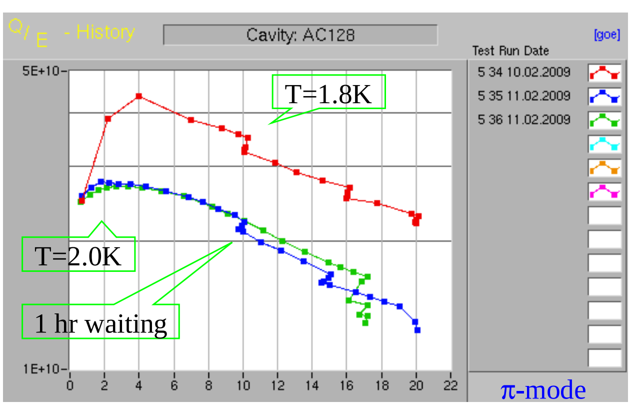

Figure 8: Cavity AC128 horizontal tests: long time test history.

Fast point measurement show the same Q_0 vs. E_{acc} curve as for the vertical test (fig.5). The difference of the slow measured Q_0 vs. E_{acc} curves (at 2 K) for cooled and not cooled HOM coupler feedthroughs (fig.7) are much more pronounced: 25 MV/m instead of 20 MV/m could be reached. After certain heating-up of the HOM couplers, using 6/9π and 5/9π modes, operating π-mode performance is degraded down to 15 MV/m and lower Q_0, see fig.6. Long time tests also show the performance degradation with slow heating-up of the HOM couplers with the π-mode, see Fig.8. The HOM couplers temperatures development during the long time test at 1.8 K with cooled feedthroughs is presented in fig.9.

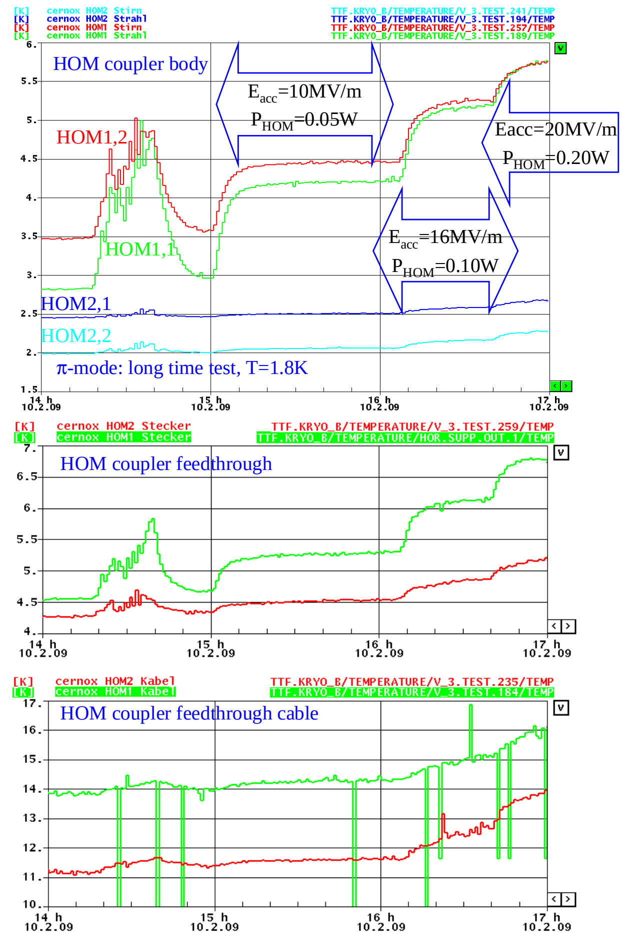

Figure 9: Cavity AC128 long time test history: HOM couplers temperatures (feedthroughs are connected to 2 K cooling circle).

SUMMARY

- CW tests of a standard 9-cell TESLA cavity installed in helium vessel and fully equipped with TESLA-TTF auxiliaries, main coupler and both Higher Order Mode (HOM) couplers, but sapphire isolator feedthroughs (JLAB design), in the horizontal test cryostat shows certain performance degradation compared to the test in vertical cryostat (cavity cooled completely with liquid helium). Two cavities were tested, both with the same trend.
- Main cavity performance limit is LHe cooling, limited at about 35W dissipated power per cavity in tank.
- Better HOM coupler feedthroughs cooling improves the cavity performance.

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