MULTIPACTING IN HOM COUPLERS AT THE 1.3GHz 9-CELL TESLA TYPE SRF CAVITY

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Abstract

During the XFEL [1] prototype module tests on the module test stand at DESY [2], [3], [4] RF power measurement anomaly on the higher order mode (HOM) couplers at the cavity operating frequency was detected and investigated. HOM coupler multipacting, predicted by the analytical simulations [5], was found to be the source of the anomalous signal peak. TESLA type SRF cavity HOM coupler multipacting simulations and observations are presented, compared and discussed.

INTRODUCTION

During the module tests of PXFEL1, 2 and 3 on CMTB [4] some RF power measurement heads, used for the accelerating cavities HOM couplers (see Fig. 1) RF power measurement at main operating frequency were damaged. The damaged RF power measurement heads have approximately -3 dB measurement error. The HOM coupler signal anomaly was investigated in search for the damage reason.

Cavities RF test data show the HOM couplers RF power anomalous jumps for some cavities during the measurements.

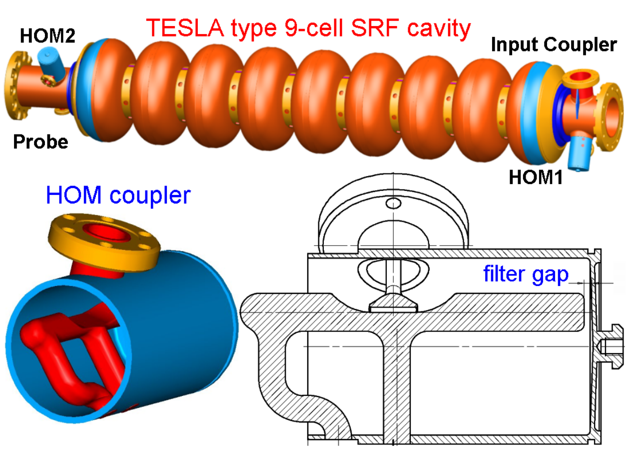

Figure 1: TESLA type SRF accelerating cavity.

XFEL PROTOTYPE MODULE MEASUREMENTS

During the module PXFEL3 test on CMTB a spectrum analyzer showed besides a stable base pulse signal sharp irregular peaks on 1.3 GHz frequency (on the base peak top), the peaks reaching +15 dB over the base signal. This effect appears after reaching certain RF power level of about 100 kW (17 MV/m) at 500 + 800 µs flat-top pulse.

Digital scope measurement with an RF diode revealed the anomalous signal structure – a very short peak about 10 µs appears about 20 µs after RF input power pulse start (see Fig. 2). It was found at both HOM couplers in cavities 1,2,3 and 7 depending on RF power level. Anomalous peak amplitude exceeds the normal HOM coupler coupled 1.3 GHz signal amplitude, but it is comparable to cavity probe signal amplitude.

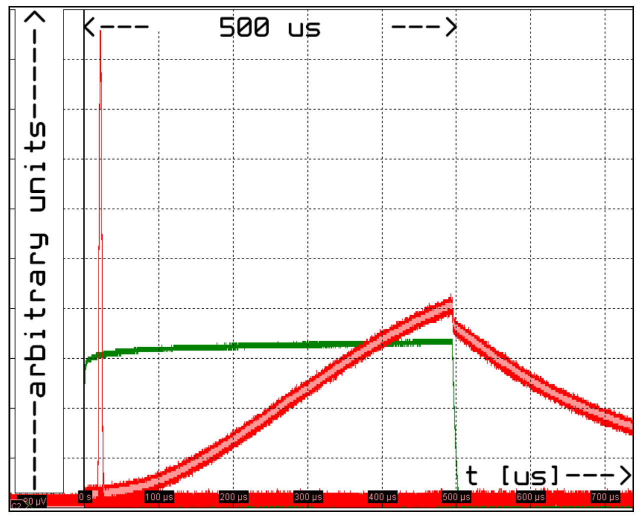

Figure 2: Anomalous peak with 500µs / 170kW RF pulse - green (21 MV/m). PXFEL3.C2.HOM1 pulse – red, measured with an RF diode.

The anomalous peak does not depend on the RF pulse length as soon as pulse is long enough for the peak to appear, about 20..30 µs.

Anomalous Peak has a definite RF power onset level, different for different cavities and HOM couplers. Increasing the RF amplitude shifts the anomalous peak in the pulse start direction (see Fig. 3). The anomalous signal is not stable, it changes its shape. It does not appear at each RF pulse, more frequent by higher RF power level, differently with different cavities HOM couplers.

Direct scope measurement without the RF diode also shows the signal with the same timing, highly modulated. RF low pass / 1.3 GHz notch filter cancels the signal.

Detuning the cavity first cancels the peak on HOM2 coupler. Partially detuned cavity (by 1 kHz, gradient decreased by 5%) has this peak on HOM2 coupler signal. Completely detuned cavity does not have the effect – anomalous peak needs the cavity field and depends on it strongly. Strong field configuration dependence is seen, partially detuned cavity field has multiple zero crossings (it oscillates) and there are multiple anomalous peaks (see Fig. 4). Detuning the neighbor cavities does not change the signal.

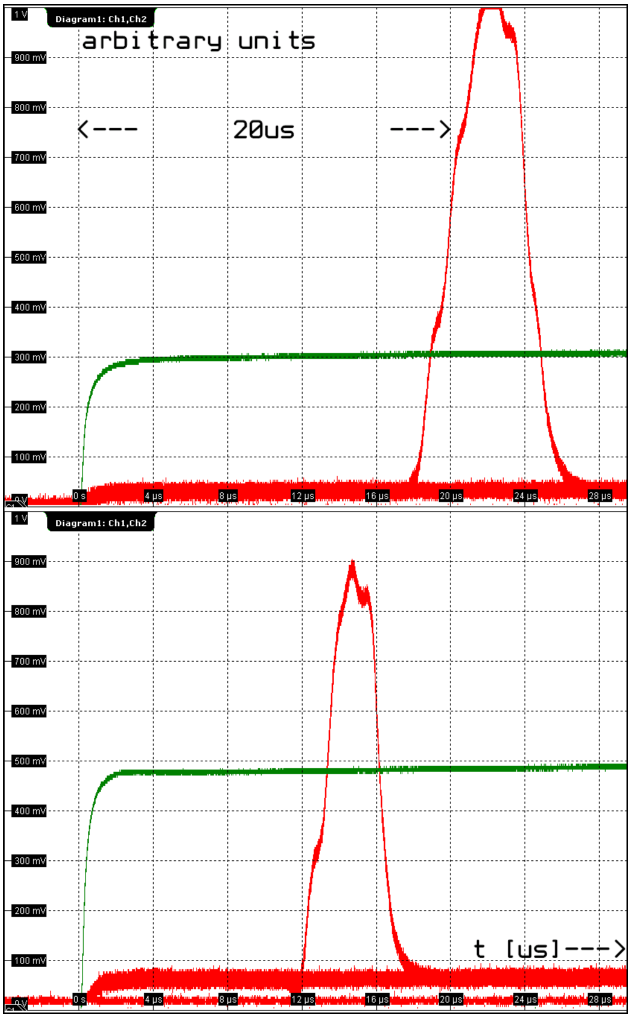

Figure 3: RF power change 170kW / 370kW, 100µs RF pulse – green, PXFEL3.C2.HOM1 pulse – red.

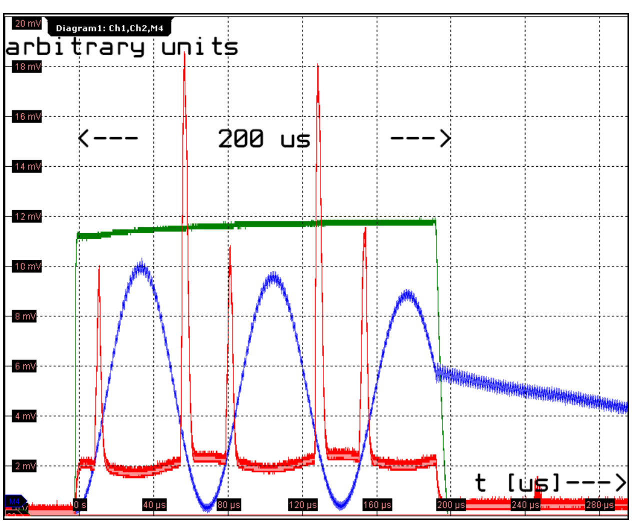

Figure 4a: PXFEL3.HOM1.C2 signal with cavity 2 partially detuned – red, blue – cavity probe signal.

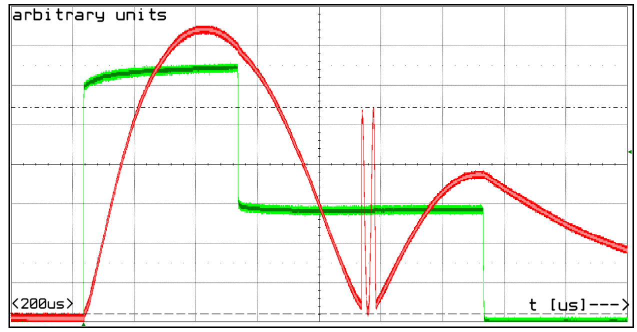

Figure 4b: PXFEL2_1.HOM2.C2 signal – red, with cavity 2 partially detuned. Input RF power pulse – green.

Additionally, the Direct Current (DC) measurement was done with a 10 V bias on the HOM1.C2 coupler using the e- interlock card, the standard part of the coupler interlock designed to measure the electron current with a small DC bias. Connection was done using the RF low pass filter from e- interlock. This measurement shows no DC signal on the interlock card. Anomalous signal effect is present, confirmed by HOM2.C2 signal. The measurement shows only the noise, no coherent signal. Thus, the anomalous signal must be the modulated 1.3 GHz RF signal.

SIMULATION DATA

SRF accelerating cavity HOM coupler multipactor was analytically predicted in [5]. New simulations were done for comparison with the experimental data using new RF field simulations.

Cavity RF Fields Simulation

TESLA type 9-cell SRF accelerating cavity RF field simulation was done using the CST Microwave Studio [6]. The simulation is summarized in Fig. 5. The HOM coupler rejection (1.3 GHz) filter 1.73 mm nominal gap field was analytically calibrated with cavity cell longitudinal electrical field maximum – the cavity accelerating electrical field value. The electrical field ratio E_{acc}/E_{gap} = 8.75. This value was used to normalize the HOM coupler rejection filter gap field to the cavity accelerating gradient value.

Multipacting Simulation

Analytical 2-points resonance simulation of the flat 1.73 mm gap multipactor was done for niobium, see Fig. 6, [5]. The simulation predicts the resonance at 170..210 kV/m gap electrical field amplitude. This gap electrical field value corresponds to 1.5 .. 1.8 MV/m cavity accelerating gradient value. The multipactor is an RF resonant electron discharge shorting the HOM coupler rejection filter gap with an electron current, causing the rejection filter de-tuning during the multipacting and, thus, HOM coupler RF power coupling change at cavity operating frequency.

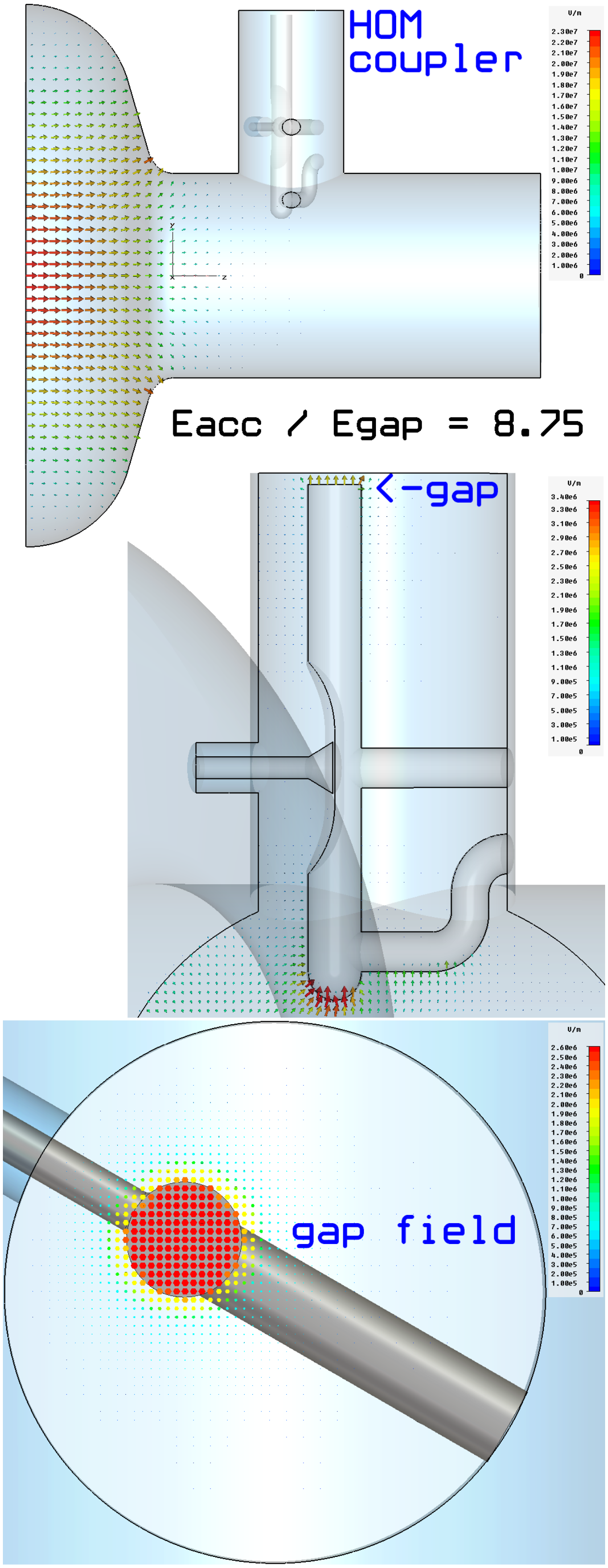

Figure 5: Cavity RF field simulation (CST Microwave Studio).

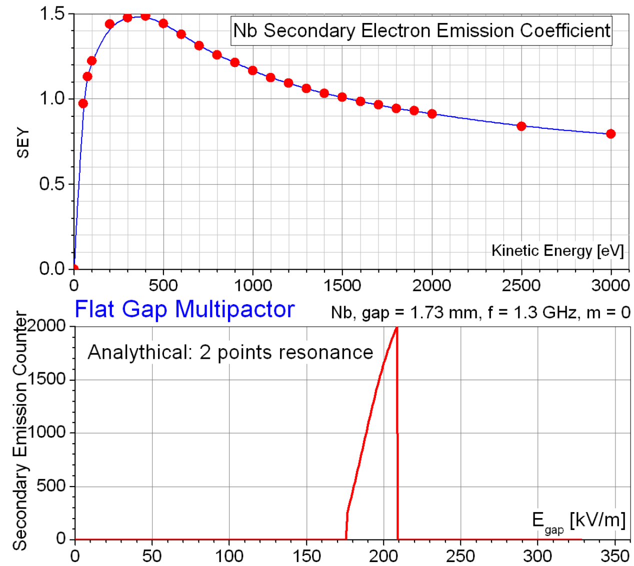

Figure 6: Flat gap multipacting simulation with niobium.

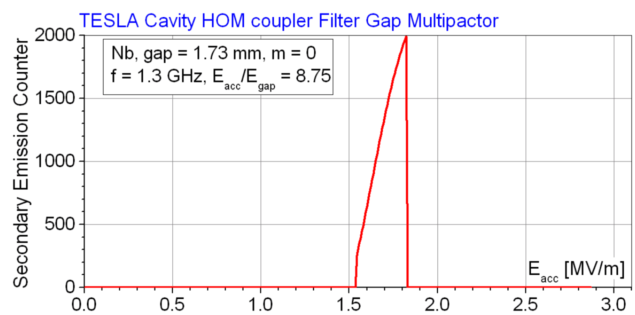

Figure 7: 1.3 GHz TESLA type cavity HOM coupler rejection filter gap analytical multipacting simulation.

SUMMARY

- Probable source of an anomalous signal from the HOM couplers is the multipacting in the HOM coupler. After 18 µs at 170 kW the cavity reaches 1.1 MV/m (same for 12 µs and 370 kW). The multipactor discharge detunes the notch filter. Effect was found in several cavities in PXFEL1,2,3 modules.
- This effect depends both on the RF input power amplitude and field in the cavity. There is no effect with long pulses but lower RF power, with a short pulse (as short as 50 µs) effect can be seen with higher RF power – even with much lower cavity field. But, if the signal is observed during the cavity detuning, the field dependence can be also seen. Partially detuned cavity with time oscillating field has multiple peaks, corresponding to the field periods.
- The anomalous peak amplitude is rather small compared to the cavity probe signal, its amplitude exceeds the one of the normal HOM coupler signal (the notch filters are very good tuned). From the other side this anomalous peak effect is amplified and

multiplied in peaks number during the cavity detuning.

- The multipacting discharge is not affecting the feedthrough / HOM coupler antenna area – DC measurements with 10 V bias (and without it) with RF low pass filter show no signal. If the multipacting is the source of the effect under investigation, it must be present at the HOM coupler rejection filter gap and be localized there, as simulation predicts.
- The HOM coupler anomalous peak signal amplitude is comparable with a cavity probe signal amplitude. Thus, this effect can not be responsible for the RF power meter damaging.

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