ANALYSIS OF THE HOM DAMPING WITH MODULATED BEAM IN THE FIRST PROTOTYPE OF SUPERSTRUCTURE

P. Castro*, A. Gössel, S. Schreiber, J. Sekutowicz, M. Wendt, DESY, 22603 Hamburg, Germany,
N. Baboi†, SLAC, CA 94025, USA, G. Devanz, CEA-Saclay, France

Abstract

Superstructures, groups of weakly coupled cavities fed through a single power coupler, are currently investigated as a more cost effective alternative to the 9-cell TESLA cavities. Two Nb prototypes of the superstructure have been built, consisting of two 7-cell cavities, and installed in the TESLA Test Facility at DESY. The HOM damping of these superstructures has been investigated with a modulated beam using the method described in [1]. A charge modulation imposed on the 54 MHz bunch train excites HOM at frequencies $n \cdot f_b \pm f_{\text{mod}}$, where n is an integer, $f_b = 54$ MHz is the bunch frequency and f_{mod} is the charge modulation frequency between 0.5 and 27 MHz. The effects of the excited HOMs on the beam transverse position are observed at a downstream BPM, followed by a direct analysis of the modes at the HOM couplers.

INTRODUCTION

An alternative layout of the TESLA Linear Collider [2], based on weakly coupled multi-cell superconducting structures (so-called superstructures) reduces cost due to a simplification of the 1.3 GHz RF system. The concept of superstructures is discussed in more detail elsewhere [3, 4]. Two 2x7-cell superstructures have been installed in the TESLA Test Facility (TTF) linac downstream of the injector. The goal of this test is to proof experimentally the expected performance of superstructures in terms of energy stability, Higher Order Mode (HOM) damping, frequency and field adjustment methods. An overview of the test results is given in [5]. The investigations of the HOMs of the superstructures with modulated beam are presented here. A HOM study on superstructures has been accomplished in combination with two other methods described in [5, 6]

MEASUREMENT PRINCIPLE

The principle of the experiment [1] is to excite HOMs resonantly by modulating the bunch charge of a long train of bunches which travels through the cavities with a transverse offset. The charge modulation generates side-bands around the bunch harmonics $n \cdot f_b$, with n an integer and f_b the bunch frequency. A HOM with a frequency f_{HOM} that coincides with one of the side-band frequencies $n \cdot f_b \pm f_{\text{mod}}$ will resonate (see Fig. 1). Once excited, the HOM deflects the next bunches in the train. Thus, the transverse position of the bunches observed with a BPM located downstream of the module is modulated with the frequency f_{mod}. Varying slowly the modulation frequency between zero and $f_b/2$ all modes with high impedance can be found. This method has been previously applied in 1998 [7] and in 2001 [8] on 9-cell TESLA cavities in the TTF linac.

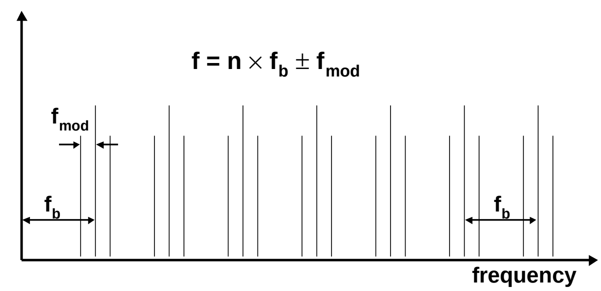

Figure 1: Spectrum of the modulated charge in the bunch train.

EXPERIMENTAL SETUP

The TTF injector is based on a laser driven RF gun [9]. Short UV laser pulses illuminate a CsKTe photocathode and produce a train of electron bunches with high peak current. For this experiment, the laser system [10] was modified to deliver 54 MHz pulse trains with a modulated charge up to 80% in the frequency range between 100 kHz and 27 MHz. The bunch train has a duration of 400 μs with an average beam current of about 2 mA.

The beam position inside the superstructures has been horizontally and vertically displaced using dipole correctors located upstream (see Fig. 2). When a HOM is excited, it kicks the beam and the induced bunch-to-bunch oscillations are detected using a re-entrant cavity Beam Position Monitor (BPM) and a stripline BPM located downstream. The difference signal between opposite antennas/electrodes is filtered at the appropriate frequency using a spectrum analyser in zero span mode. During the first 200 μs of charge modulation, the BPM difference signal is dominated by the charge variation itself. For the last 200 μs, the beam current is constant and the amplitude of the signal corresponds to an oscillation in the beam position along the bunch train caused by the deflecting HOM. An example can be seen in Fig. 3 for the modulation frequency $f_{\text{mod}} = 16.981$ MHz.

The determination of the HOM frequency has been done by picking up the signal at the three HOM couplers at-

* pedro.castro@desy.de
† On leave from NILPRP, PO Box MG-36, 76900, Bucharest, Romania

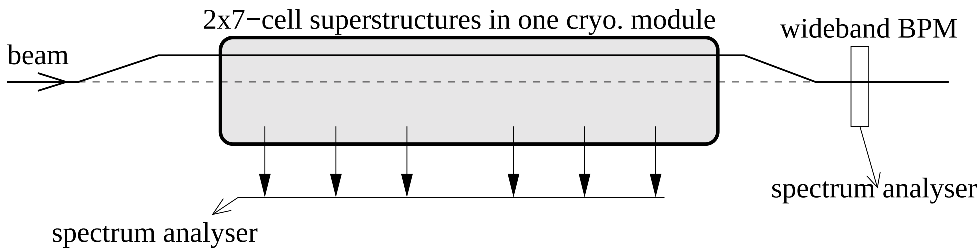

Figure 2: Schematic layout of the experimental setup.

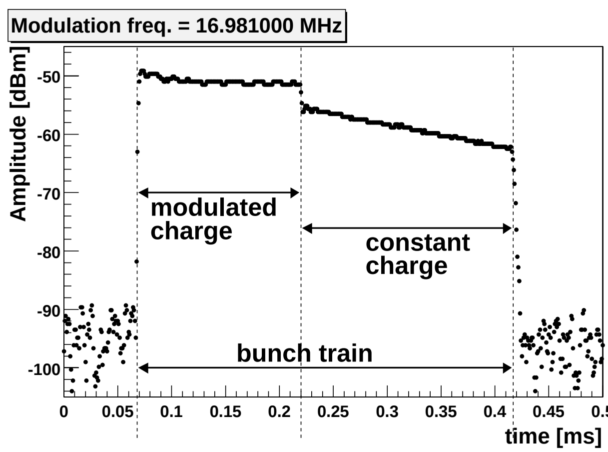

Figure 3: BPM difference signal filtered with a spectrum analyser.

tached to each superstructure. The spectrum analyser is used again in zero span mode and scanned through the signals of the HOM couplers. All frequencies $n \cdot f_b \pm f_{\mathrm{mod}}$ situated in (or close to) the frequency ranges of the first five dipole passbands are scanned. Thus, the mode frequency is identified and the Q value of the resonance is determined from the decay-time of the signal. An example of the signals obtained is given in Fig. 4.

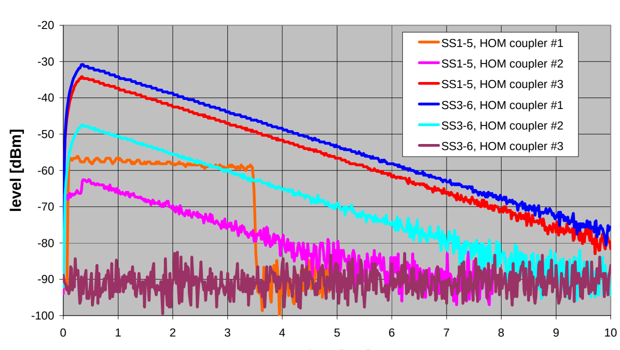

Figure 4: An example of the signals from the HOM couplers of the first superstructure SS1-5 and of the second superstructure SS3-6 at 3076 MHz.

RESULTS

A scan over all frequencies between 0.5 MHz and 27 MHz has been done in both horizontal and vertical planes, in order to cover modes of any polarization. The results are shown in Fig. 5. The amplitude of the oscillations induced by the excited HOM(s) after 200 μs of charge modulation is plotted as a function of the modulation frequency. The beam offset and charge are slightly different in the two scans, and therefore the amplitudes of the resonances can not be compared directly, but with an appropriate factor.

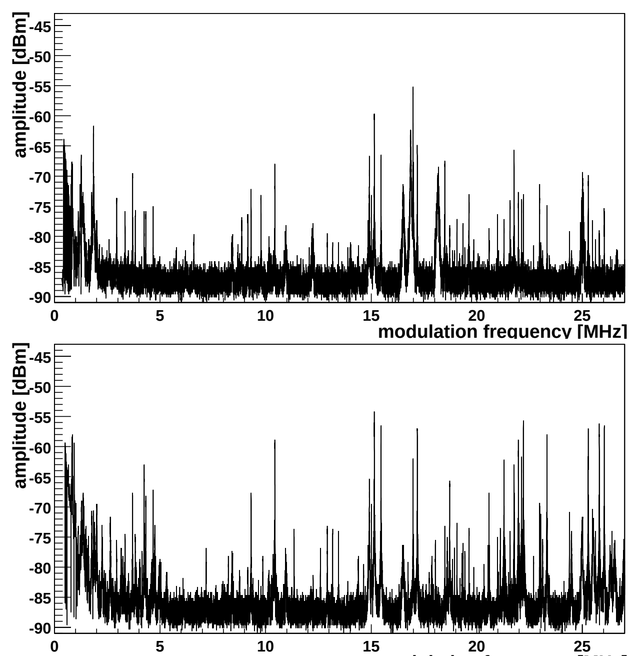

Figure 5: Beam oscillation amplitude after 200 μs charge modulation as function of the modulation frequency. Upper plot: horizontal scan. Lower plot: vertical scan.

About 90 modes have been excited and detected using this method. The mode frequency has been obtained from the HOM signals. The Q value is obtained from the decay time of the HOM signal. The results are compared with the measurements made with the network analyser [5]. An example of this analysis is shown in Fig. 6 for the range of modulation frequency between 26.0 MHz and 26.4 MHz. Not all HOMs are detected with this method. Modes with a decay time shorter than 4 μs could not be observed with this technique, but are in general not dangerous for the beam.

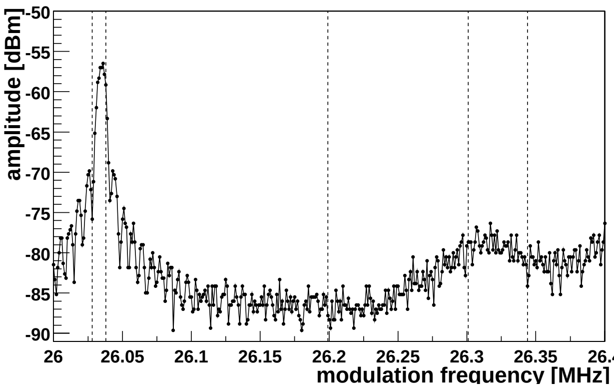

Figure 6: Example of a zoom into Fig. 5 (lower plot) where the amplitude of the vertical beam oscillation versus the modulation frequency is shown. Vertical lines correspond to the frequencies measured with the network analyser.

In the frequency range of Fig. 6, three of five expected modes have a high impedance $Z = (R/Q) \cdot Q_{\text{ext}}$, as it is shown in Fig. 7. Two are dipole modes (at approx. 2.573 GHz, marked with larger triangles) and one is a quadrupole mode (at approx. 2.3 GHz, the second from the left). The decay time of both dipole modes is about 1 μs and they are not seen in the scan of the frequency modulation. The only enhanced and remaining peak is the quadrupole mode which has a decay time of about 100 μs. The damping of both dipole modes was confirmed with the decay of output signals from the HOM couplers. The other two expected modes shown in Fig. 7 were not excited due to their low impedance. The search of other high (R/Q) modes has been performed in similar way.

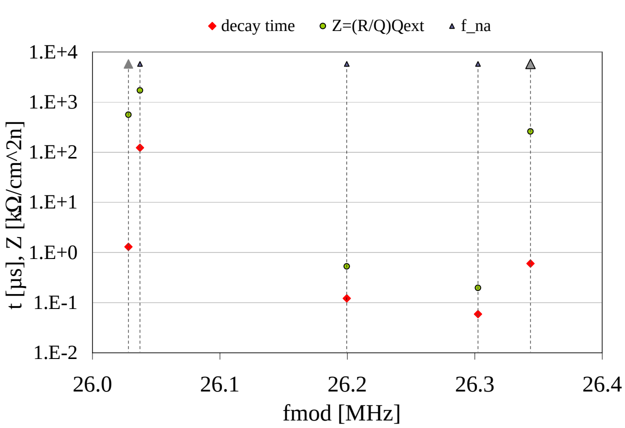

Figure 7: Decay time τ and impedance Z of modes shown in Fig. 6 (vertical lines).

CONCLUSIONS

The investigations on the HOM damping of the superstructures with modulated beam together with two other methods described in [5, 6] have proven that all dipole modes relevant for the TESLA collider (up to 2.58 GHz) are well damped by at least a factor of 5 better than specifications ($Q_{\text{ext}} \leq 10^5$). Four modes out of 420 measured modes were found to have a large Q_{ext} of 10^7 to $2 \cdot 10^8$. These modes are in the 5th dipole passband at about 3.08 GHz. Their (R/Q)s are almost zero and therefore they do not degrade the quality of the TESLA beam.

ACKNOWLEDGMENT

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