SEARCH FOR TRAPPED MODES IN TESLA CAVITIES

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Abstract

In resonant cavities which are connected via beam pipes fields usually tend to propagate with shrinking wavelengths. Nevertheless there may also exist some non-propagating resonant modes („trapped modes“) in the frequency range above the beam-pipe cut-off with relative high shunt impedances which are strongly localised in the inner part of a accelerating structure. Due to their field distributions these trapped modes can hardly be coupled to dampers at the ends of the cavity and therefore could have dangerous effects to beam dynamics. Their detection is very difficult, if one considers that they are embedded in a spectrum of several hundred resonant modes. We therefore started to search trapped modes in a 9-cell copper TESLA cavity. The principles of our method and results from measurements are presented in this paper.

1 INTRODUCTION

For the next generation of electron-positron linear colliders with initial center of mass energies of 350...500 GeV luminosities above 10^{33} $cm^{-2}s^{-1}$ are required [1]. High luminosities correlates with small transverse beam emittance, so that any kind of beam instabilities has to be controlled to avoid emittance growth. One major cause for emittance dilutions in a high energy linear accelerator are wakefields, which are excited by the bunches itself traveling through the accelerating structure. These wakefields could act back on the exciting bunch itself (Single Bunch Breakup) or on all following bunches (Multibunch Beam Breakup) which would be more and more deflected. Especially for superconducting structures with high quality-factors, these wakefields could strongly affect beam dynamics. To preserve the emittance along the whole accelerator, dangerous Higher Order Modes (HOMs) caused by wakefields have to be damped or/and the structure has to be detuned. Differently from long stacked structures with damped cells within the structure [2], the TESLA HOM-damping scheme foresees two couplers attached to both sides of a 9-cell cavity and a single absorber between an 8-cavity module [3]. If HOM-power propagates it can be diminished by the HOM-dampers, but there also may exist some trapped modes which are strongly localised within the cavity. Due to their vanishing field distributions to the ends of the cavity, no strong coupling to the dampers is possible, so they might have considerable influence to the beam dynamics. Therefore we made measurements with a TESLA copper 9-cell cavity following the basic interest to find such trapped modes in the high frequency range.

2 THE MEASUREMENT

2.1 The Test Setup

To measure a frequency spectrum in transmission we coupled in the RF-power with an antenna fed through a small hole in the middle plan of the sixth cell of the cavity and coupled out ditto with a second antenna with about 30° distance from the first. The antennas were fixed with the help of brass bases mounted on the surface of the cavity. Hollow waveguide pipes of 78mm diameter and a length of 0,5m were flanged on both sides of the cavity and models of two HOM-couplers and a input coupler were assembled between the cavity and the waveguides. Necessary for the measurement method each pipe was equipped with a movable short, driven by a stepping motor, provide for different boundary conditions. For perturbation measurements we fed a nylon thread through the holes on the axis of the shorts. We used a spherical dielectricum as bead in order to perturbate transversal and longitudinal fields in like manner. Data is taken by a HP8719C network analyzer. The network analyzer and the stepping motors are controlled via GPIB with a computer, using LABVIEW™ and *Mathematica*™ to work up output files.

2.2 Method

Compared to propagating modes trapped modes should be less affected by variing the peripheral boundary conditions at the waveguide flanges, due to their vanishing field distributions to the ends of the cavity; thus we started to measure the transmission spectrum in a range of 4...8.2 GHz for several positions of the shorts. By overlaying the measured data, remaining pikes in a spektrum indicate transmission signals (S_{21}) not affected by variing the peripheral boundary conditions. This means low coupling to the waveguide pipes, which is one criterion for trapped modes. Hence, we went in our most stable parts of the spectrum for a bead-pull measurement to confirm whether there are localised modes or not (so far we make no statements about the shunt impedances of the trapped modes). The field measurements were performed using a non-resonant bead-pull method, assuming that for small perturbations holds $E^{\wedge 2} \sim |\Delta S_{21}|$ [4,5].

2.3 Results

The following pictures (see fig. 1 and fig. 2) show two measured spectra for different combinations of positions of the stepping motors altogether overlayed in each picture.

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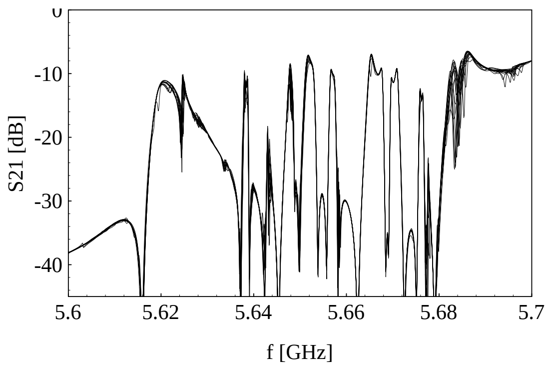

Figure 1: Transmission S_{21} in dependence on frequency for 16 different boundary conditions (f = 5.6...5.7 GHz) .

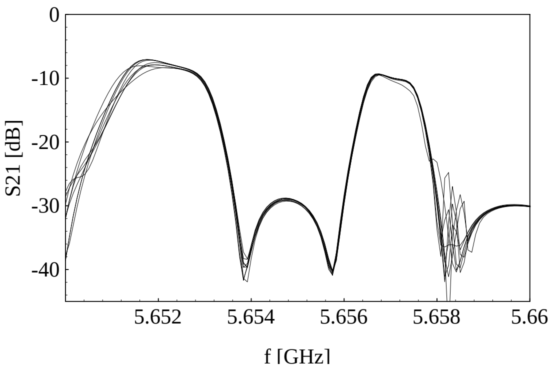

Figure 2: Transmission S_{21} in dependence on frequency for 9 different boundary conditions; zoomed region of fig.1 (f = 5.65...5.66 GHz) . Bead-pull measurements were made at frequencies around the pikes.

The first figure shows a measurement in the frequency range of 5.6...5.7 GHz, where we found some regions with remaining pikes, independent on the positions of the shorts. We examined this regions properly and found some very distinct pikes which are shown in Figure 2.

For perturbation measurements we proceeded in the same manner like we did for the spectral measurements, i.e. measure with different positions of the shorts and overlay measured data (at a given frequency). For all measurements we took 401 positions along the structure and 9 different boundary conditions, moving the shorts along almost the maximum lengths of the waveguide pipes. For some special frequencies located around the pikes, imaged in fig.2, we made bead-pull measurements, to investigate wether fields are concentrated within the inner part of the cavity. Figure 4 shows our result for a frequency of 5.6524 GHz. To get information about the location of the single cavity cells, refer to fig.3, where results of a bead-pull measurement for the accelerating π-mode of the TESLA cavity at 1.3003 GHz is shown (we index cell 1 to 9 from left to right). If we compare both figures, we observe no field distribution at the end cells but in the inner cells, i.e. a trapped mode. Notice the steep decrease of coupling from cell 8 to 9. We also found a localised mode in the adjacent pike at a frequency of 5.6572 GHz (see fig. 5).

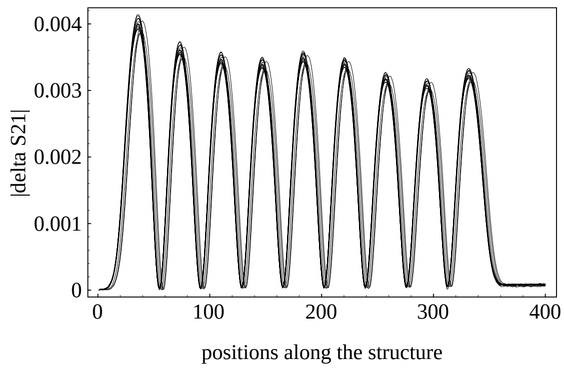

Figure 3: Bead-pull measurement at the accelerating π-mode f=1.3003 GHz of the TESLA cavity; pikes give location of the single cells.

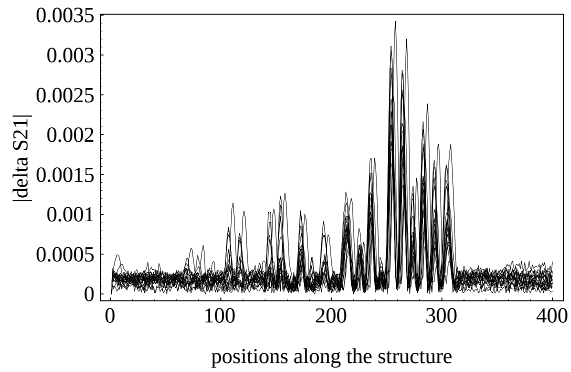

Figure 4: Bead-pull measurement at f=5.6524 GHz.

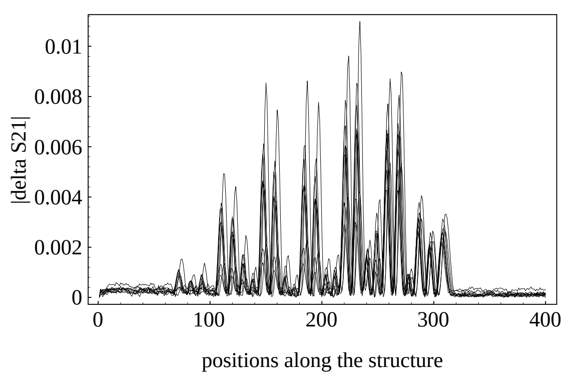

Figure 5: Bead-pull measurement at f = 5.6572 GHz.

In fig. 7 one of the mostly occuring examples of a proof to the contrary is demonstrated, where a spectral measurement (see fig. 6) still shows a pike hardly influenced by the positions of the shorts at 7.4167 GHz, though the field distribution is not localised and strongly dependent on the boundary conditions. Finally in fig. 9 another localised field distribution, found at the frequency of 8.1727 GHz, is displayed (refer to the corresponding spectral measurement illustrated in fig. 8).

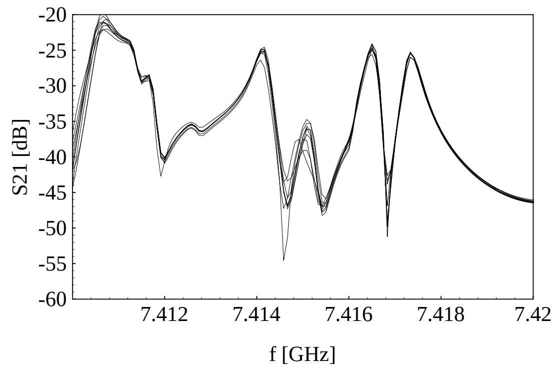

Figure 6: Transmission S_{21} (f = 7.41...7.42 GHz).

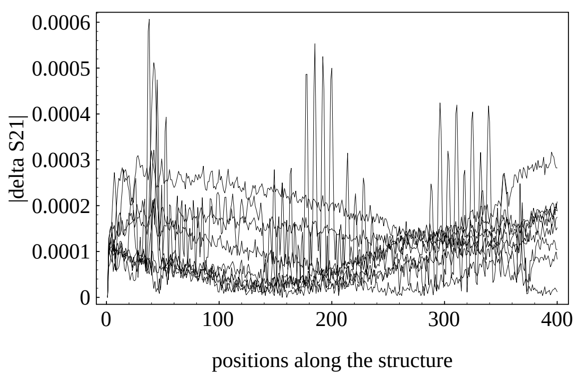

Figure 7: Bead-pull measurement at f = 7.4167 GHz.

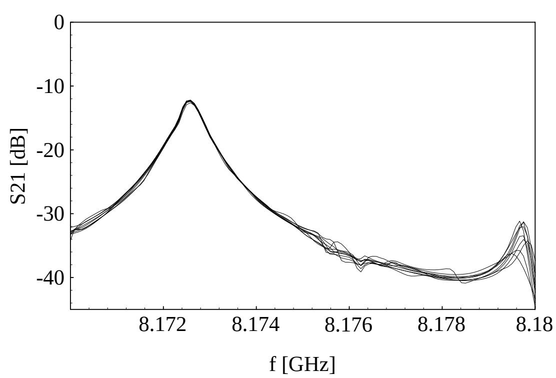

Figure 8: Transmission S_{21} (f = 8.17...8.18 GHz).

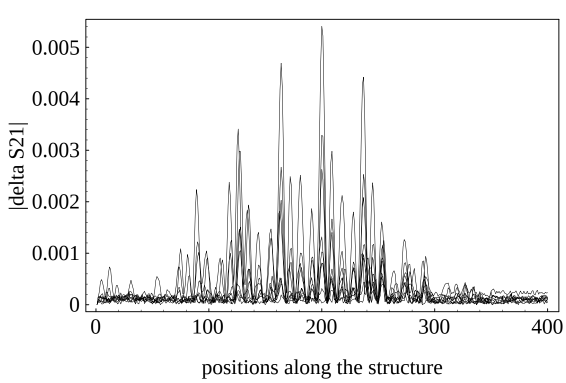

Figure 9: Bead-pull measurement at f = 8.1727 GHz.

2.4 Accuracy

Since the fundamental cut-off frequency of the waveguide pipe (d=78mm) appear at 2.254 GHz (TE11-Mode), the field distribution for the accelerating mode of the cavity at 1.3003 GHz vanishes exponentially in the waveguide pipes. Hence, only very small influences of boundary variations should appear in fig. 4. The amount of remaining fluctuations comes mainly from thermal drifts, we tried to avoid as far as possible by covering the structure with polystyrene, mechanical tensions and oszillations of the bead, provoked from movements of the stepping motors itself or other mechanical excitations.

On the other hand the influence of the antennas, fed in the sixth cell, change its resonant character due to the changed geometrie and hence can lead to the effect of trapped modes which would not be the behaviour of the hollow cavity itself. For further investigations we are going to take remedial measures by variing the depth of the antennas or couple into one of the adjacent cells to prove whether the trapped modes found remain localised.

3 CONCLUSION

In cavities without dampers in the inner part of the structure trapped modes can hardly be damped and hence can strongly affect beam dynamics, especially if they are superconducting. We recently started to search for trapped modes in a copper TESLA cavity. Up to now we found three of them in the frequency range of 4...8.2 GHz. From our experience they occur very rarely but the existence of more than the ones shown cannot be excluded. So far we have no results about shunt impedances of the trapped modes, so that further investigations have to be done.

4 REFERENCES

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5 SUPPORT

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