INVESTIGATION OF A HIGH-Q DIPOLE MODE AT THE TESLA CAVITIES

N. Baboi*, M. Dohlus, DESY, Hamburg, Germany
C. Magne, A. Mosnier, O. Napoly, CEA, Saclay, France
H.-W. Glock, Uni Rostock, Germany

Abstract

Higher order modes (HOM) can have a destructive influence on the beam emittance in the future linear colliders. Therefore it is important that the quality factor of the high impedance modes be damped under a safe level. Although attentive care was taken in designing the superconducting 9-cell cavities and the HOM couplers for the TESLA collider, a high Q and high impedance mode was discovered in some cavities at the TESLA Test Facility (TTF). In order to discover the reason for which this particular mode is very little damped, a series of investigations have been carried out. The mode frequency is higher for the studied cavities comparatively to others, where this mode seems to be properly damped. Field distribution measurements at the separate cavities show a quasi-trapping of the mode. The simulations and measurements done at individual cavities show that for certain boundary conditions the field is minimum at the location of both HOM couplers in a tube.

1 INTRODUCTION

Damping of the higher order modes (HOM) is crucial for the success of the future linear colliders. The accelerating cavities designed for the TESLA collider are based on superconducting 9 cell cavities grouped in modules of 8 cavities, using an accelerating frequency of 1.3 GHz [1]. At such low frequency, the wake field issue is more relaxed than in the case of S-band structures, but still the high quality factors Q of the modes at 2 K may have an intolerable effect on the beam. In order to damp these modes, each cavity is therefore provided with 2 HOM couplers, placed at an reciprocal angle of 115°.

At TTF several experiments have been made in order to study the HOMs. By modulating the beam current [2], several high impedance modes have been found to have a very high Q [3]. Specially a mode around 2.585 GHz, the last of the 3rd dipole band, having an estimated impedance R/Q = 15 Ω/cm^2, was found to be badly damped in 2 cavities of the first module. Nevertheless, the other polarization of the same mode is better damped. It was found that this mode is badly damped in one of the cavities of the 2nd and 3rd modules as well. The results are summarized in Table. 1.

Table 1. Results of HOM investigations for the last mode of the 3rd dipole passband (R/Q = 15 Ω/cm^2)

Cavity nr./module	Freq. [GHz]	Q
#3 (S10) / 1	2.5845	$1.1 \cdot 10^6$
#6 (S11) / 1	2.5862	$8.6 \cdot 10^4$
#5 (A15) / 2	2.5845	$4.2 \cdot 10^5$
#7 (S28) / 3	2.5906	$6.5 \cdot 10^5$

After the first cryomodule was dismounted we took the opportunity to do RF measurements with cavities isolated from the string of 8 cavities.

2 VERIFICATION OF HOM COUPLERS

Some of the HOM couplers are dismountable. These were interchanged between cavities S7 ('good', with a better mode damping) and S10 ('bad', with a high Q). With all 4 couplers, we measured exactly the same reflection and transmission curves, for a given cavity. In conclusion, a bad damping due to defective couplers is excluded.

3 THEORETICAL AND EXPERIMENTAL STUDIES OF CAVITIES

The mode has been characterized experimentally and studied by simulation and theory.

3.1 Low field level in the tubes.

3.1.1 Measurements of the field profile

Copper tubes were mounted on each side of the cavity. Metallic disks were setting the boundary conditions. The distribution of the radial electrical field on the axis was measured for each cavity by the bead-pull technique. A dielectric cylinder was used. In Fig. 1, IC denotes the input coupler port that was closed with a metallic plane, while HOM couplers were mounted at the K1 and K2 ports.

On Fig. 1 one can see that the field is mainly concentrated in the seven inner cells and is low in the tubes for both cavities, especially in the right-hand tube. In the end cell the field amplitude drops faster for S10 than for D4, but the difference is small.

* On leave from: NIFLRP, 76900 Bucharest, Romania

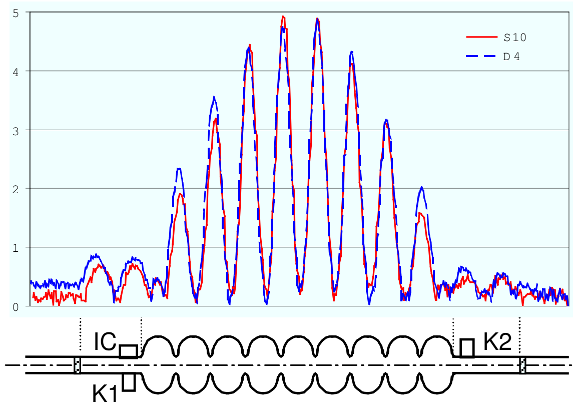

Figure 1: Field distribution in a 'bad' (S10) and in a 'good' (D4) cavity

3.1.2 Simulations of a cell detuning

Because some correlations between the cavity length and the external Q values were observed, we evaluated the influence of cavity deformations.

Simulations of the field profile were made first with the geometry of an ideal cavity and then with one detuned end cell. The length of the last cell was increased by 2 mm. In the simulation, metallic boundaries were considered at the end of the 241 mm long tubes, in accordance with the above measurements. The nominal frequency is 2.576680 GHz.

This shows that a deformation of the end cell increases the trapping of the mode. But this cannot account for the large Q spread between different cavities, up to 10^6.

Then the tube boundaries must be considered.

3.1.3 Measurement of the mode frequency as a function of the boundary

The transmission through the cavity was measured with 2 short antennas passed through small holes in the tubes. In Fig. 2 the frequency is plotted against the position L of one metal boundary, while the other is kept fixed. For L between 200 and 280 mm the curve is very flat, with a frequency almost constant of 2.579 GHz. The field profile of Fig. 1 is measured with such ("plain") boundary conditions.

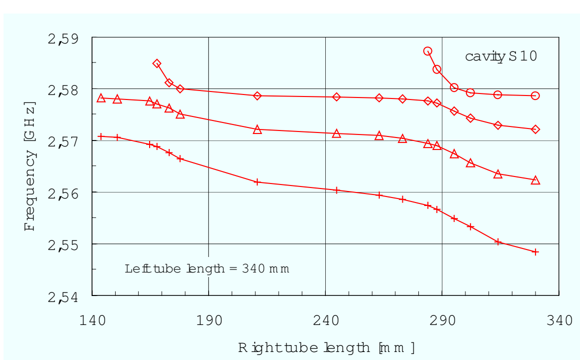

Figure 2: Frequency dependence on the boundary

In a 30 mm wide region the frequency vary by about 4 MHz, showing that the field in the tube can be high and very sensitive to the boundary location in these "tube enhancing" conditions.

3.1.4 Interpretation

From both profile and frequency measurements it is observed that the mode has a low field in the tube for "plain" boundary conditions. The mode damping is therefore worsened, whatever the position of the HOM couplers. The problem affects all cavities, with some differences due to the deformation of the cells.

For "tube enhancing" conditions the field in one tube is high. Then the mode should be properly damped. In a chain of cavities, the boundary conditions are set by the tube length and the frequency of the neighbouring cavities.

Due to the spread in the cavity geometries and interspace, the boundary conditions cannot be mastered. Indeed the instability occurs rather frequently, i.e. in 3 of the 16 cavities of the first two modules (see Table 1).

3.1.5 Simulation of boundary conditions

An asymmetric field distribution can happen if the neighbouring cavities impose virtual boundary conditions equivalent to special positionings of the metallic disks placed in the tubes on either side (shown in Fig. 1). In some cases a field distribution was measured with a significant part of the mode energy, 5 to 50 %, in one tube.

Computing only such cases, when the field is low in one tube, we looked for the conditions when in the other tube the field energy is lowered as well, only by varying the metallic disks. The tubes are assumed to be of copper. The position of the metallic disks was chosen so that the mode frequency is practically independent of the position of the left boundary and therefore determined by the right one. A position of the right disk was found for which only about 0.4 % of the total energy is outside the cavity. In this case the Q is also very high of the order of 10^7 (no HOM absorbers) and the mode frequency is 2.577 GHz. The field is again almost symmetric, looking about like in Fig. 1.

For these boundary conditions, by taking into account also the HOM couplers, Q was again estimated. Various levels of the effective transmission T from the wave from the cavity to the absorber, a measure of the coupling efficiency to this mode, were assumed. For T below 5 %, Q is above 10^6.

It is worthwhile mentioning that the calculated equivalent boundary condition set by the neighbouring cavity, when this is a few MHz lower in frequency, corresponds to the ones found above especially for frequencies between 2.579 and 2.585 GHz.

3.2 Field minima at HOM coupler location

Low T values, for which the high Q values mentioned above were obtained, are rather unrealistic. Therefore additionally we look for a situation for which both absorbers in one tube don't couple to the field. Therefore the geometry of the tube between cavities was reconstituted, as shown in Fig. 3. The opening for the power coupler was closed with a metallic plane, while at the other ports HOM couplers, noted with K1 and K2,

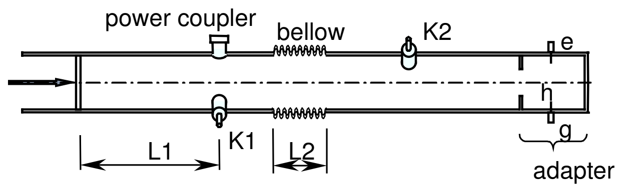

Figure 3: Experimental setup

were mounted with the same geometry as for the TESLA cavities. On one side of the construction a so-called adapter was mounted, that ensures an optimum matching for frequencies around 2.585 GHz. In the figure, antennas noted with e and g are in the power coupler plane, while f and h in the perpendicular one. On the other side, a metallic disk could be moved inside the tube.

For each position of the metallic disk, we measured the

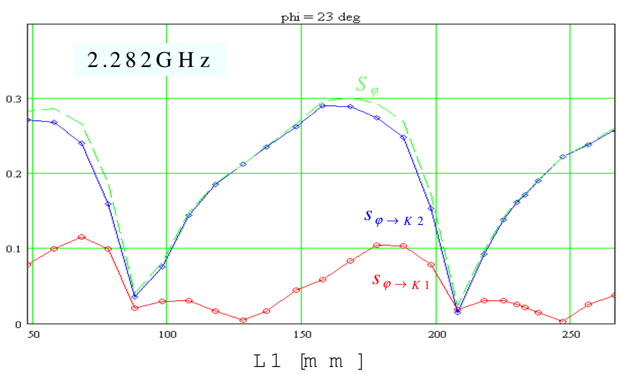

Figure 4: Transmission of a polarized wave (φ) to K1 and K2 ($S_{\varphi\to K1}$ and $S_{\varphi\to K2}$) and the effective absorption $S_\varphi = \sqrt{\left|S_{\varphi\to K1}\right|^2 + \left|S_{\varphi\to K2}\right|^2}$

transmission from antennas g and h to K1 and K2. By a linear combination of the results, the transmission could be calculated for each polarization angle. In Fig. 4 the transmission level from the adapter to K1 and K2, respectively, is plotted as a function of L1 for a frequency of 2.582 GHz and a polarization angle for which the coupling to both absorbers is simultaneously low. It is interesting to remark that the considered plane is approximately perpendicular to K1, while a second solution is found for a polarization angle roughly perpendicular to K2. It is worthwhile to remark that the curves do not change much when one changes the frequency. It remains to show that this experimental results essentially don't change through the presence of the power coupler, but this is experimentally more difficult to do.

4 PROPOSED REMEDY

A remedy to cure the bad damping of the mode is to settle the boundary by changing the tube diameter at some distance from the cavity. A simulation has been done with a reduction of the tube diameter (from 78 down to 66 mm) at 90 mm from the iris. This raises the field level in the tube and prevents a field minimum at the coupler location.

In all cavities with a bad damping, the mode frequency was higher than for the design cavity. This proves a deformation of the cavity. A tighter tolerance during the cavity production is therefore desirable.

5 CONCLUSION

A high impedance dipole mode was found to have a high Q in a few cavities of TTF. A few cavities were available for tests after disassembling from the cryomodule. The measurements and simulations show that the field level in the tubes may decrease due to the end cell detuning, as well as to special boundary conditions induced by a lower mode frequency in the neighbouring cavity. Still, such high Qs as the measured ones can only be computed with the assumption that the HOM absorbers work very poor, which is rather unrealistic. But another fact adds to the explanation of the bad damping, that the boundary conditions may impose for two angular polarizations a minima of the field at the coupler location.

A special tube design has been proposed as a remedy to all this.

The HOM issue in general, including the mode studied herewith, is important also for the newly proposed superstructures. Therefore more experiments with beam are necessary in order to find out if there are other modes with insufficient damping.

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REFERENCES

[1] R. Brinkmann et al. (eds.), DESY Report, DESY 1997-048, Vol.I, 1997

[2] S. Fartoukh, CEA/Saclay preprint, DAPNIA/SEA-98-18 and DESY report, TESLA 98-13, 1998

[3] S. Fartoukh et al., Proc. IEEE Particle Accelerator Conference (PAC 99), New York, 1999