# HIGHER-ORDER MODES IN A 36-CELL TEST STRUCTURE[1]

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*Abstract*

In a multibunch collider scheme deterioration of the beam emmittance due to long range wakefields is a severe problem to overcome. There is evidence that detuning the accelerator structure with respect to HOM-modes is not sufficient in all cases. Therefore it seems worthwhile to study single and distributed HOM-damping concepts as complementary means for emmittance preservation. In order to study the physics of trapped higher order modes and in order tovalidate various computer codes a detuned 36 cell test structure has been designed and built.

The physical dimensions of this structure were chosen to show strong mode trapping. Thus it is an appropriate object to study the effects which have to be expected in a real constant gradient structure.

Theoretical simulation results and measurements are presented.

## 1 INTRODUCTION

The S-Band 500GeV Linear Collider Study SBLC forsees about 5000 constant-gradient (cg) acceleration structures of 180 cells with a loaded gradient of 17 MV/m. It considers a bunch train of 125 bunches with a spacing of 16ns from bunch to bunch. To achieve a high luminosity any cumulative beam break-up along the bunch train has to be avoided. Wakefield effects driven by HOMs are one of the primary sources of emittance growth. Consequently, the suppression of these HOMs is a very crucial point in all actual linear collider designs. The major interest of calculations was focussed on the modes of the first dipole band since they cause the severest deflecting effects, but also the 3rd and 6th dipole passband need to be studied.

Calculations for the SBLC structure were carried out with ORTHO [1] for a somewhat simplified 180–cell structure with 30 landings. One of the main results was that not only the first $\pi$-like dipole modes influence the beam dynamics but about 140 modes. A major part of these deflecting modes is trapped inside the cg structure, that is without contact to the end cells.

Since the phenomenon of trapped HOMs in tapered waveguides was neither theoretically nor experimentally well known and has a strong influence on the design of damping schemes further HOM investigations have been started:

Besides the development of a double-band coupled oscillator model (COM) a test structure was designed.

The goal was to find a structure which is easy to measure , easy to manufacture, which is computable with different numerical methods (MAFIA, URMEL–T, ORTHO, COM) without geometric approximations, and which shows the clear appearance of trapped modes.

Performing RF-measurements on long structures is severely limited by the appearance of mode overlap therefore a relatively short structure had to be chosen. In order to get a both mechanically and thermally stable structure a massive design was chosen. For low mechanical tolerances a simple geometry was designed.

The numerical HOM analysis with discretization methods is limited to relatively short cg structures while semi–analytical methods and coupled oscillator models can handle much longer structures with very small cell–to–cell deviations. The semi–analytical program ORTHO has been developed in order to calculate the scattering matrices, electromagnetic fields and other parameters for cg structures when roundings of the cells and the irisses are neglected. MAFIA and URMEL–T are well tested codes which consistently solve Maxwell's equations. For this reason the test structure was chosen long enough to show the typical trapped modes but short enough to be computable by MAFIA and URMEL–T. Dohlus developed some special coupled oscillator model (COM) for the SBLC structure which is characterized by overlapping of the first and second dipole passband: For each cell, a parallel equivalent circuit represents the $TM_{110}$-like modes and a serial equivalent circuit represents the $TE_{111}$-like modes. Each circuit of each band is coupled to its adjacent circuits and neigboring circuits of the second band.

Two designs of 36 cells have been compared with MAFIA, URMEL–T, ORTHO, and COM. One geometry was just every fifth cell of the evenly tapered 180–cell structure. The design, which finally was chosen, has a very strong tapering of the iris, constant outer radius and twice as thick irisses as the original SBLC structure. This structure better fulfilled the demanded characteristics. Comparisons gave a good agreement in the resonant frequencies and in the field distribution, which is very important since a clear appearance of trapped modes inside the structure was found for several modes. Also a very similar shape of the loss parameter curve was found. However, the sensitivity of the loss parameter against any field error has to be stressed.

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## 2 MEASUREMENTS

### *2.1 The Test Setup*

The structure, made of standard OFHC copper, consists of 36 cells clamped together by truss rods. Overall length is 1300mm, cut-off pipes of 100mm length are attached to each end of the structure. The cell geometry is similar to the one chosen for the SBLC, except for the iris thickness which is 10mm instead of 5mm. The iris openings are evenly tapered from 40mm diameter at the beginning to 20mm at the end.

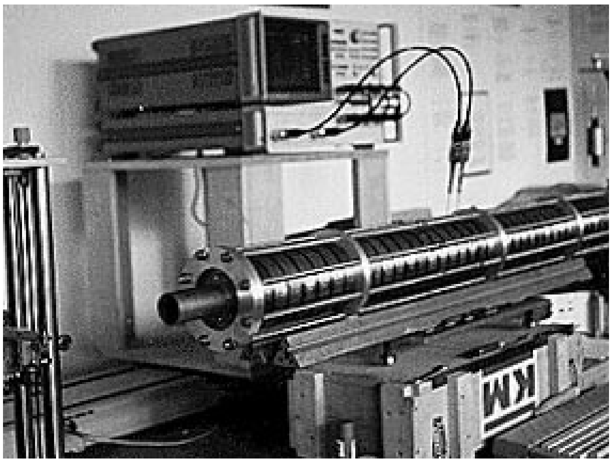

Figure 2.1:Picture of the test-setup

Proper alignment is ensured by laying the structure on top of an optical bench. The field measurements were performed using a modified nonresonant bead pull technique [2, 3]. Data is taken by a HP8753c network analyzer for 801 discrete positions along several paths parallel to the cavity axis. In Figure 1 a picture of the test setup is shown.

### *2.2 The Measurement Method*

The method applied is a vriant of the nonresonant beadpull technique as described elsewhere [5]. In the measurements we are interested in both the longitudinal and the transversal component of the electric field. If we use isotropic dielectric material with shapes like rotational ellipsoids the form factor â of the bead becomes a sum of independent quantities. Two beads of different shape (e.g. needle and shim) are needed.

$$A\begin{pmatrix}\dfrac{\Delta s_{21}^{(1)}}{a^{[1]}{}_z}\\[2ex]\dfrac{\Delta s_{21}^{(2)}}{a^{[2]}{}_z}\end{pmatrix} = \begin{bmatrix}1 & f_1\\ 1 & f_2\end{bmatrix}\cdot\begin{bmatrix}\tilde{E}_z\\ \tilde{E}_\perp\end{bmatrix} \qquad (1)$$

$$\text{with}\,\tilde{E} = \frac{E^2}{P_{loss}},\ A = \frac{(1+k_1+k_2)^2}{2\omega\sqrt{k_1 k_2}},\ \text{and}\,f = \frac{a_\perp}{a_z}$$

After performing two measurements along the same path using the different beads equation (1) is then solved for E.

## 3 RESULTS

For the measurements two ceramic beads of different shapes (needle, Ø 0.6mm, length 7.5mm and shim, Ø 4.7mm, 0.31mm thick) were used. Both beads were calibrated in a $TM_{010}$–pillbox for their longitudinal and transversal perturbation constants. The needle consisting of $Al_2O_3$ showed very stable values of over the period of measurements whereas the shim revealed a significant change. It is believed that this is due to hygroscopic properties of the bead.

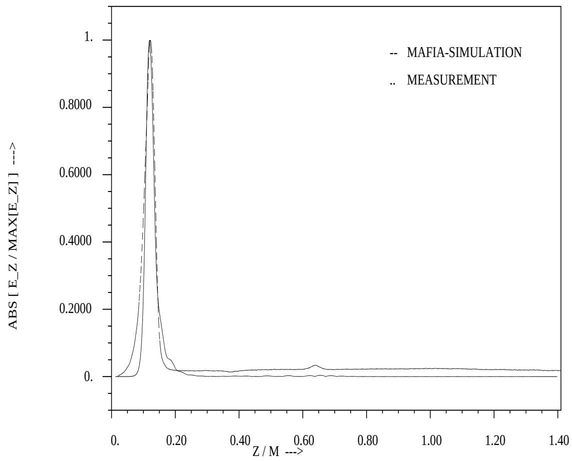


Figure 3.1:Transversal E-field of Mode #13, frequency 4.150295 GHz, on-axis

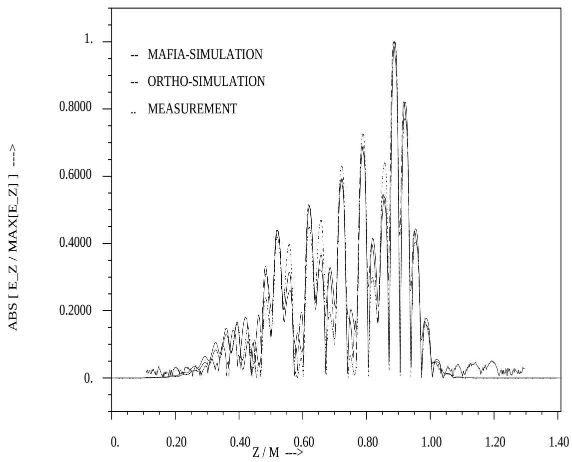


Figure 3.2:Mode #19, Longitudinal E-field, 4.18557 GHZ, taken at kr = 1, 7 mm off-axis

Several modes of the first dipole passband were measured and compared to numerical predictions. It appeared that the choice of discretization parameters is cruicial for proper results. Mode #13 was first found with MAFIA. The measurements proved the existence of this mode very nicely. Except for this mode all other members of the first passband start with a zero phaseshift at the wide iris end and stop with a $\pi$-like characteristic. Again the agreement between calculations and measurements is very well for all other modes studied. Also the numerical computations show good agreement for the loss-parameters calculated as can be seen in Figure 3.6.

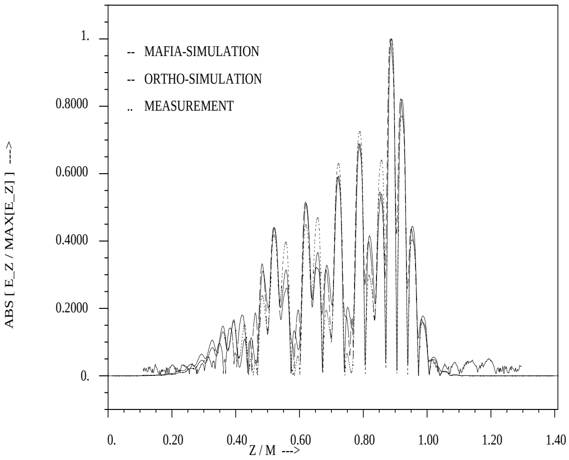


Figure 3.3:Mode #20, 4.2395 GHz, 6 mm off-axis

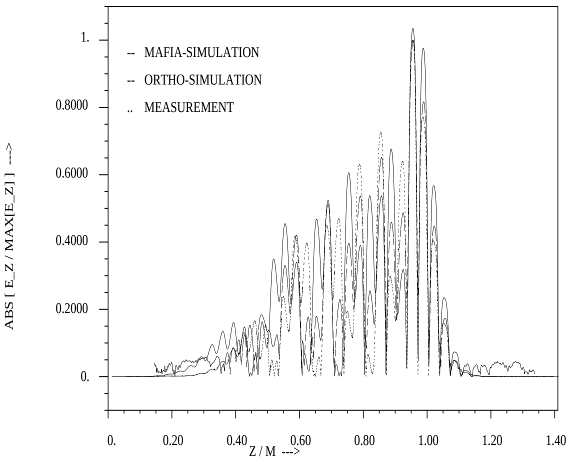


Figure 3.4:Mode #21, 4.25165 GHz, 6 mm off-axis

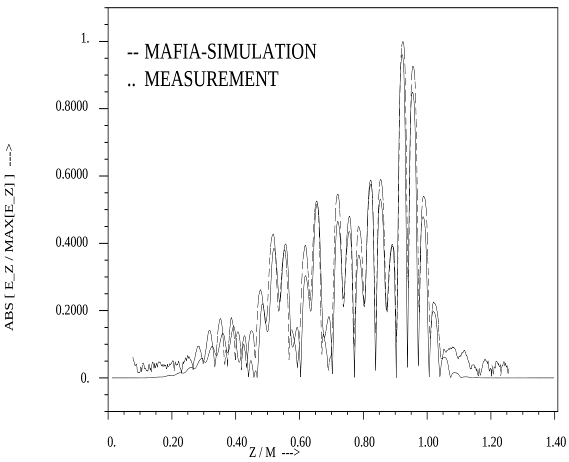


Figure 3.5:Mode #22, 4.2632 GHz, 6 mm off-axis

Having a closer look at Modes #19 to #22 it appears that with increasing frequency the field pattern is shifted one cell towards the narrow iris end of the structure.

This behaviour can be expected by the calculations [1]. In all figures the ordinate denotes the value of the electric field strength normalized to the square root of the power coupled into the cavity, the abscissa denoting the position along the structure's axis.

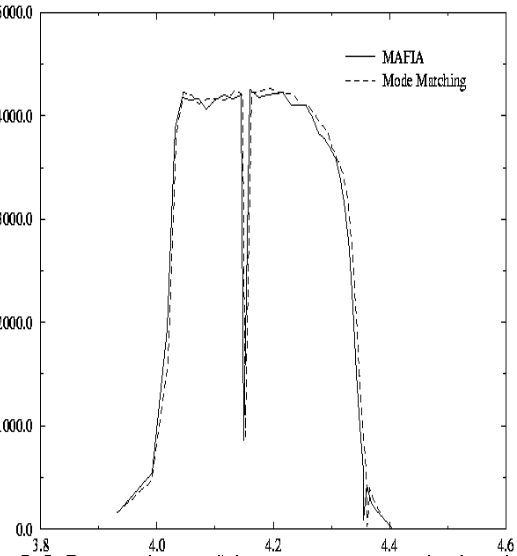


Figure 3.6:Comparison of lossparameters calculated with MAFIA and mode matching technique [6]

All methods give the field geometry in very good agreement to the measurement. Only the absolute values of the field amplitudes differ in some cells.

# 4 CONCLUSIONS

The field geometries calculated and measured showed very good agreement. On average frequencies differ less than 1‰. The Qs measured are about 20% below the calculated values which is an acceptable value for cups clamped together. From the results of the experiment one can conclude that the numerical codes will be applicable for longer structures as needed for the design of a real linear collider structure.

# 5 REFERENCES


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