THE S-BAND 36-CELL EXPERIMENT*

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Abstract

In a multibunch collider scheme deterioration of the beam due to long range wakefields is a severe problem to be overcome. While, in principle, it is possible to couple selectively to dangerous Higher Order Modes (HOMs) a different way is to prevent coherent excitation of these wakes by means of modifying a constant gradient accelerator tube such that a structure detuned with respect to HOM modes is obtained. Since the phenomenon of longer interacting dipole modes which are trapped completely in an inner part of the accelerating structure has, to our knowledge, never been studied experimentally – even theoretically it was not notorious – it was decided to design and build a test structure with the characteristics mentioned above. First results of measurements and numerical predictions are presented.

I. INTRODUCTION

The S-Band 2*250GeV Linear Collider Study SBLC forsees 2452 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.

Previously first calculations for the SBLC structure were carried out with ORTHO [1] for a somewhat simplified 180–cell structure with 30 landings. The main results were the following:

– The loss parameter curve showed a somewhat oscillatory behaviour which reflects the local periodicity of the structure.

– From the experiences at SLAC a peak was expected in the loss parameter pattern at the lower end of the first dipole passband. Instead of this, the curve showed a nearly flat maximum extended over 2/3 of the first dipole passband.

– Consequently, not only the first π-like dipole modes influence the beam dynamics but about 120 modes. A major part of these deflecting modes is trapped inside the cg structure, that is without contact to the end cells.

Since these results contradicted the usual ideas about the behaviour of HOMs in tapered waveguides and strongly influenced the design plans for damping strategies of the SBLC structure, further studies were set up on the analysis of the HOMs. Mainly these subjects have been treated:

– Development of the double–band coupled oscillator model (MCO).

– Development of a test structure with the following characteristics: a) easy to measure , b) easy to manufacture, c) computable by different numerical methods (MAFIA, URMEL–T, ORTHO, MCO) without geometric approximations, d: appearance of trapped modes.

On principal at least semi-analytical methods, discretization methods and coupled oscillator models could be used for the numerical HOM analysis. While discretization methods are limited to relatively short cg structures 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 (MCO) 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 MCO. 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.

II. MEASUREMENTS

A. The Test Setup

The structure, made of standard OFHC copper, consists of 36 cells clamped together by truss rods. Overall length is

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1300mm, cut-off pipes of 100mm length are atached 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.

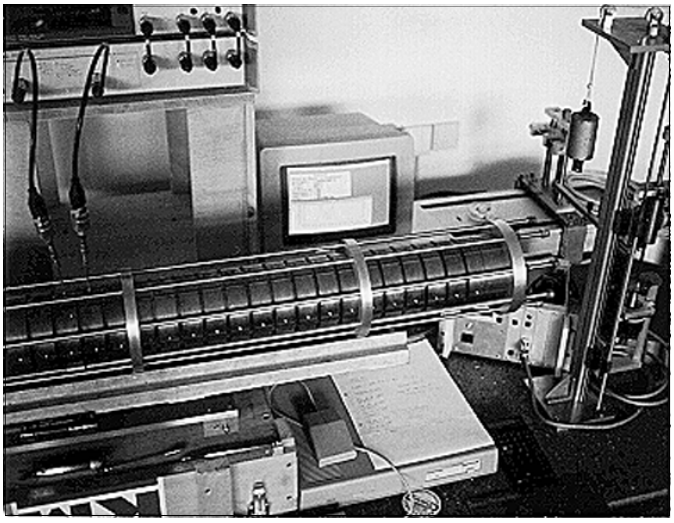

Figure 1: Picture of the test setup

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.

B. The Measurement Method

The method applied measures the change of the transmission through a cavity when a bead is moved along a path inside it. Starting from a lumped circuit representation of a resonance one finds expression (1) under the assumption that the bead is sufficiently small to change the resonant frequency of the cavity only by a small amount.

$$\Delta s_{21} = \frac{2\sqrt{k_1 k_2}}{(1 + k_1 + k_2)}\, i\Omega, \quad \text{with} \quad \Omega = Q_0\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right) \qquad (1)$$

Combining equation (1) with Slater's formula [4] leads to the final expression (2). It should be mentioned that (2) provides inherent control of the validity of assumptions and thus information about the accuracy of the measurement since one has only to check for the real part of Δs_{21} not to exceed about 5% of it's magnitude (say).

$$\Delta s_{21} = -i\, \frac{2\sqrt{k_1 k_2}}{(1 + k_1 + k_2)}\, \frac{\omega_0}{P_{loss}}\, \hat{a}\, |\mathbf{E}_0|^2 \qquad (2)$$

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 $\hat{a}$ of the bead becomes a sum of independent quantities. The right end side of (2) can then be written as

$$\hat{a}\, |\mathbf{E}_0|^2 = \sum_\nu a_\nu E_\nu^2 \qquad (3)$$

allowing to solve for logitudinal and transversal components individually. Two beads of different shape (e.g. needle and shim) are needed.

$$A \begin{pmatrix} \frac{\Delta s_{21}^{(1)}}{a_z^{<1>}} \\ \frac{\Delta s_{21}^{(2)}}{a_z^{<2>}} \end{pmatrix} = \begin{pmatrix} 1 & f_1 \\ 1 & f_2 \end{pmatrix} \begin{pmatrix} \tilde{E}_z \\ \tilde{E}_\perp \end{pmatrix},$$

$$\text{with } \tilde{E} = \frac{E^2}{P_{loss}},\ A = \frac{(1 + k_1 + k_2)^2}{2\omega\sqrt{k_1 k_2}},\ \text{and } f = \frac{a_\perp}{a_z} \qquad (4)$$

After performing two measurements along the same path using the different beads equation (4) is then solved for $\tilde{E}$.

C. 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.

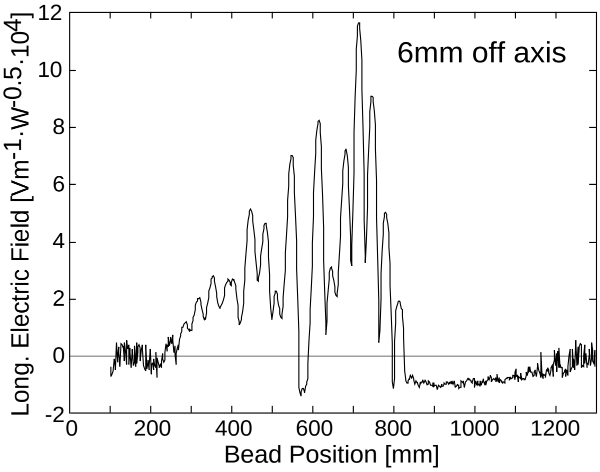

Figure 2: Longitudinal E–field of mode #15, 6mm off axis

Table I.

Mode #16. Transv. Shuntimpedance transittime not included

	MAFIA	Measured
f [GHz]	4.17099	4.17477
R_T/Q [Ω]	521	626
Q	12379	9850

Table II.

Mode #16. Transv. Shuntimpedance transittime not included

	MAFIA	Measured
f [GHz]	4.18557	4.18931
R_T/Q [Ω]	556	605
Q	12471	10150

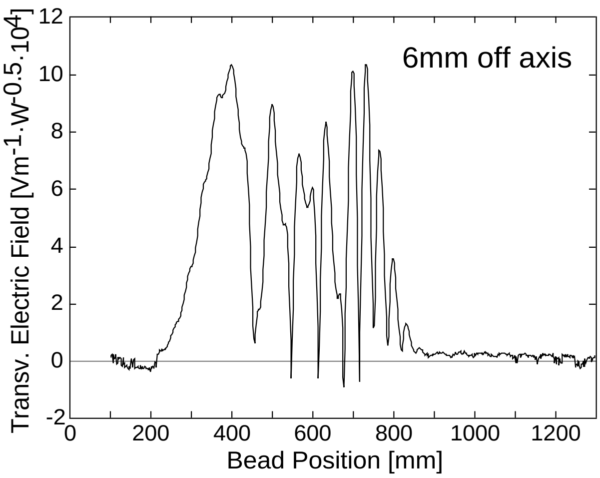

Figure 3: Transversal E–field of mode #15, 6mm off axis

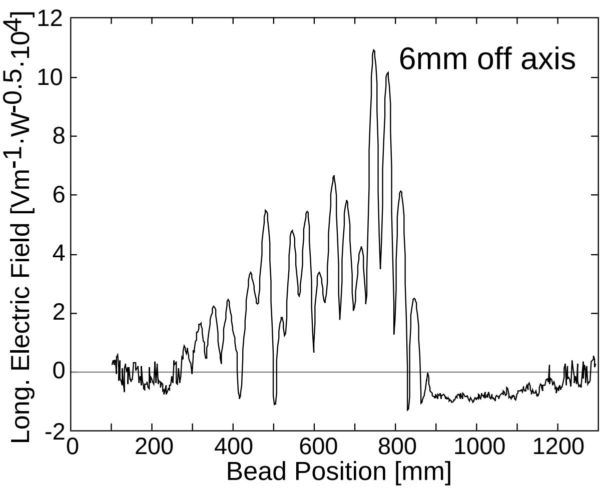

Figure 4: Longitudinal E–field of mode #16, 6mm off axis

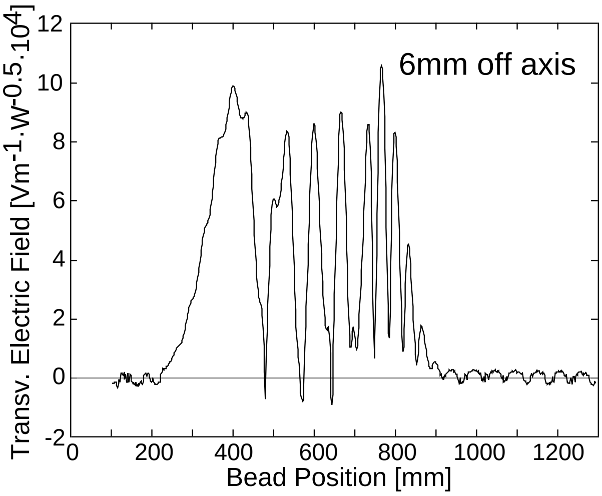

Figure 5: Transversal E–field of mode #16, 6mm off axis

It was decided to repeat the various calculations for the exact geometry of the structure as built. So presently only MAFIA calculations are available to be compared to the results.

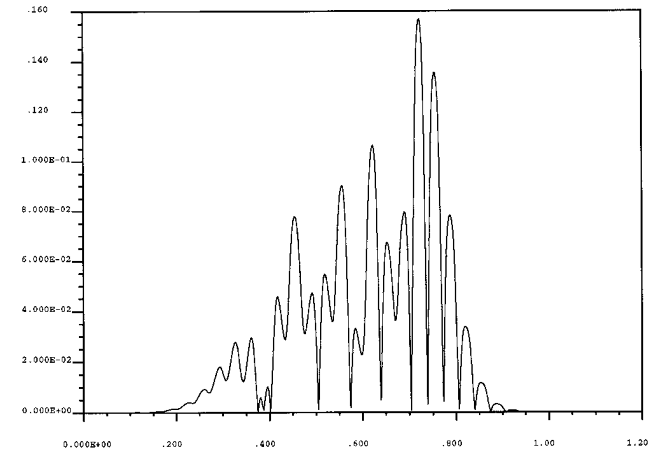

Figure 6: Long. E–field of mode #15, MAFIA, 6mm off axis

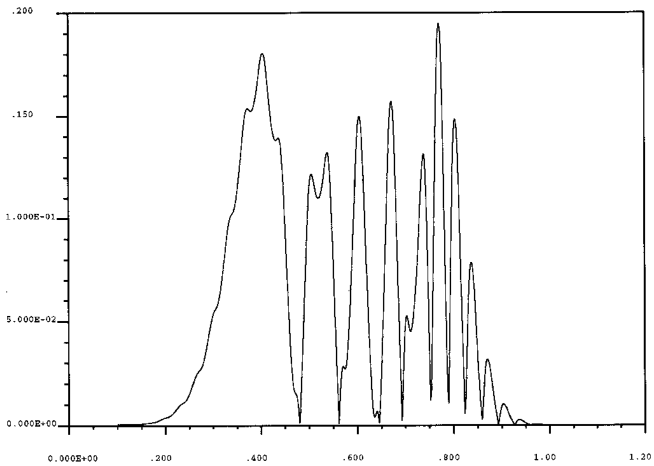

Figure 7: Transv. E–field of mode #16, MAFIA, 6mm off axis

III. 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. While for mode #16 the R_T/Qs differ about 8% – which is well inside the estimated 15% accuracy limit of the measurement – results for mode #15 deviate about twice that value.

IV. REFERENCES

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