# PRELIMINARY STUDY ON HOM-BASED BEAM ALIGNMENT IN THE TESLA TEST FACILITY


N. Baboi, G. Kreps, M. Wendt, DESY, Hamburg
G. Devanz, O. Napoly, R.G. Paparella, CEA/Saclay, DSM/DAPNIA, Gif-sur-Yvette



*Abstract*

The interaction of the beam with the higher order modes (HOM) in the TESLA cavities has been studied in the past at the TESLA Test Facility (TTF) in order to determine whether the modes with the highest loss factor are sufficiently damped. The same modes can be used actively for beam alignment. At TTF2 a first study on the beam alignment based on the HOM signals has been made in the first cryo-module, containing 8 accelerating cavities. Four modes with highest R/Q in the first two cavities have been monitored. One bunch has been usually used. The cavity center could be found for each of the modes. The results are presented in this paper.


## INTRODUCTION

The TESLA Test Facility – phase 2 (TTF2) [1] at DESY is equipped with various monitors: beam position monitors, beam loss monitors, screens, wire scanner etc. However difficulties have been encountered to align the beam over long sections of the linac constituted by the cryo-modules. These contain eight 9-cell superconducting accelerating cavities, which are cooled together to about 2K. Each cavity is about 1 m long. Beam alignment in the cavities is important in order to avoid transverse kicks on the beam from higher-order modes (HOM), which may lead both to a single-bunch deformation and to beam break-up along the bunch train.

These monitor-free long sections can be filled by the signals from the HOM couplers. Such couplers are placed at either side of each cavity in order to extract energy from the fields excited by charged particles and hence damp the higher-order modes. In the past, signals from the HOM couplers have been used to study the modes, and to find out if the damping is sufficient for the dipole modes with high R/Q, i.e. good coupling to an off-axis beam [2]. The same HOM signals can be used to monitor the offset of the beam with respect to the cavity axis [3], since their amplitude is proportional to it. To improve the alignment tolerances for both the collider and the FEL applications of TTF superconducting modules, this beam-based method should achieve a positioning resolution significantly better than 500 µm obtained by the cavity mechanical alignments.

First studies on the possibility to align the beam in the cavities have been made. The amplitude of the fields excited by the beam at several resonances in the first two cavities of the first TTF module has been measured as a function of the beam position. In this paper the measurements are described and the results are discussed.

## THE METHOD

### *Setup*

Fig. 1 shows schematically the first part of the TTF2 injector in the first phase of commissioning. A gun accelerates the electrons emitted by a photo-cathode to 4.5 MeV. A horizontal and a vertical steerer can deflect the beam, correcting for possible errors in the transverse and angular alignment of the gun. Eight cavities in module ACC1 accelerate the beam with a gradient of 12 MV/m.

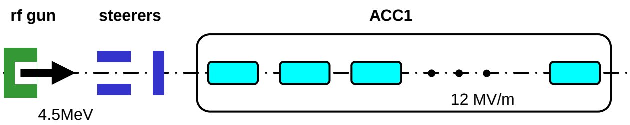


Figure 1: Schematic view of the alignment setup

The frequency spectrum of the wake fields excited by the beam is monitored with a spectrum analyzer. The spectrum of each cavity consists of resonant modes grouped in passbands by the type of the mode. There are 9 modes in each passband, and for the case of dipole modes there are 2 polarizations for each mode.

Fig. 2 shows such a spectrum for one mode of the first dipole passband of the first cavity. The two polarizations can be distinguished and their quality factors Q, of about $9.3\cdot10^3$ and $2.4\cdot10^4$, have been measured a priori with a network analyzer. This mode is one with highest R/Q. Four modes with highest R/Q have been used. Their frequencies and R/Q as predicted from simulations for an ideal TESLA cavity are shown in Table 1.

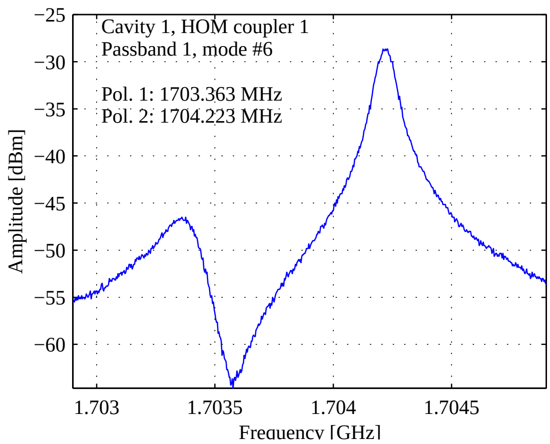


Figure 2: Mode #6 of the first dipole passband in cavity 1 of ACC1

Table 1: Dipole modes with highest R/Q used for beam monitoring as predicted by simulations

| Dipole passband | Mode # | Frequency (simulation) [MHz] | R/Q [MΩ/m$^2$] |
|---|---|---|---|
| 1 (TE-like) | 6 | 1713.7 | 11.21 |
| | 7 | 1738.3 | 15.51 |
| 2 (TM-like) | 4 | 1864.7 | 6.54 |
| | 5 | 1872.7 | 8.69 |

### *Principle*

By the help of the horizontal and vertical steerers, the beam position in the cavity studied could be varied. The beam position with respect to the case of un-deflected beam (i.e. all steerers between the gun and the module are off) was calculated based on the steerer calibration and the transfer matrix from the steerer to the middle of the cavity. Notice that the effect of the beam angle with respect to the cavity axis was ignored in this experiment. It will be further studied and our analysis refined when two additional steerers are installed in the TTF2 injector.

A simple method to find the axis of a mode in a cavity is to monitor the integral power of a mode as a function of the 2D position of the beam. The spectrum analyzer provides a convenient filter, with variable bandwidth, but especially with variable frequency. Since the spectra take a long time to record, due to the low repetition frequency of the beam of 1 Hz, one can monitor the signal amplitude in time domain. A faster method is described below and has been adopted for our first measurements.

Each polarization of a dipole mode has a transverse symmetry axis. When the beam is somewhere on this axis, that particular polarization is not excited, and transverse deflections along this axis will not be seen. In this case the corresponding peak in Fig. 2 will disappear. In exchange, when moving the beam on the perpendicular direction, the amplitude of the HOM peak will change linearly with the beam offset with respect to the mode axis. In this way one can use one polarization to monitor movement in one direction and the other for the orthogonal direction.

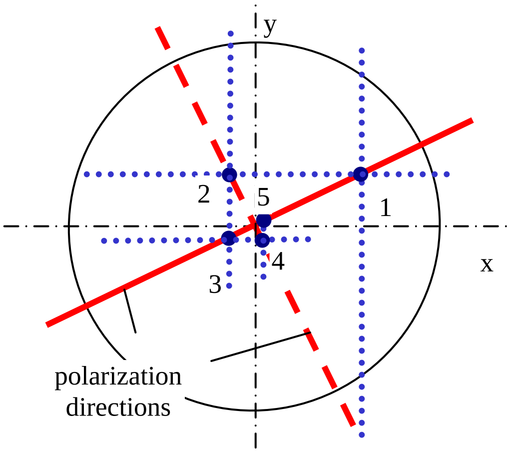


Figure 3: Alternate horizontal and vertical beam position scans for a mode with oblique polarization axes.

In reality the two polarizations have an arbitrary axis, randomly oriented with respect to the horizontal plane. When steering the beam position in the horizontal and vertical planes we have chosen the modes responding best to changes in each plane. Then we have made one scan say in the horizontal plane with one polarization until we found a point on the symmetry axis of the mode, followed by another scan in the vertical plane monitoring the other polarization until finding the minimum. Then by iterating alternate scans one approaches the electrical center of the mode, as illustrated in Fig. 3.

## MEASUREMENTS AND RESULTS

The time domain signals for one scan in the horizontal plane for the second polarization of mode #6 (second peak in Fig. 2) of the first passband of cavity 1 are shown in Fig. 4. A filter bandwidth of 300 kHz was used. The vertical position of the beam was 0.45 mm, with respect to the un-deflected position. One bunch per beam, of about 1 nC, was used.

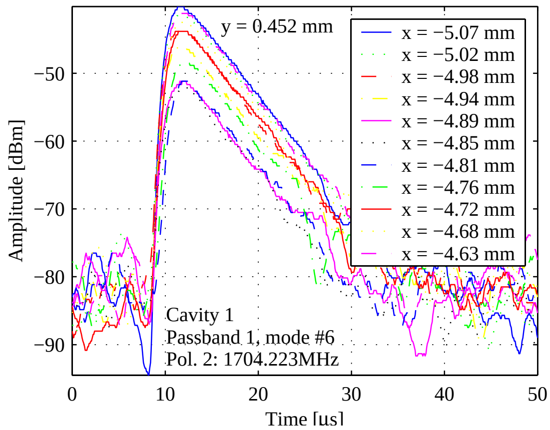


Figure 4: Time domain signals for the first polarization of the 6$^{th}$ mode of the 1$^{st}$ dipole band of the first cavity.

The HOM signal builds up rapidly after the bunch passes the cavity, at about 8 μs in the plot. Then the amplitude of the signal decays with a rate given by the quality factor of the mode. The variation of the signal amplitude with the beam position can be observed. The signal is minimized when the beam is on the axis of the mode. The amplitude is not zero in this case because of contributions from the other polarization and probably of an angle in the beam trajectory.

The amplitude of the signal in linear scale as a function of the beam position is presented in Fig. 5. Several scans have been made in the horizontal and vertical planes using alternatively the two polarizations. The beam position for minimum HOM amplitude is determined and its value is then used for the next scan. In the plots, the data is fitted by straight lines and the values inferred from the fits slightly deviate from the values determined during the measurements without using a fit. Note that for this mode four scans were sufficient to find the cavity axis. This was the case for all 4 modes measured in cavity 1, while for cavity 2 in general more scans were necessary.

This can be explained by the fact that, for the modes studied in cavity 1 the polarization axes are close to horizontal and vertical, as corroborated by the observation that the two resonance peaks shown in Fig. 1 are well decoupled when large horizontal and vertical beam offsets are imposed. This is not the case for the modes of cavity 2 where the polarization axes are oblique and more scans are therefore needed to converge towards the mode center. We believe that this difference between the two cavities is due to deformations in the cavity.

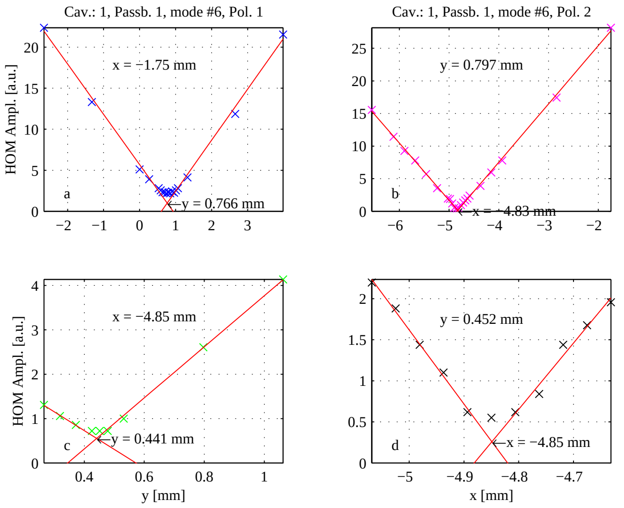


Figure 5: HOM signal amplitudes for each polarization of mode #6 of the first passband of cavity 1 as a function of the beam position.

It is remarkable that if the steerers between the gun and the module are switched off, the beam has a large horizontal offset in cavity 1. This seems to show that there is either a large offset of this cavity with respect to the gun axis, or that the gun components are not well aligned, shooting the beam at a rather large angle. This fact will be further analyzed in the next TTF2 run.

### *Beam position resolution and HOM centers*

In the central regions of the scans, steps of about 50 µm in horizontal and vertical beam displacements have been used for both cavities and all modes. With a HOM amplitude signal resolution of 1 dBm, the effect of these steps could be clearly observed even at the minimum as illustrated in Fig. 4. Such a resolution on the beam position is also inferred from the fit accuracy and by comparing the center positions given by the minimum of the signal or by the fitting procedure.

However, the electric centers of the dipole modes do not coincide with such a fine resolution since they are essentially set by the relative cell to cell displacements and by their field distributions in the cavity. Fig. 6 compares the relative positions of the 9 cell geometric centers with the electric centers of the 4 dipole modes, by arbitrarily superposing their two barycenters. The mode centers differ by 100 µm or less in both planes. Clearly more experimental data as well as theoretical investigations of the electromagnetic properties of cavities with realistic geometries and cell eccentricities are needed.

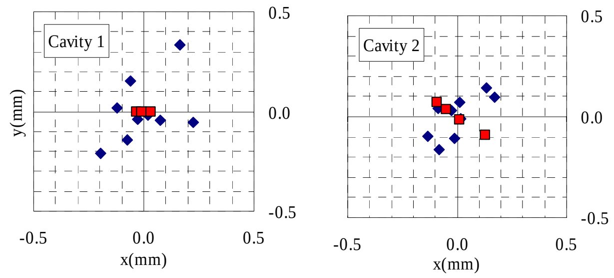


Figure 6: Relative positions of the 9 cell centers (blue diamonds) and of the 4 dipole mode centers (red squares).

## CONCLUSIONS

The preliminary measurements presented in this paper show that by monitoring the HOM signal amplitude for two polarizations of a dipole mode, one can measure the electrical center of the modes with a resolution of 50 µm. Due to cavity deformations, the main dipole modes have different electrical centers which differ by about 100 µm in most cases. This method provides a way to align the beam with respect to each accelerating cavity with a resolution much better than the 500 µm accuracy of the cavity mechanical alignment in the cryo-modules. In the case of a cryo-module, one could align the beam through the middle of the first and the last cavities, or define an axis of the module based on the information about the cavity alignment in the module, which can be obtained also from these measurements.

Although the procedure described here, based on moving the beam, is lengthy, this would be necessary only at the beginning. Then one can calibrate the HOM signal, so that one can have a direct indication of the beam position. Alternatives to this method will also be studied in the future. One is to use 2D scans with the total power of both polarizations of a mode, or even use the total power at the HOM couplers.


### *Acknowledgements*

We would like to thank all the TTF2 operators and coordinators for their participation in the measurements. In particular we would like to thank P. Castro for his help in analyzing the data, and the effort to prepare future measurements. We also would like to thank J. Sekutowicz and M. Dohlus for many useful discussions.


## REFERENCES


[1] B. Faatz for the FEL team, “ The SASE FEL at the TESLA Test Facility as User Facility”, FEL 2002 Proceedings, Argonne, 2002

[2] Ch. Magne et al., “Measurement with Beam of the Deflecting Higher Order Modes in the TTF Superconducting Cavities”, PAC 2001 Proceedings, p. 3771, Chicago, 2001

[3] G. Devanz et al, “HOM Beam Coupling Measurements at the TESLA Test Facility (TTF)”, EPAC 2002 Proceedings, p. 230, Paris, 2002