ACTIVE HOMS EXCITATION IN THE FIRST PROTOTYPES OF SUPERSTRUCTURE

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Abstract

An alternative layout of the TESLA collider [1], based on superstructures [2], reduces investment cost for the main accelerator due to a much lower number of input couplers and resulting from that, a simplification in the RF distribution system. In May 2002, two first Nb prototypes of the superstructure (P1, P2) were installed next to the injector in the TESLA Test Facility linac (TTF) at DESY to verify experimentally the predicted RF-properties. Part of the experimental program was devoted to the damping of Higher Order Modes (HOM). Good suppression of HOMs in both prototypes has been achieved with HOM couplers based on the coaxial line technique [3]. A several methods have been applied to measure impedances $Z=(R/Q)\cdot Q_{ext}$ of parasitic modes. We report here mainly on results of the active mode excitation method and the measurements of HOMs' parameters by means of a Network Analyzer, which we performed on cold- and on warm prototypes. The other method, HOMs excitation by charge modulation, is reported in more detail in [4].

INTRODUCTION

The superstructures, chains of superconducting multi-cell subunits connected by $\lambda/2$ long tube(s), have been proposed as a replacement for the standard 9-cell TESLA structures. At present, the 2x9-cell (Fig.1) superstructure is seen as the most attractive version, compromising: reduction of cost and an improvement of the performance and being moderately demanding on the production [5]. This version was studied at the time when manufacturing of the subunits of the first original 4x7-cell version was well advanced. In Fall 2001, the decision was made to build, for the test in the TTF linac, two prototypes of a 2x7-cell superstructure instead of one 4x7-cell prototype. The RF-properties of the 2x9-cell and the 2x7-cell versions are very similar as confirmed by the HOMDYN [6] simulation. The acceleration process of the TESLA beam (old or new set of parameters) showed the same, very small bunch-to-bunch energy variation for both versions [7]. Since the scheme of the HOM suppression in both versions is also very similar, we conclude that a beam test of the 2x7-cell prototypes will deliver enough data to verify the superstructure concept.

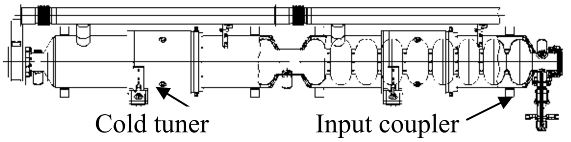

Figure 1: 2x9-cells: The left subunit is shown in He vessel with a cold tuner. The right one is shown with only one input coupler needed to transfer power to 18 cells.

Each prototype has three HOM couplers attached to the end beam tubes and to the interconnection (Fig. 2). The diameter of the interconnecting tubes for all versions of the superstructure has been chosen to keep the accelerating mode well below the cut-off frequency of the tubes. This allowed to avoid heating of HOM couplers attached at the interconnecting tubes by the magnetic field of the accelerating mode. Although the superstructure is made of many cells, the damping is better than for a standard multi-cell cavity with the same number of cells, since pairs of HOM couplers can suppress parasitic modes of much shorter subunits. The attached couplers were of the same type as those used for standard 9-cell TTF cavities. We should mention here that the 2x9-cell version has four cells more than the tested prototypes and an additional HOM coupler will be attached at the interconnection to compensate for that. Both prototypes were examined for the RF-properties of HOMs prior to their assembly in the cryomodule. We will show examples of the measured results in the next section. The discussion here is limited to the dipole modes, since these are relevant for the TESLA beam quality.

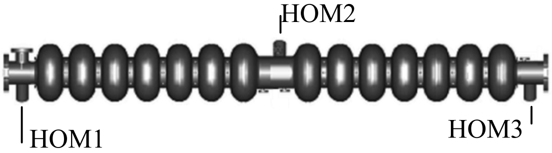

Figure 2: Prototype of 2x7-cell superstructure with three attached HOM couplers: HOM1÷HOM3.

HOM MEASUREMENTS AT 300 K

The computed dipoles of the 2x7-cell prototypes, with significant (R/Q), are listed in Table 1. When compared to the dipoles of a standard 9-cell cavity or to the dipoles of 2x9-cell superstructure, the average impedance per cell is almost the same. This is why the damping specification, $Q_{ext} \leq 10^5$, for these modes holds for all three cases. We have measured frequency, Q_{ext}, and if it was possible, the field profile and angular orientation of both polarizations for each of these modes. The last two measurements were performed by means of the perturbation method. The frequency change was measured vs. the longitudinal position or vs. the angular position of a dielectric perturbing bead. In case of many modes these measurements were impossible due to very strong overlapping of modes and/or difficulty in modes excitation. As an example, the measured profiles of one polarization of the mode No. 45 are shown in Fig. 3 (P1) and in Fig. 4 (P2). The field profile in P1 is similar to the theoretical one. The energy is stored in both subunits. The

Table 1: Computed dipoles, 2x7-cells

Mode No.	f [MHz]	(R/Q) [Ω/cm^2]
11	1717.658	17.0
12	1722.436	13.9
14	1757.921	12.1
21	1858.651	5.2
24	1871.893	10.3
45	2574.259	27.0
47	2641.672	4.4

actual (R/Q) in this case is well estimated by its computed value. Unlike this, for P2, the measured field showed that frequencies of subunits differ for this mode and the energy is stored in one subunit only. Although this happened the damping of a parasitic mode can still be provided since HOM couplers are attached at both ends of a subunit. This situation is similar to that of a standard multi-cell cavity. The actual (R/Q) value is near to its computed value for a single 7-cell structure. For these measurements we defined an angular orientation of dipoles as a direction parallel to the maximum of electric field in the x-y plane. In this measurement a dielectric bead was moved angularly in the mid plane of a cell having maximum stored energy. The measurement was done for both subunits in a prototype. For each bead position (increment of 30°) we measured the frequency of the mode. Fig. 5 shows the result measured for mode No. 11 (lower polarization) of prototype P1. The angular position of the electric field maximum (minimum frequency) is the same in both subunits. This means that coupling between subunits does not cause additional angular rotation of the dipole. We observed this, within an accuracy of ± 15°, for other modes which have almost the same stored energy in both subunits. However, when only one subunit has stored energy, the angular position of the mode is determined by irregularities of the shape in this subunit only.

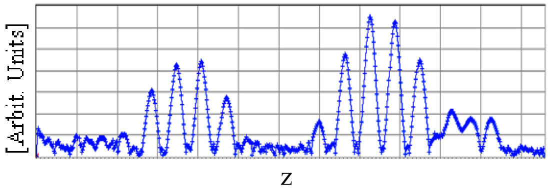

Figure.3: Prototype P1. Field profile of the lower polarization of dipole No. 45, f = 2568.558 [MHz].

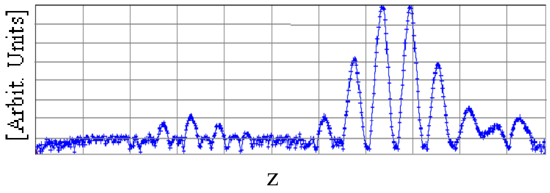

Figure.4: Prototype P2. Field profile of the higher polarization of dipole No. 45, f = 2568.471 [MHz].

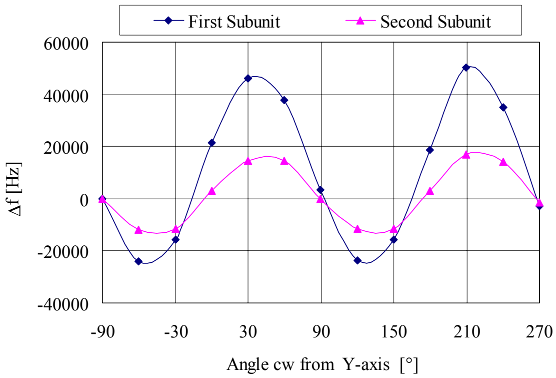

Figure 5: The lowest frequency is measured at the angle when the perturbing dielectric bead is placed in the highest electric field.

HOM MEASUREMENTS AT 2K

At first we measured for both cold prototypes, by means of Network Analyzers, f and Q_{ext} of modes up to 3.2 GHz. In total, 420 modes have been investigated. This data gave us a first estimation of Z and was used to identify dipoles, which interaction with the beam should be measured by the active excitation method to verify their impedance. The sketched setup used for the active mode excitation method is shown in Fig. 6. A chosen dipole mode was excited via one of the HOM couplers with a continuous wave amplifier. Transversal fields of the mode caused sweeping of the on axis injected beam, whose position was measured by a BPM 15 m downstream from the cryomodule. Knowing the RF power coupled into the superstructure one can estimate the amplitude of the deflection. It depends on this power, on the impedance of the mode, on the beam energy and on the distance between the structure and the BPM. The position of the beam in the BPM also shows angular orientation of the mode. One can apply the active method to modes which couple well to HOM couplers. Forty seven modes were measured in this way. An example of measured BPM signals is shown in Fig. 7a,b. In this particular case one polarization of the dipole No. 45 was excited with 20 W forward power. The damping of this mode was good. Its Q_{ext} was $2.1 \cdot 10^4$ (5 times below the spec). We measured the deflection in both planes for 32 bunches (2 nC) in 32 µs long pulses. Ten consecutive pulses are shown in each figure. The strong oscillation of the beam position was

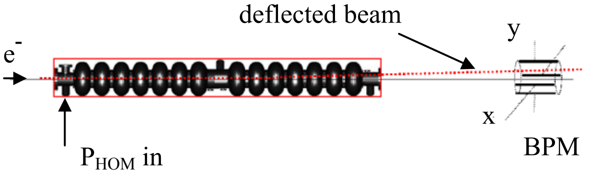

Figure 6: The setup (not in scale) for the active mode excitation. P_{HOM} is the forward power delivered by the

amplifier. BPM measures position of the beam, both in vertical (y) and in horizontal (x) directions.

observed when the power was applied (Fig. 7b). The mode has been tested six times, for various settings of the optics and for various HOM couplers used to transfer RF-power into the cavity. The computed (R_comp) and the measured deflections are presented in Fig. 8, among these values for other modes of prototype P1. The differences between computed and measured deflection were mainly due to the optics setting and due to direct coupling of a part of the RF-power into the beam line [8]. This happens for propagating modes when an external HOM coupler is used as the input port. Fig. 9 shows the measured polarization. Here the differences were due to calibration errors of the BPM signals. Nevertheless, the measured deflection gave the estimation of Z, which in the worst case would be 2 times higher than expected from the Network Analyzer measurements; however it still is harmless to the TESLA beam. The measured polarization showed that this mode, when excited by the accelerated beam, will deflect it almost horizontally.

We measured other modes in a similar way, however not all showed such a deflection as the mode 45 described above. The method still needs further development. All applied methods to measure the HOM damping have verified the good suppression of dipoles in both prototypes of the superstructure. A summary of the measurements is shown in Fig. 10. After the beam test we are more convinced that the 2x9-cell version should not have a major problem in regard to the HOM damping.

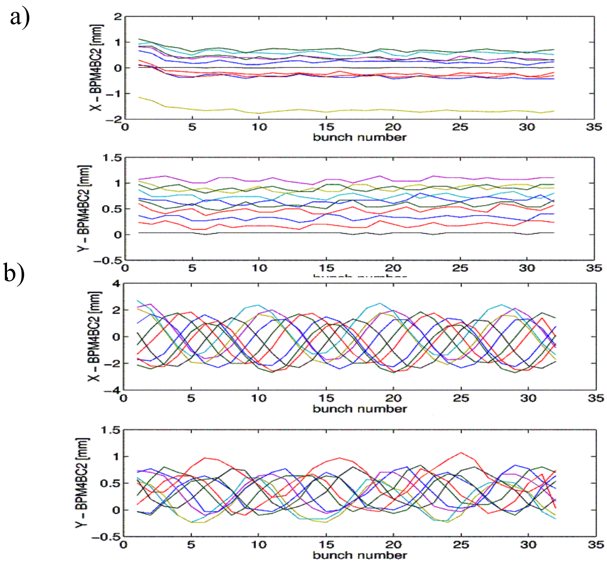

Figure 7: BPM signals without (a) and with (b) the excitation of the dipole mode.

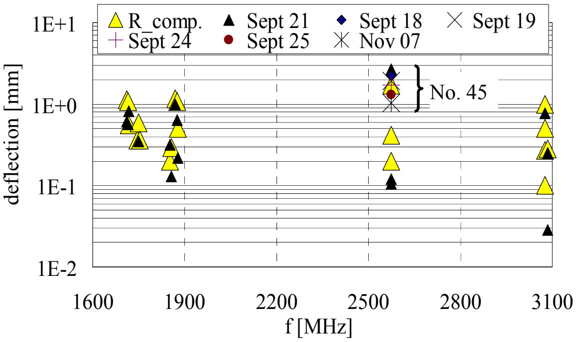

Figure 8: Computed (R_comp) and measured amplitudes of the deflection for dipole modes of the P1 prototype.

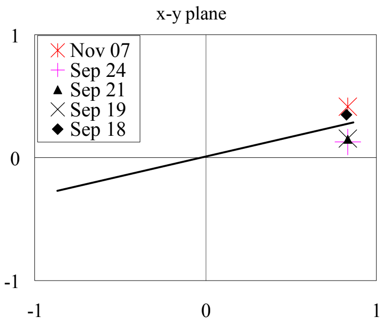

Figure 9: Normalized position of the deflected beam in the x-y-plane. The line shows polarization.

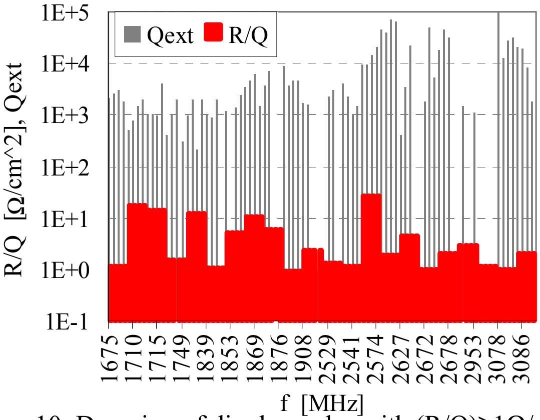

Figure 10: Damping of dipole modes with (R/Q)≥1Ω/cm^2.

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