HOM DAMPING REQUIREMENTS FOR THE TESLA SUPERSTRUCTURES

N. Baboi[1], R. Brinkmann, H. Chen[2], M. Liepe and J. Sekutowicz, DESY, Hamburg, Germany

Abstract

A chain of four non-resonantly coupled 7-cell cavities is thought to replace the 9-cell cavities considered in the standard design of the accelerating structures for the TESLA main linac. The main advantages of these so called superstructures are the reduced number of power couplers and the increased fill factor in the linac. This paper deals with the damping of the higher order modes (HOM) to a level where they cause no harm on the beam. Calculations have been performed in order to set a safety limit to the quality factors. The measurements done on a copper model of the superstructure show that the required damping level can be achieved.

1 INTRODUCTION

Modules containing eight superconducting 9-cell cavities were initially envisioned to be used for acceleration in the main linac of the TESLA linear collider [1]. A new type of accelerating structure, called superstructure, is recently studied and proposed to replace the older design [2]. A superstructure is made of four 7-cell cavities with interconnection tubes of $\lambda/2$ length. The whole chain of 28 cells is fed through one power coupler. This leads to an overall reduced number of such couplers. Moreover, with such layout the fill factor in the main linac is increased. Some questions arise regarding the achievable flatness of the accelerating mode, but it was proved that a flatness at least as good as for the 9-cell cavities can be achieved. In this paper we present studies regarding the required damping level of the higher order modes (HOM) that have to reach the level set by help of beam dynamics simulations.

2 SIMULATIONS

The frequencies and the impedances of the HOMs of the first passbands were computed with the help of the MAFIA code. In Fig. 1, the highest impedances, R/Q, of the dipole modes of the first three passbands are shown for the superstructure (4 $\times$ 7 cells), as well as for the 9-cell cavity [1]. The impedances were normalized to the number of cells, which gives us the possibility to roughly compare the two structures. As it can be seen, the values are in general smaller for the superstructure. About the same modes (or equivalent) have the highest impedance as for the 9-cell case. A special attention requires the 3rd dipole passband, since in more cavities of the TESLA Test Facility one mode with an R/Q of 15 Ω/cm^2 was found to be insufficiently damped.

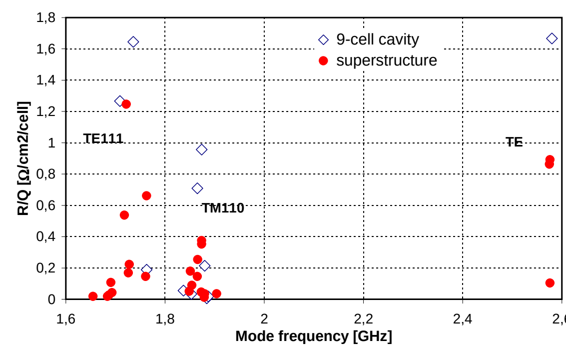

Figure 1: Highest dipole mode impedances

The beam dynamics in the TESLA main linac was simulated, in order to study the effect of the HOMs. Each module contains 3 superstructures replacing the 8 9-cell cavities. The main linac was structured as initially proposed in [1]. In the first section, from 3.2 up to 50 GeV, focusing and defocusing quadrupoles are placed alternatively after each two accelerating modules. For the next two sections, up to 150 and 250 GeV, respectively, the quadrupole spacing is 3 and 4 modules respectively. The quadrupoles are considered to be perfectly aligned on the accelerator axis. The accelerating cavities are transversely misaligned with 500 μm rms. The gradient is 21.7 MV/m (25 MV/m for 9-cell).

The lower gradient allows for the acceleration of a higher beam current. The main parameters of the bunch train are shown in Table 1 comparatively to the ones initially proposed [3].

		reference	new
current	[mA]	8	9.5
charge	[nC]	5.8	3.2
bunch spacing	[ns]	708	337
number of bunches/pulse		1130	2820
pulse length	[μs]	800	950

Table 1: Main parameters of the bunch train

The bunches are assumed to be rigid. The short range

[1]On leave from NILPRP, 76900 Bucharest, Romania

[2]On leave from Tsingua University, 100084 Beijing, China

wake fields are here not taken into account. No special problems are expected in this respect for this kind of structure, since the shape of the cell is about the same as for the 9-cell cavity. The frequencies and impedances of the dipole modes are the ones shown in Fig. 1. The first higher order monopole passband was also taken into account. 10 classes of cavities with a spread of 0.1 % rms in frequency were assumed. The quality factors of the modes were set to various values in order to look for the safety limit as regards the beam dynamics. The kicks from the HOMs were assumed to be concentrated at the center of the superstructure. 10 runs with various random cavity misalignment and cavity detuning were done for each case. For all the simulations mentioned below, the same 10 machines were considered, i.e. each cavity has the same offset and HOM frequencies. The only difference are the quality factors of the HOMs. This allows for a better comparison between various cases.

First, the quality factors, Q, of all HOMs were set to $5 \cdot 10^5$, except for the 4 dipole with a impedance bigger than 15 Ω/cm^2 and 2 monopole modes with R/Q bigger than 150 Ω, for which a Q of $1 \cdot 10^5$ was assumed. The highest R/Q for a dipole mode is 35 Ω/cm^2, while for the monopole modes it is 300 Ω. (Note that we mention here R/Q per superstructure, while in Fig.1 it was given per cell.) The obtained longitudinal multi-bunch energy spread is negligible, of the order of 10^{-4} %, but the transverse normalized multi-bunch emittance is quite large, being close to the desired vertical emittance at the interaction point, $3 \cdot 10^{-8}$ m·rad. In the next step, the Qs of the 4 dipole modes with the highest impedance were lowered to $5 \cdot 10^4$. This does not bring much change in the emittance. Therefore all other modes were damped as well from $5 \cdot 10^5$ to $2 \cdot 10^5$. Now the emittance obtained is well below the maximum admissible value. The beam dynamics was simulated for some more cases as well. The most interesting results are shown in Table 2. The maximum normalized multi-bunch emittance ε_n obtained in the 10 random simulations done for each case is given.

Dipole modes number	Q	R/Q [Ω//cm^2]	max ε_n [m·rad]
27 4	$5 \cdot 10^5$ $1 \cdot 10^5$	 > 15	$2 \cdot 10^{-8}$
27 4	$5 \cdot 10^5$ $5 \cdot 10^4$	 > 15	$1.5 \cdot 10^{-8}$
27 4	$2 \cdot 10^5$ $5 \cdot 10^4$	 > 15	$5 \cdot 10^{-9}$
24 7	$2 \cdot 10^5$ $5 \cdot 10^4$	 > 10	$2 \cdot 10^{-9}$
27 4	$2 \cdot 10^5$ $1 \cdot 10^5$	 > 15	$8 \cdot 10^{-9}$
31	$2 \cdot 10^5$		$2 \cdot 10^{-8}$

Table 2: Multibunch emittance for various choices of Q

As it can be seen, damping most of the modes to a level of $2 \cdot 10^5$ is sufficient, except the ones with a $R/Q > 15$ Ω/cm^2, for which values under $1 \cdot 10^5$ are desirable. Still, a stronger damping will be tried for these modes, as well as for the modes with $R/Q > 10$ Ω/cm^2, since locally they can give a very strong kick to the beam. In practice, only some of the 27 modes considered in the simulations will reach $2 \cdot 10^5$, which relaxes even more the damping level required for the others. The transverse position standard deviation is in all cases under 10 μm and can be easily corrected by a feedback system.

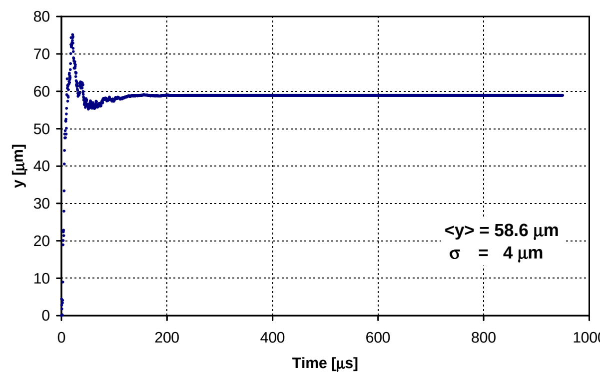

Figure 2: Bunch train at the end of linac

In Figures 2 and 3, one of the worst result obtained from the simulations done for the case of 27 modes having $Q = 2 \cdot 10^5$ and 4 with $1 \cdot 10^5$ is shown. The bunch offsets in the vertical plane are plotted in Fig. 2 and the normalized multi-bunch emittance in the same plane in Fig.3 . It is important to remark here that, as seen from Fig.2, less than 10 % of the train contribute in fact to the emittance growth. Therefore the term we used above of multi-bunch emittance is not a good parameter to describe the properties of the bunch train, but it enables us to compare the various calculations we made.

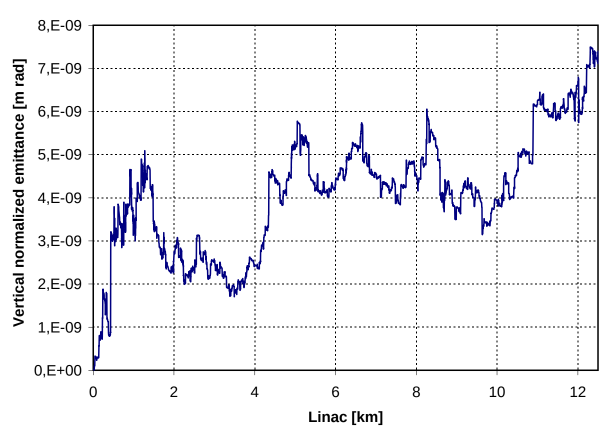

Figure 3: Multibunch emittance along the linac

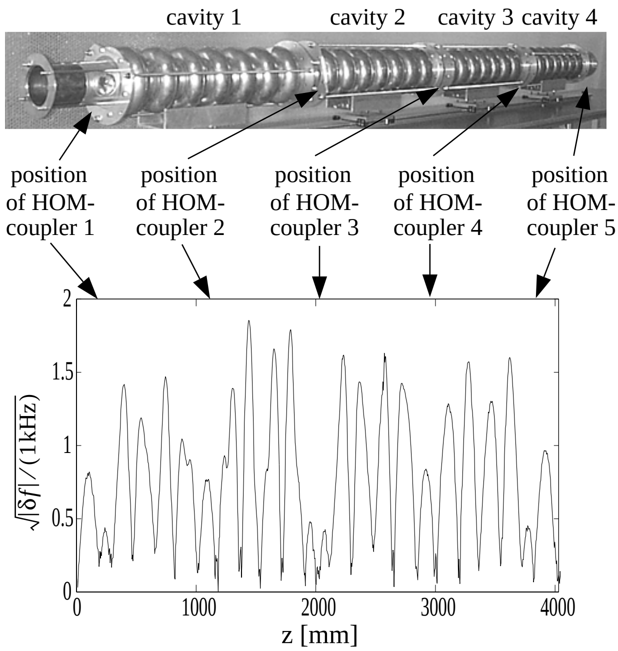

Figure 4: Field profile for the TE111 mode with the highest R/Q

3 MEASUREMENTS ON A TEST BENCH

To achieve the required damping level, five HOM couplers are attached to a copper model of the superstructure [4]. Three are placed at the interconnecting tubes and two at end tubes. Their geometry is almost the same as for the 9-cell cavities. The external Qs were measured for all modes up to 3 GHz for various angular positions of the couplers.

In Fig. 4 the field profile for the TE111 mode with the highest R/Q is shown.

The results of the tests show that a very good damping is achieved for most of the modes, with respect to the requirements. Only few modes are near the limit value (see Fig. 5).

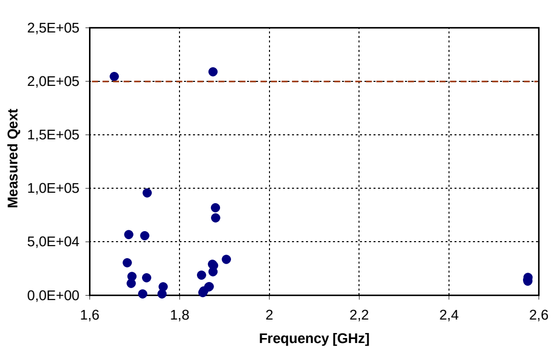

Figure 5: Measured Q_{ext} at the copper superstructure model

The measured Q_e of the modes were used for new simulations. Again 10 random cases were considered. The case with the highest obtained emittance is shown in Fig. 6.

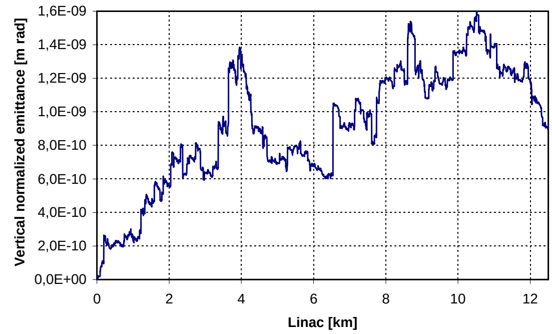

Figure 6: Multibunch emittance along the linac, based on measured Q_{ext}

A prototype of the niobium superstructure is under construction and it will be installed and test with beam in the TESLA Test Facility in the early 2001.

4 CONCLUSIONS

By help of beam dynamics simulations, the required damping of the HOMs was estimated. The monopole modes are less critical, Qs of $5 \cdot 10^5$ and $1 \cdot 10^5$ being low enough from beam dynamics point of view. But, on the other hand, the monopole modes are limited by the peak power capability of the cables to a Q of $4 \cdot 10^4$. For most of the dipole modes, a quality factor under $2 \cdot 10^5$ is sufficient, while for a few high impedance modes a level below $1 \cdot 10^5$ is necessary. In practice many modes will have much lower Qs. By experimental measurements it was found that the required damping level can be achieved for all modes.

A detailed technical study of TESLA is recently being done [5]. 4 superstructures will be put in one cryomodule. The main linac is parted only in two sections, from 5 to 125 GeV, and up to 250 GeV.

5 REFERENCES

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