NUMERICAL EVALUATION OF BEAM COUPLING IMPEDANCES IN HEAVILY DAMPED ACCELERATING CAVITIES *

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Abstract

The longitudinal and transverse shunt impedances of the accelerating cavity to be used in the PEP-II B-factory are calculated. The cavity is connected to dissipative loads through three waveguides to achieve good HOM suppression. The code POPBCI is used to evaluate the shunt impedance of the lossy structure as a function of frequency. The availability of a reliable simulation tool allows a careful dimensioning of the structure, aiming at the attainment of a suitable trade-off between the damping of the unwanted modes and the degradation of the Q-factor and longitudinal shunt impedance of the accelerating mode.

1. INTRODUCTION

The prevention of bunch-to-bunch beam instabilities due to the wake-fields excited by the beam itself is an issue that arouses an increasing interest in the design of high intensity storage rings. The frequency behavior of the longitudinal and transverse beam coupling impedances defines the conditions for the onset of instabilities, which are highly probable when these impedances exhibit closely spaced, sharp resonance peaks, like those due to the Higher Order Modes (HOM) of the accelerating cavities. Thus the primary cure for preventing coupled-bunch instabilities consists in smoothing these peaks. The conventional approach is to provide the accelerating cavity with dampers, most of them consisting of absorbing loads connected to the cavity through waveguide sections and suitable irises or loops. Dimensioning the waveguides in such a way as to place their cut-off frequency between the frequency of the fundamental mode and the frequency of the first HOM, the dampers do not affect appreciably the Q-factor of the fundamental (accelerating) mode, whereas the Q-factors of HOMs are lowered to different extents, depending on their coupling with the propagating waveguide mode(s). In any case, an effective damping of almost all HOM can be achieved only by a tight coupling between the waveguides and the cavity, which, in turn, requires that they are connected through large apertures. The design of the overall structure, and in particular the calculation of the coupling impedances at the beam harmonics, is a difficult task, since the electromagnetic solvers commonly used for the analysis of three-dimensional resonators cannot manage the dissipative loads at the end of the waveguides, being limited to solve problems with Dirichlet and Neumann boundary conditions.

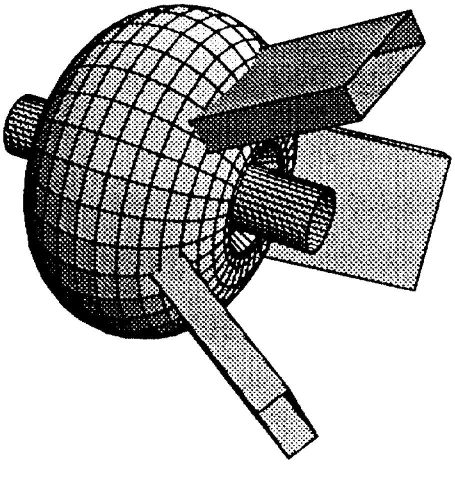

Fig. 1

HOM-free accelerating structures have been studied at the Department of Electronics of the University of Pavia (Italy) during the last two years: a strategy was suggested [1] for realising non conventional resonators (named "Single Trapped Mode Resonators", or STMR), and a novel algorithm has been presented [2], well suited for calculating the longitudinal and transverse shunt impedances of cavities connected to waveguides loads. The algorithm is based on an eigenfunction expansion: the field produced by the beam in the damped structure is expressed in terms of the resonating frequencies and of the modal fields of the lossless cavity that one obtains when the waveguides are short-circuited at a distance from the cavity. Thus the proposed algorithm, implemented in the code POPBCI (POst Processor for Beam Coupling Impedances calculation) [3], can take advantage of the results of conventional electromagnetic packages that are used for the modal analysis of lossless cavities. POPBCI gives $R_{\parallel}$ and $R_{\perp}$, the real part of the longitudinal and transverse beam coupling impedances, at any frequency up to a maximum value of about 0.8 times the frequency of the highest resonance calculated in the modal analysis. Since the effect of the apertures between the accelerating structure and the beam pipe is neglected, the obtained results are meaningful only up to the cut-off frequency the beam pipe; at higher frequencies, how-

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ever, the HOM suppression is enhanced by the additional energy leakage through the beam pipe.

The code POPBCI is a useful tool in the design of heavily damped accelerating cavities: it permits to dimension carefully the coupling structures, looking at a suitable damping of the unwanted modes without reducing too much the value of $R_{||}$ and the Q-factor of the accelerating mode.

2. NUMERICAL SIMULATIONS

We report the results of some preliminary simulations concerning the design of the 476 MHz accelerating structure to be used in the PEP-II B-Factory (see fig. 1). The selected damping scheme consists of three waveguides connected to the cavity body: the structure has a three-fold symmetry around the beam axis and three planes of symmetry passing through the centre of the waveguides. This configuration permits the damping of both monopole and dipole HOMs, without loss of rotational symmetry of the fields in the axial region [2]. Moreover, the need of damping modes having an even symmetry with respect to the equatorial plane suggested to displace the waveguides with respect to the cavity equator, as pointed out in [2].

In the simulations the width of the waveguides was 25 cm: thus their cut-off frequency was 600 MHz, between the frequency of the fundamental mode (476 MHz) and of the first dangerous HOM (≈660 MHz). Two sets of simulations were carried out, referring to waveguides of different height, namely 5.08 cm and 2.54 cm. In both cases coupling between the cavity and the waveguides was through inductive irises 21.3 cm wide and of the same height as the waveguides. The modal analysis was carried out using the code ARGUS, that gave the resonant frequencies, the Q-factors and the modal fields of the cavity with short circuits at the waveguide ports, located at a distance of about 27 cm from the cavity body. Modes up to about 1200 MHz were considered. In order to reduce the computing time, the modal analysis was performed exploiting the symmetry: only half of the structure was modelled, enforcing a magnetic wall condition on one of the symmetry planes passing through the beam axis.

Fig. 2 refers to the case of 5.08 cm waveguides: it reports the frequency plots of the longitudinal (fig. 2a) and of the transverse (fig. 2b) coupling impedances. Impedances are plotted in logarithmic scale and are normalized to reference values of 6 MΩ and 30 MΩ/m, respectively. Fig. 3 reports the same quantities for the case of 2.54 cm waveguides. For comparison, fig. 4a,b shows the shunt impedances of the short-circuited cavity. Actually, the reference impedances were chosen in order to be close to the largest values in these plots. The effectiveness of the proposed scheme is apparent: damping in the range of 20 - 30 db is achieved in both cases for the most dangerous HOMs, with a minimum loss in the shunt impedance of the accelerating mode (we found a value of about 5.1 MΩ in both cases). The different height of the waveguides affects only the detail of the plots, the difference in damping being limited to a few db for corresponding frequency ranges. The sharp peak that can be observed in fig. 2b, 3a and 3b near 1030 MHz corresponds to a mode having a very low value of either the axial electric field and of its transverse gradient. Probably this mode is a TE-like mode, (which should not contribute to either the longitudinal or the transverse impedance), that was calculated with a poor accuracy: the low value of the corresponding impedances for the short-circuited cavity (see fig. 4), confirms this guess. This mode does not couple too much with the waveguides, and its damping is very limited: in any case, whether it is a genuine solution or not, this mode is probably not dangerous, thanks to the low value of the impedances (30 - 40 db below the reference).

The structure we considered is asymmetric with respect to the cavity equator: thus also the electric field of the accelerating mode should be asymmetric. Numerical simulations show that this asymmetry is fairly small, the differences of the values of the axial fields being less than 10%. In any case, if a complete symmetry is a vital issue, it is possible to add three more waveguides, symmetrically placed with respect to the equatorial plane. The damping of this six waveguides configuration has been investigated on a simple pill-box model, and its effectiveness has proven to be very good.

The Q-values shown near the residual peaks in the impedance plots of fig. 2,3 have been calculated directly from the frequency responses. The usual definition of Q-factor was considered, i.e. $Q = f_0/\Delta f$ (f_0 = center frequency; Δf = bandwidth between the frequency points where the real part of the impedance halves). Although this definition holds only for high Q-values, and thus is objectionable in the present case, the calculation has been performed in order to compare these results to those presented elsewhere in these Proceedings [4], obtained using the Kroll-Yu method [5]. The agreement is fairly good, especially for the first HOM. At higher frequencies, however, when the modal spectrum becomes quite crowded, the Kroll-Yu method becomes more difficult to apply, and the differences are more sensible. This is mainly due to the fact that the when the coupling is high, the resonances tend to overlap: in this case the field excited by any beam harmonic is a superposition of many resonant fields. As a result the contribution to each impedance peak in the damped structure comes from many resonating modes of the undamped cavity. This is apparent in the plots of fig. 2 and 4: for instance, the peak of $R_{\perp}$ near 1050 MHz (see fig. 2,3b) depends on the coupling between a group of modes in a band from 1000 to 1150 MHz.

3. CONCLUSIONS

The code POPBCI was used to calculate the wideband coupling impedances of the damped accelerating structure proposed for the PEP-II B-Factory. The results of the numerical simulations show the effectiveness of the damping scheme. They compare well, qualitatively at least, with the values of the Q-factors calculated by the Kroll-Yu method. The computational efficiency of the method we used is good, since a single run of an electromagnetic solver gives all the quantities to be considered by POPBCI for the impedance calculation.

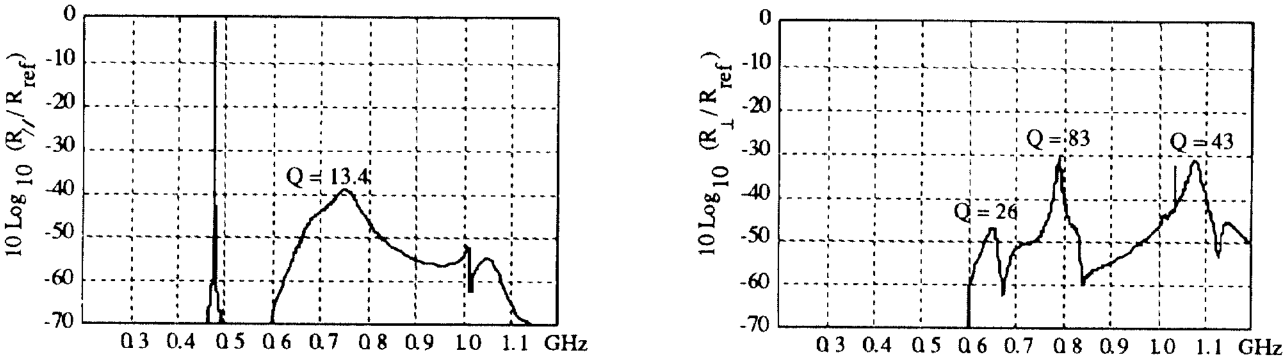

Fig. 2 - Longitudinal (a) and transverse (b) shunt impedance for the structure of fig. 1. Reference impedance are 6 MΩ for longitudinal impedance and 30 MΩ/m for transverse impedance. Waveguide height is 5.08 cm.

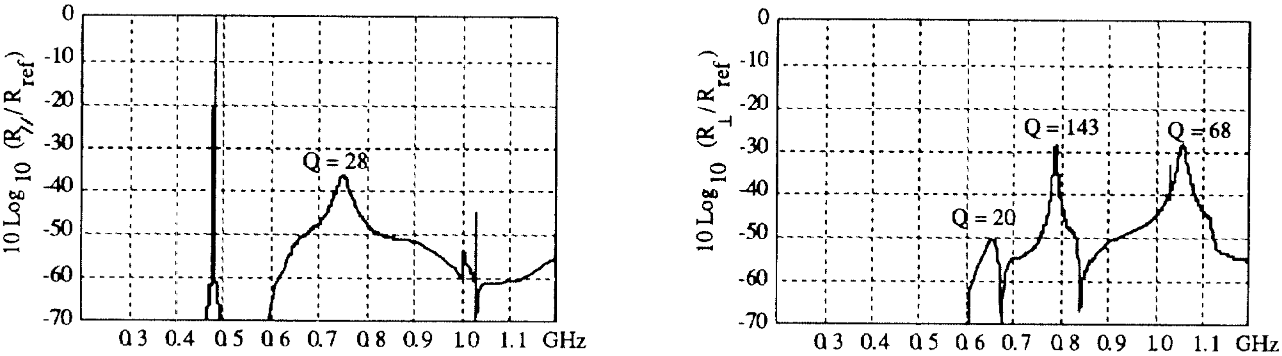

Fig. 3 - Same plots as in fig. 2, but for waveguide height of 2.54 cm.

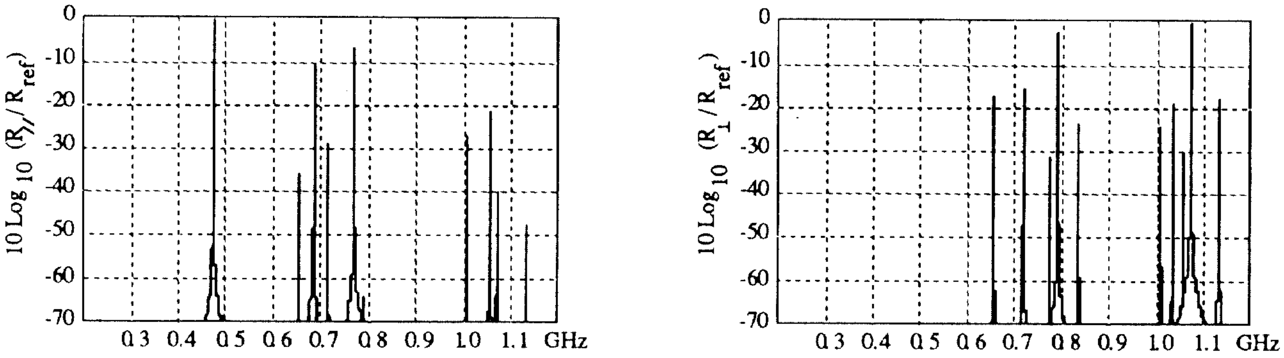

Fig. 4 - Longitudinal (a) and transverse (b) shunt impedance for the cavity of fig. 1, when the waveguide loads are replaced with short circuits. Reference impedances are the same as in fig. 2 and 3.

4. REFERENCES

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