Further Developments of the Broad Band H.O.M. Suppressor at Trieste

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Abstract

By coupling two waveguides to a smooth shape cavity a satisfactory damping of the H.O.M. spectrum has been obtained. Several configurations and different absorbing materials have been tested, with a particular care in the design of the waveguides terminations. The accelerating electric field component has been measured in order to verify the actual shunt impedance value of the damped resonator. The design of a pill-box resonator coupled to two waveguides through large apertures has been started, since a more compact and efficient structure is expected. First results are shown here.

1. INTRODUCTION

An adequate damping of the Higher Order Modes (H.O.M.) spectrum is required for the ELETTRA Synchrotron Light Source Storage Ring RF cavities. Otherwise multibunch instabilities can be excited in the RF cavities, since the number of bunches is quite high (432) [1], [2].

It is well known that the H.O.M. power induced in the cavity by the beam can be fed out, through large holes on the cavity walls, into waveguides. This power is then dissipated by the waveguide termination. A broad band suppressor is then realized, without affecting largely the fundamental mode of the cavity. This solution could be chosen for the Trieste Synchrotron Light Source, since, when optimized, it can lead to a H.O.M. free resonator.

The design procedure should take into account several parameters. In order to optimize them, different structures have been designed and tested.

The first tests with pill-box cavities have shown that the waveguide should have a square section. This allows to have the lowest cut-off frequency of the second propagating mode of the waveguide, TE11. In this way resonances of the cavity like the TM011 mode or the TE111 mode that couple more strongly to the TE11 waveguide mode than to the dominant TE10 mode are quite completely damped. Furthermore, there should be an offset between waveguide and cavity so that the waveguide doesn't see any zero of the cavity modes field pattern. To achieve this result also the hole position should be asymmetrical with respect to the cavity and waveguide axis. It is intended that, along with the mentioned condition on its position, the hole should have the largest possible area, and therefore a square section has been chosen for it. Finally, it seems sufficient to couple two waveguides shifted by an azimuthal angle of 90° to kill also almost all dangerous multipole resonances [3].

The experience on pill-box cavities has been successfully applied in the design of a suppressor for a smooth (or bell) shape cavity.

2. THE PERFORMANCE ON A SMOOTH SHAPE CAVITY

2.1. The Damped Resonator

The cavities which are presently intended to be the first cavities which will be mounted on the ELETTRA storage ring are smooth shape resonators at 500 MHz [4]. Hence, a damped resonator has been developed starting from a prototype of this smooth shape cavity. In the final configuration two waveguides are coupled to the cavity; between their axis there is an azimuthal angle of 90°. Due to the particular elliptical geometry of the resonator a satisfactory damping has been obtained giving an inclination of about 50° to the waveguides with respect to the cavity symmetry plane. This enhances the coupling to some dipole modes which have low fields in the equatorial region of the cavity. An offset of 60 mm introduces the necessary asymmetry in the coupling between cavity and waveguide. The resonance frequencies of the first three modes of the cavity have such values (see Table 1) that the possible choice for the waveguide section is practically restricted to a square section of 290 mm side size. (fc TE10 517 MHz, fc TE11 731 MHz). The holes on the cavity walls have a square shape in the cut section with the diagonal size of 230 mm. One reason for these quite large holes is to couple sufficiently the modes with low fields in the equatorial region.

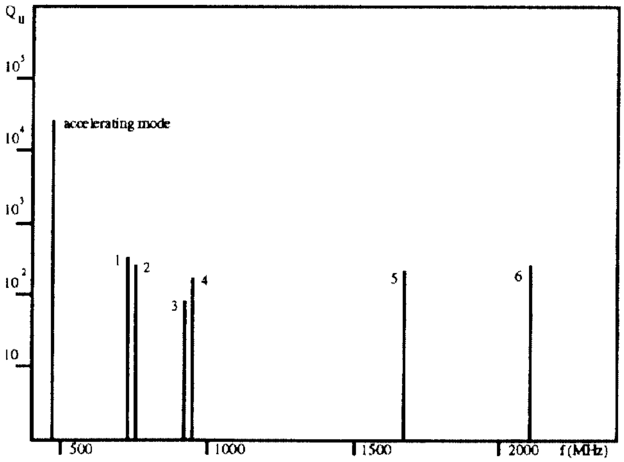

Figure 1. The Mode Spectrum of the Damped Resonator.

The mode spectrum of the damped resonator is shown in Figure 1 [5]. The results which are shown there don't take into account either the optimization of the waveguide termination shape and material or the presence of a vacuum window in the waveguide close to the connection to the cavity.

The first two dipole resonances (D1 and D2) and the first longitudinal H.O.M. (L2) of the smooth cavity are listed in Table 1, together with the accelerating mode (L1). It should be pointed out that the identification of the resonances of the damped cavity around 735 MHz (1,2 in Fig. 1) and around 940 MHz (3,4) with the modes D1, D2 and L2 of the original smooth cavity is not so certain (°). It is more probable that these resonances arise in the new resonating structure made up by the cavity and the shorted waveguides. In fact, the damping effect on those modes, particularly on the resonances at 935 (3) and 952 MHz (4) is highly influenced by the type of termination used in the waveguide.

Table 1

Modes below 1 GHz in the Smooth Shape Cavity

	Undamped Cavity		Damped Cavity	
mode	fr (MHz)	Q_0	fr (MHz)	Q_0
L1	500	42000	467	26000
D1	743	44000	(°) 732	300
D2	748	40000	(°) 737	250
L2	944	43500	(°) 952	170

2.2 Waveguide Termination Design

As already mentioned, an important item in the design of the H.O.M. suppressor under discussion here is the termination of the waveguide, which should dissipate the H.O.M. power excited by the beam in the cavity.

The traditional design of a rectangular waveguide load optimizes its performance for the TE10 mode, which is the usual mode for the waveguide to work. In our particular case, the field pattern in the waveguide can be similar to that of the TE10, but it can be also quite different. This may happen for example when the TE11 configuration is excited by modes of the cavity. Hence the design for the load should take into account all possible field configurations in the waveguide.

The common TE10 loads are cones or wedges or pyramids placed in the center of the waveguide, that is where the TE10 mode has the maximum electric field. The TE11 mode has low electric field there, while it becomes stronger moving towards the corners of the waveguide. Hence, a wedge has been put in each corner of the waveguide along with a cone in the center. The comparison with the cone only solution is shown in Table 2. Both shapes have been obtained in the laboratory with graphite loaded foam-rubber. As it was expected, we have a good improvement for the two resonances around 940 MHz.

Table 2

Comparison between Q factors with different load shapes

Load Shape	mode 1 732 MHz	mode 2 737 MHz	mode 3 935 MHz	mode 4 952 MHz
Cone	300	250	90	170
Cone + Wedges	320	250	damped	80

To furthermore enhance the behaviour of the load, we have then looked for commercial absorbers. An absorber that fits nicely the frequency range and the attenuation requirements we need, is the ECCOSORB VHP-45®. The base of the pyramids has been reduced to 290x290 mm, to fit into the waveguide.

Table 3

ECCOSORB VHP-45® damping performance.

Load Shape	mode 1 732 MHz	mode 2 737 MHz	mode 3 935 MHz	mode 4 952 MHz
Pyramid	240	130	damped	55
Pyr. + Wedges	280	160	damped	65

As it is shown in Table 3, the ECCOSORB VHP-45® absorber improves the damping also on the resonances (1) and (2), while the Q of the resonance at 952 MHz is again reduced by about 30%. The result obtained with the wedges in the corners is now slightly worse than without them, even if still better than the corresponding result in Table 2. This could be due to the fact that the wedges have been cut in our laboratory and the resulting shape has been not sufficiently sharp.

Finally it seems that with a good commercial absorber and with the described shape a very good damping of the H.O.M.'s can be achieved. It is to be noted that, since we expect a few kW of H.O.M. power dissipated in the waveguide termination, the choice of the absorber will have to concern also with this problem.

2.3 Dimension of the ceramic window in the waveguide.

In the final configuration the waveguides should be in air. Therefore a ceramic window will be placed at the beginning of the waveguide, close to the connection to the cavity. Along with the mechanical and thermal problems, the ceramic window could affect the efficiency of the coupling of the H.O.M.'s to the waveguide. Actually, the 290x290 mm square section of the waveguide should be reduced to locate the ceramic, in order to minimize the mechanical troubles; on the other hand the lower the area of the window, the worse the H.O.M. coupling. To find out how much a ceramic window could reduce the damping and how large the minimum acceptable area is, we simulated the ceramic window in the waveguide. A 2 mm thick metallic sheet has been put inside the 2 m long waveguides, 200 mm far from the cavity. In the center of the sheet a square aperture has been opened. Its dimension has been increased till an acceptable damping has been found.

This happens with a 200x200 mm aperture, which has an area equal to about half the area of the original waveguide section. In Table 4 it is shown that with this half area aperture the Q's of the listed modes are quite similar to those obtained with the full aperture. Mode 1 and 2 behaves better with small windows than with large ones. This could confirm that they originally are waveguide and not cavity modes. Anyway, the 200x200 mm window is a good compromise.

A circular window of the same area (Φ 230 mm) has then been tested, since this should be the ideal geometry for the ceramic. As it can be seen in Table 4, the Q factors have values similar to those of the square window.

Table 4
Effects of an aperture for the ceramic window in the waveguide

Window Shape	mode 1 732 MHz	mode 2 737 MHz	mode 3 935 MHz	mode 4 952 MHz
square 150x150	25	70	400	210
square 200x200	230	160	damped	60
circular Φ 230	170	125	60	85
square 290x290	240	130	damped	55

A dielectric layer (ε_r 6.5) has then been fixed on the sheet with the 200x200 square aperture; the behaviour, shown in Table 5, is still satisfying. Finally, a ceramic window of circular or square section, with an area equal to about 50% of the waveguide section, doesn't influence the H.O.M. damping.

Table 5
Q values with a dielectric layer on the aperture

Window Shape	mode 1	mode 2	mode 3	mode 4
square 200x200	230	160	damped	60
+ dielectric layer	280	200	damped	50

2.4 Electric Field Measurements.

The accelerating mode in the damped resonator has a Q of 26000. The measured R/Q is equal to 145 Ω, leading to an R_{sh} of 3.8 MΩ, that requires six RF plants instead of four.

The two large holes at 90° degree in the cavity may cause a distortion to the electric field of the fundamental mode with a transverse component on the beam axis. It has been evaluated that if the transverse component is less than 1.0% of the longitudinal one, the beam orbit displacement is compensated by putting two cavities in the same section but rotated by an angle of 180° between each other.

From the electric field measurements the distortion introduced by the waveguides has been found to be less than 0.3%, hence the above condition is met.

3. CONCLUSION

The H.O.M. damping achieved in the configuration with two waveguides coupled to the smooth shape cavity through large holes on the cavity walls (Fig. 1 , Tab. 1) should be enough to avoid multibunch instabilities in Elettra [6]. A further enhancement of the performance has been obtained by properly choosing the waveguide load shape and material as well as the shape of the ceramic window. The influence on the accelerating mode is low, even if it should be better reduced.

However the engineering of the prototype seems to be the critical point, due to the complex geometrical shape of the connection between cavity and waveguide. The very large waveguide section, due to the mode spectrum of the cavity with the first H.O.M. frequencies very close to 500 MHz, leads to a pretty huge structure. With such a section the evanescent field attenuation in the guide at 500 MHz is low, so that the distortion effects on the accelerating electric field are enhanced, with a corresponding relatively low Rsh. All these reasons lead to the conclusion that the smooth geometry is not the best one if a waveguide suppressor is implemented. For this purpose a cylindrical geometry is more suitable.

Thus the choice is between a nose-cone cavity and a pill-box cavity. The first one has the advantage of a higher shunt impedance, but has a more critical Es/Ea ratio. However the conclusive reason to decide for the pill-box cavity in this specific application is the H.O.M. frequency distribution below 1 GHz. The experience acquired up to now with the prototypes points out that the higher the frequency of the TE111 mode and of the TM011 mode in the cavity the smaller can be the waveguide, with the result of a much more compact damped resonator. Hence a pill-box cavity with rounded corners has been designed. The radius is 230 mm and the height 180 mm. The TM011 frequency is around 1 GHz, the TE111 frequency is above 900 MHz. These frequencies are roughly 200 MHz higher than for an equivalent nose-cone cavity for the TM011 mode and 30 MHz for the TE111 mode. Compared to the smooth shape cavity they are respectively 50 MHz and 170 MHz higher in the pill-box cavity; in this last case also the first dipole mode (TM110-like) is 60 Mhz higher in the pill-box cavity. A waveguide with TE10 cut-off at 600 MHz matches all cut-off requirements; it can be also much shorter, since the reactive attenuation at 500 MHz is 60 dB/m.

The shunt impedance (RT^2) of the fundamental mode of the pill-box is only 15% lower than in the equivalent nose-cone cavity and 12% lower than in the smooth shape cavity. This means that with an upgrade from four to six RF plants (which is in any case foreseen also with the smooth shape cavity for operation at 2 GeV of the machine) we are still able to give the required power to the beam. The smaller waveguide section also avoids a large spreading of the accelerating field lines into the waveguide; consequently the field distortion should be minimized as well as the shunt impedance reduction.

All preceding considerations are very positive for a compact, almost H.O.M. free resonator. A pill-box based structure is now being produced in our workshop. The tests on it will start as soon as possible.

4. REFERENCES

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