The Design of a Pill-Box Cavity with Waveguide HOM Suppressors

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Abstract

High suppression of the higher order mode (HOM) spectrum of an accelerating radio frequency cavity can be obtained with two waveguide suppressor coupled through a large aperture to the cavity. An intensive experimental work led us to choose a pill-box shape for the central body of the resonator. Along with a heavy damping of the whole HOM spectrum, the electromagnetic characteristics measured on a 'cold' prototype show that the accelerating performance of the fundamental resonator mode remains satisfactory. After having thoroughly tested the cold prototype, the design of a power resonator has been started. The more interesting aspects of this design, concerning mainly mechanical, thermal and vacuum topics are described here. The choice of the microwave absorbing material is discussed as well.

1. INTRODUCTION

The HOM of the radio frequency cavities of the Elettra Synchrotron Light Source Storage Ring could drive multibunch instabilities, due to the high current and to the many short length bunches [1], [2].

From the very early beginning of the project, the use of dedicated waveguides to suppress almost the whole HOM spectrum has been investigated in order to prevent the rise of these instabilities [3], [4], [5], [6].

Large apertures in the cavity walls should guarantee the highest possible coupling to most HOM. The electromagnetic power of the HOM is then fed through waveguides to absorbing loads, while the accelerating mode frequency lies quite below the cut-off frequency of the guides. To improve the transmission of the power to the load the section of the waveguide has been chosen square; in this way also the TE11 mode of the waveguide can propagate at relatively low frequencies.

The challenging tasks of this design are to provide large apertures on the cavity walls without affecting too much the fundamental mode parameters, like quality factor and R/Q, and to overcome the mechanical, thermal and vacuum topics presented by the connection of large waveguides to the resonator. Along with this, the microwave absorbing material for the load and the shape of the termination have to be chosen.

On the other hand, the behaviour of such a resonator during the conditioning procedure and the power operation is still unknown. Therefore, after an intense experimental activity on a cold resonators, with satisfactory results, which are shown in the following, we are presently concerned with the design of a power prototype.

2. THE COLD PROTOTYPE

Dedicated waveguides to damp the HOM spectrum have been tested in our laboratory on several cavities of different shape, pill-box, pill-box with nose cones, smooth shape (bell shape). It has been found that for our design the optimal shape is the pill-box without nose-cones.

The geometry of this shape presents wide plane surfaces. On these surfaces it is quite simple to open large square section apertures and the connection to a square section waveguide doesn't present particular mechanical problems.

At the same time in the pill-box cavity the frequencies of the first dipole and monopole modes can be distributed, with a proper choice of the internal profile of the resonator, in a way that minimizes the dimension of the waveguide section.

Hence the pill-box shape has been chosen. Its profile has been optimised with OSCAR2D and URMEL-T simulations. The fundamental mode parameters for the final profile are listed in Table 1 [7].

Table 1
Pill-box cavity fundamental mode parameters
(Electrical definition of shunt impedance)

f_r (MHz)	Q	R/Q (Ω)	R_{sh} (MΩ)	$R_{sh}T^2$ (MΩ)
509	36800	150	5.5	3.4

The fist dipole mode (TM_{110}) frequency lies for this cavity around 794 MHz, while the first monopole mode (TM_{011}) frequency is about 980 MHz. Thus, a waveguide with a 250x250 mm square section, that is TE_{10} cut-off frequency at 600 MHz and TE_{11} cut-off frequency at 850 MHz matches the requirements for this cavity. The reactive attenuation at 500 MHz is roughly 60 dB/m, which should be sufficient to limit within an acceptable range the spread of the accelerating mode field into the waveguide.

Two holes are placed on the side walls of the cavity. They are 180x180 mm large; their position is asymmetrical with respect to the waveguides symmetry plane, in order to avoid coincidence of the zero's of the cavity fields with the symmetry planes of the waveguides. There is an azimuthal angle of 90° between the two apertures, so both polarizations of the dipole modes should be damped.

The waveguides are 1500 mm long, plus 250 mm of the connection piece to the cavity; they are terminated with a pyramid of commercial absorber, ECCOSORB VHP-45®. The pyramidal load has a 250x250 mm large base and is 1140 mm long. It is a low power absorber, not cooled, which has been useful for the low power tests.

A sketch of the cavity is presented in figure 1. The connection between cavity and waveguide is pointed out.

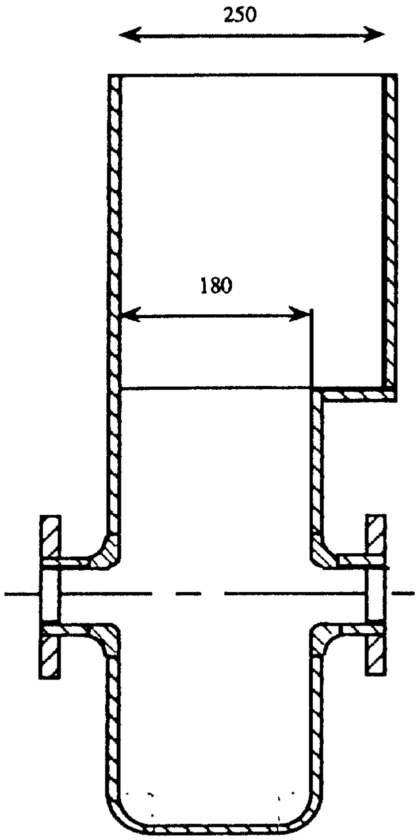

Fig. 1 Lateral view of the cavity-waveguide connection

The electromagnetic parameters of the accelerating mode, as measured on the damped cavity, are shown in Table 2. It should be noted that, for this low power prototype, no particular care has been taken in brazing; furthermore the connection pieces between the cavity and the waveguides are just screwed. Thus the information on the Q-factor is not very significant; we expect an improvement in the power prototype.

Table 2
Pill-box cavity fundamental mode parameters
with waveguide suppressors

f_r (MHz)	Q	R/Q (Ω)	R_{sh} (MΩ)
500	25000	120	2.8

Even if we consider a pessimistic value of 2.5 MΩ for the shunt impedance, six cavities installed on the Elettra storage ring will be able to provide the required energy to the beam, at 1.5 GeV as well as at 2.0 GeV, with the present 60 KW RF plants. Actually we expect a nicely higher value for the Q factor, that is a shunt impedance value between 3.5 and 4.0 MΩ.

Once it was verified that the damped cavities could be adequate for the light source, the performance of the suppressor has been measured. The results are summarized in Table 3.

Table 3
HOM suppression results

mode	Without damping fr (MHz)	Without damping Q	With damping fr (MHz)	With damping Q
D1	790	31100	/	/
D2	971	25000	980	20
M2	1047	28300	1039	70
M3	1173	46900	1138	20
D3	1184	20600	1175	25
D4	1404	41300	1388	50
D5	1431	23100	1428	50
M4	1515	33300	1530	40
D6	1668	14400	1631	55
D7	1699	8200	1680	50
M5	1822	50300	/	/
M6	1902	16600	1916	190
M7	2079	29600	2026	50
M8	2190	20800	2176	80

The results in Table 3 concern monopole and dipole modes, that is the modes that can cause the growth of instabilities. The resonances above the cut-off frequencies of the beam tubes are not taken in consideration. The dipole modes are classified with D# , the monopole modes with M#. This kind of classification is used rather than that with the original pill-box modes, since the identification of some field patterns in the damped resonator is quite uncertain.

The first monopole mode, D1 or TM_{110}, is completely damped. The other two resonances below 1.0 GHz present now a Q value lower than 70. Furthermore all the Q's are reduced to better than 1% of the undamped value.

The M2 resonance, that is the TM_{011} or common mode, is one of the most dangerous one. The Q value is now reduced to 70, but some experimental work on the load shape has shown that an improvement can be achieved by optimizing the termination. This is true also for other resonances.

The cold prototype has thus been completely characterized. The indication for the construction of a power prototype is very positive, so this will be the next step in our design.

3. Considerations on the Power Prototype Design

A. Cavity Design

A preliminary sketch of the pill-box cavity can be seen in figure 2. In this sketch the two apertures in the cavity walls are shown, together with the connection pieces to the waveguides.

In order to avoid any effect on the electron beam caused by the asymmetric geometry of the cavity, it has been decided to install two cells on the ring, close each other, with the second having the waveguides rotated by a 180° angle. The cells should be de-coupled and should take few space on the ring. So the beam tubes of the cavity will have exactly the same section of the vacuum chamber, as it is shown in figure 2. The higher cut-off frequency of the vacuum chamber section could limit the HOM power transmission through the chamber, but this should be acceptable since the low power measurements showed a good behaviour of the HOM dampers also in the higher frequency band.

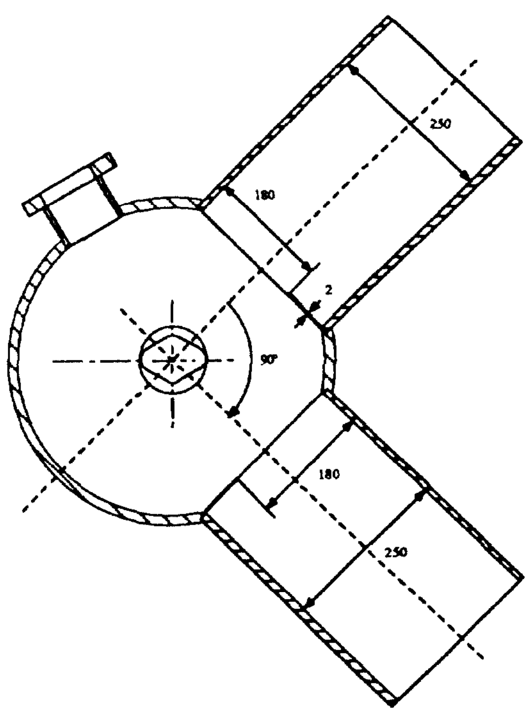

Fig. 2 Sketch of the power prototype.

The cooling system of the cavity will be designed taking into account particularly those areas surrounding the apertures on the walls where the power dissipation is expected to be critical, especially between the two waveguides. An intensive simulation activity is under development, with the support of commercial f.e.m. packages.

B. Suppressor Design

Along with the design of the power resonator, we are concerned with the study of the suppressor, that is the waveguide and the absorbing load.

Since the waveguide volume is big, it would be advisable to have the most part of the waveguides in air, by insulating the vacuum of the cavity with a ceramic window in order to limit the pumping requirements. At the same time this would allow a relatively easier design of the absorbing load.

The ceramic window should be inserted into the waveguide sufficiently far away from the cavity in order to avoid heating due to the fundamental mode field. Depending on the material characteristics and on the shape of the ceramic window there could be a negative effect on the HOM damping capability of the suppressor. Therefore we performed measurements on a prototype in which a glass window, 5 mm thick, was inserted in the waveguide. It was found that the smallest shape for a still acceptable damping effect is equal to a circular window with a diameter of 200 mm; the Q-values measured in this configuration are similar to those in Table 3. Since the window for the power prototype will be an alumina window, we are investigating how the damping changes with different permittivity and different thickness.

An alternative to the ceramic window is to have the waveguides under vacuum. This design would be more advisable from the suppressing point of view, since there is no mismatching along the waveguide, but it would present more technical difficulties. A powerful pumping system should be dimensioned to keep under high vacuum the waveguides .

Furthermore the load should be designed for operation under ultra high vacuum. Thus the microwave absorbing material should have a low outgassing rate, should be a good thermal conductor and, finally, should adapt a wide frequency band. Microwave absorbing materials with these characteristics have been already produced, but their reliability should be tested [8].

So, even if we develop the research activity also in this direction, we will first study the feasibility of a prototype with an alumina window placed into the waveguide.

4. REFERENCES

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