500 MHz CAVITIES FOR THE TRIESTE SYNCHROTRON LIGHT SOURCE ELETTRA

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Abstract

The first OHFC copper prototypes of the 500 MHz RF cavities for Eletra have been produced. The measured values of the electromagnetic parameters are shown: they are in good agreement with the ones calculated by the code OSCAR2D. The mechanical and thermal behaviour of the cavity was simulated with the F.E.M. code ABAQUS and then measured on the prototypes at our facility. Along with the results presented here, the optimization of the cavity shape, in order to minimize the mechanical stresses, and the design of the cooling system of the cavity are discussed. Details on an external tuning system, which changes the length of the cavity, are also given. Higher Order Mode couplers will also be developed for our cavities: the performances of two prototypes of waveguide couplers with a cut-off frequency above the fundamental mode are described.

Introduction

The ELETTRA synchrotron light source will be characterized by a low emittance storage ring with beam energies in the range between 1.5 and 2 GeV [1]. The layout of the RF system foresees four cavities at 1.5 GeV and six cavities at 2 GeV [2]. The cavities for the ELETTRA RF system have been designed taking into account the high accelerating voltage requested by the particular beam characteristics [1]. A "sphere like" cavity shape was therefore chosen, since this ensures a surface electric field lower than in an equivalent "nose-cone" cavity; this, together with the open geometry, minimizes the multipactoring effect [3]. Furthermore, the excitation of Higher Order Modes (H.O.M.) in this cavity should be reduced since the open geometry allows the propagation of modes with resonant frequencies above the cut-off frequencies of the drift tubes. Nevertheless, the multibunch instabilities analysis, performed taking into account the modes trapped into the cavity, indicates the necessity of H.O.M. broadband damping [4]; a broadband suppressor is being at present developed in our laboratories [5]. Along with this, to avoid the arise of additional, spurious resonant modes, the frequency of the cavity will be not tuned by means of an internal plunger but with an external tuning system. The chosen geometry shows also an advantage for the cooling system, since the magnetic field distribution is such to have a large maximum of the dissipated power in the outer region of the cavity, which can be cooled in an easy way by means of cooling pipes brazed on the cavity surface.

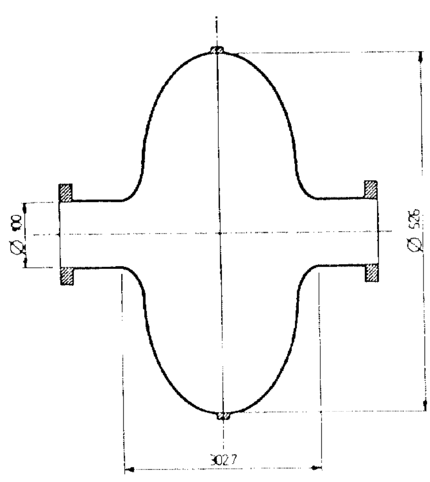

Figure 1. Square section of the ELETTRA cavity prototype.

The resonant cavity prototypes have been built by local Italian firms; a sketch of the prototype section is shown in fig.1. The thickness of the prototype is 3 mm.

Electromagnetic Parameters

The electromagnetic parameters of the cavity have been computed with the code OSCAR2D [6] for longitudinal modes and with the code URMEL-T [7] for transverse modes [8]. Then they have been measured on the prototype.

A comparison between the results of the simulation and the measured values is shown in Table 1 for the accelerating mode, that is the fundamental mode of the cavity. The measured values are very close to those used for the RF power system design [2].

Table 1. Fundamental Cavity Mode.

	computed value	measured value
Frequency (MHz)	500.2	499.9
Quality factor	45000	42000
Shunt Imp. (MΩ)	7.85	7.33
Transit Time Fact.	0.700	---
Effect.Sh.Im.(MΩ)	3.85	3.59

Measurements have been performed also on the H.O.M. of the cavity; they are shown, together with the computed values, in Table 2 for the longitudinal modes; Table 3 lists the transverse modes (dipole only). The modes shown are those with resonance frequency that is lower than the cut-off frequencies of the drift tubes of the prototype (radius of the drift tubes 10 cm).

Table 2. Longitudinal modes of the ELETTRA cavity.

mode	frequency (MHz)		quality factor		R (KΩ)
	OSCAR2D	measured	OSCAR2D	measured	OSCAR2D
2	945	944	46000	43500	1600
3	1061	1060	61000	57000	30
4	1415	1421	54000	49500	400
5	1513	1509	63500	53500	400
6	1608	1614	74000	53000	1600
7	1864	1875	55500	42000	400
8	1941	1947	83000	64000	200
9	2074	2087	61000	24000	40
10	2112	2120	89000	30000	2200

Table 3. Transverse (dipole) modes of the ELETTRA cavity.

mode	frequency (MHz)		quality factor		R (KΩ)
	URMEL-T	measured	URMEL-T	measured	URMEL-T
1	748	743	55000	44000	1.60
2	751	748	57000	40000	6.20
3	1120	1120	48000	39500	9.40
4	1231	1221	93000	89500	0.04
5	1276	1248	67000	37000	4.60
6	1313	1307	69000	58000	0.85
7	1599	1561	52000	38000	0.03
8	1676	1638	84000	32000	7.20
9	1718	1713	86000	62000	0.70
10	1755	1720	120000	38000	1.70

The shunt impedance quoted in the two tables above is the effective shunt impedance, defined by the formula

$$R = \frac{V^2 * T^2}{2P_w} \quad ,$$

where T is the transit time factor.

The values that we have measured on the prototype have been used in a first computation of multibunch instabilities [4].

Cavity Tuning System

The RF cavities will be provided with three tuners: a fast electronic tuner, a slower mechanical tuner and a very slow thermal tuner.

As far as the mechanical tuner is concerned, copper cavities are usually tuned by means of a plunger tuner. However, since there could be the risk of multipacting on the tuner piston and since high frequency modes, which might be dangerous for the beam, could arise, we have decided to tune the cavity by modifying its axial length, like it has been done at CERN for superconducting cavities [9].

As a first step we have analyzed the behaviour of such a system. First, an axial load acting on the flanges of the cavity has been simulated with the F.E.M. code ABAQUS [10]; the deformed shape of the cavity has been obtained, along with the internal mechanical stresses. Then, the deformed shape of the cavity has been simulated with OSCAR2D to obtain an evaluation of the corresponding frequency shift. The diagram in fig.2 shows the link between frequency shift and axial displacement; we obtain about 80 KHz per tenth of mm.

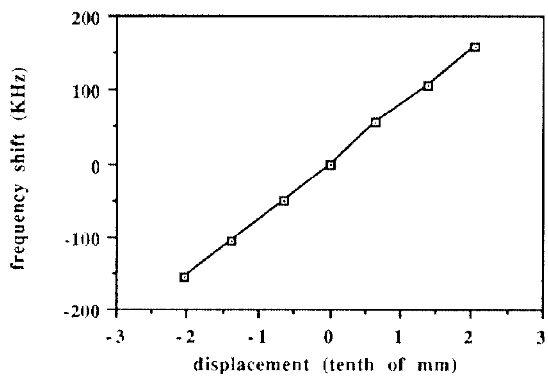

Figure 2. Cavity tuning system simulation: frequency shift vs. axial displacement (of each cavity neck).

The load that has to be applied to obtain the requested displacement is shown in fig.3; the spring constant of the cavity is equal to roughly 1000 N per tenth of mm.

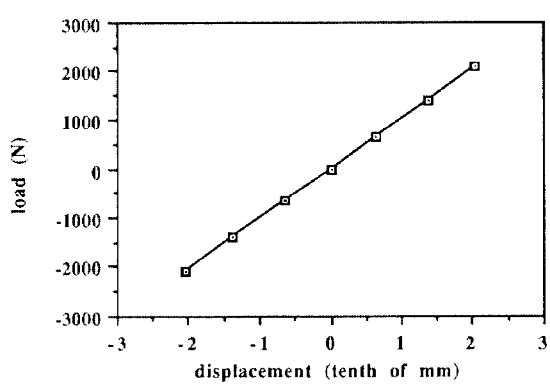

Figure 3. Cavity tuning system simulation: axial load applied to the cavity.

To check the reliability of the simulation we have carried out some measurements on the prototype. The measured frequency shift is shown in fig.4.

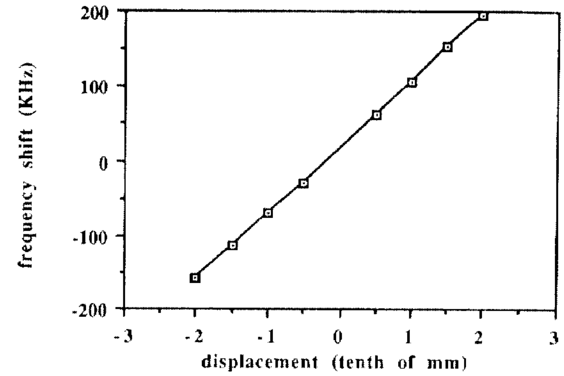

Figure 4. Measured frequency change.

The measured ratio between frequency shift and displacement is equal to about 90 KHz per tenth of mm. Also the spring constant of the cavity, equal to about 1250 N per tenth of mm, is slightly larger than the computed one; anyway there is a good agreement between simulation and measurement.

The tuning range of the cavity is determined by the maximum load one can apply with the cavity still in the elastic region. A load of about ±1400 N is requested to obtain a frequency shift of ±100 KHz; the corresponding maximum internal stress evaluated by ABAQUS is 21 N/mm^2, well within the elastic limit of soft copper ($\approx$ 36 N/mm^2). This tuning range covers our tuning requirements since the maximum frequency shift requested to compensate the beam loading is equal to 82 KHz at 2 GeV [8].

At present a tuning cage is being developed with a DC motor as driving element; since the matched Q is the half of the theoretical one, 1/10 of the bandwith is equivalent to about 3 μm. The smallest step of the system should be of this order.

The distributed load applied all over the cavity surface when vacuum is created inside the cavity has also been simulated with ABAQUS. With the cavity wall thickness of 3.0 mm the maximum internal stress is 21 N/mm^2 when the cavity is hold on its necks. This means that, in these conditions, the cavity will remain in the elastic region also with vacuum inside. Therefore with the chosen thickness the cavity will have an adequate tuning range and at the same time it will stand the vacuum load.

Temperature Depending Parameters

The knowledge of the dependance of resonance frequency on temperature is mandatory to evaluate the thermal tunability of the cavity and to fix the requirement for thermal stabilization. This dependance is theoretically equal to 9.0 KHz/°C [8].

This value is essentially confirmed by the simulation with ABAQUS and OSCAR2D, which gives a result of about 8.0 KHz/°C. With fixed cavity necks, the internal stresses corresponding to a ΔT of 20°C (180 KHz in frequency) are far away from dangerous values; the maximum values on the cavity walls are of about 5 N/mm^2.

The measurements performed on the prototype are summarized in fig. 5.

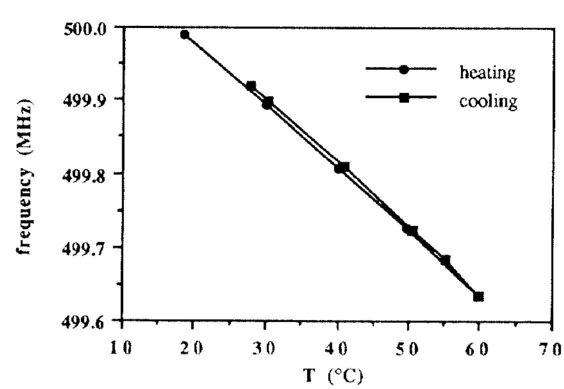

Figure 5. Measured thermal cycle of the cavity.

The thermal cycle shown in fig.5 is equivalent to 8.5 KHz/°C both in heating and in cooling.

Hence the measurement confirms the expected value. The requirement for thermal stability is therefore confirmed to be ±0.5°C [8].

As far as the cooling system of the cavity is concerned, it should be able to carry off up to 36 KW of power, which is the maximum value of power wasted in the cavity walls; this maximum is reached at 2 GeV and 400 mA [8]. With a water temperature increase of 5°C the necessary water flow is roughly 6 m^3/h. To guarantee this water flow cooling pipes will be brazed on the cavity surface; they will be connected in more parallel circuits to keep the water speed sufficiently low. This system has been simulated with ABAQUS; with a film coefficient of 15000 W/m^2°C and a sink temperature of 25°C the cavity temperatures range between 29.3°C and 32.6°C, that is an acceptable temperature distribution.

A Proposal for a Broad Band H.O.M. Coupler

An adequate damping of the H.O.M. of the ELETTRA cavities is requested to prevent multibunch instabilities. The optimum solution in the design of H.O.M. suppressors is the design of a broad band device with high-pass filter characteristics. Since waveguides are very sharp high-pass filters, we developed a structure with a waveguide directly coupled to a cavity. The waveguide cut-off frequency is enough higher than the resonance frequency of the cavity in order to minimize the damping effect on the fundamental mode, that is in our case the accelerating one. In our first prototype the cavity is a pill-box cavity resonating in the fundamental TM_{010} mode at 500 MHz and with the first H.O.M. distributed like the ELETTRA cavity modes. The spectrum of the pill-box cavity is shown in fig.6.

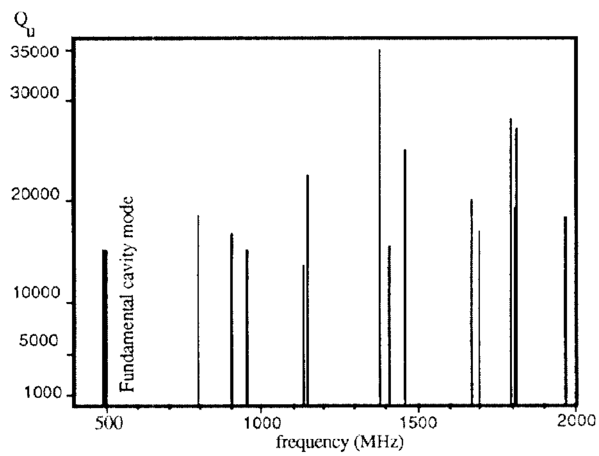

Figure 6. The undamped pill-box cavity spectrum up to 2 GHz.

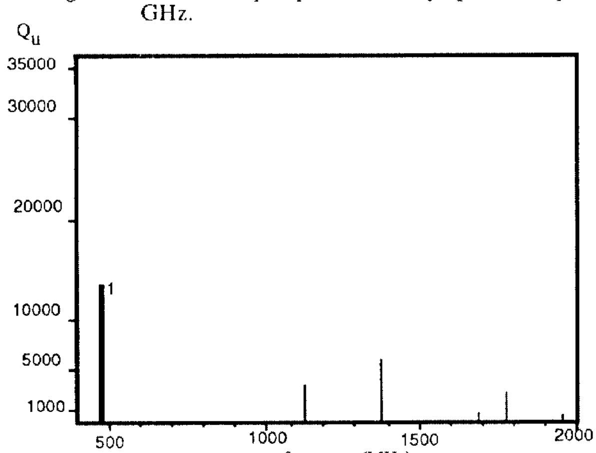

Figure 7. Mode spectrum of the pill-box cavity coupled to a square section waveguide.

As a first step the coupling aperture between cavity and waveguide has been made as large as the waveguide section; the waveguide end is closed on a dummy load. A first waveguide of rectangular section with a=250 mm did not give the expected results. After some field pattern analysis we have seen that some of the first cavity modes were coupled with the second waveguide mode, TE_{11}. This mode was under cut-off; consequently the energy of the cavity modes could not be dissipated in the dummy load thus remaining largely undamped. In order to have a lower cut-off frequency of the TE_{11} mode in the waveguide a square section waveguide has been designed, with side length equal to 250 mm. This prototype damps quite satisfactorily the H.O.M. as fig.7 shows.

The comparison between fig.6 and fig.7 points out the obtained damping of the H.O.M. spectrum: 14 modes out of 16 H.O.M. taken into account are practically damped; the damping effect on the fundamental mode is acceptable since it is in the order of 12% of the undamped value.

A second prototype in which the cavity has been coupled to a circular waveguide has also been tested: the measurements show a behaviour similar to that of the device with square section waveguide. The circular waveguide has slightly smaller dimensions.

At present we are analyzing different possible sizes and shapes of the coupling aperture. First measurements have given satisfying results with enhanced damping effects in comparison to those shown in fig.7.

Conclusion

We have summarized the development of the RF cavity prototypes for ELETTRA. The electromagnetic measurements performed on the prototypes confirm the calculated values. The mechanical and thermal behaviour of the cavity have been analyzed and tested; the results have been used to give the design specifications for the mechanic tuner and for the cooling system. The next prototype, which will be soon available at our facility, will be provided with tuning and cooling system. In this way it will be possible to test the RF power system feeding power to the cavity. A preliminary prototype of H.O.M. suppressor has been developed; the first results are encouraging, therefore we will design a waveguide device to be coupled to the ELETTRA cavities.

Acknowledgment

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