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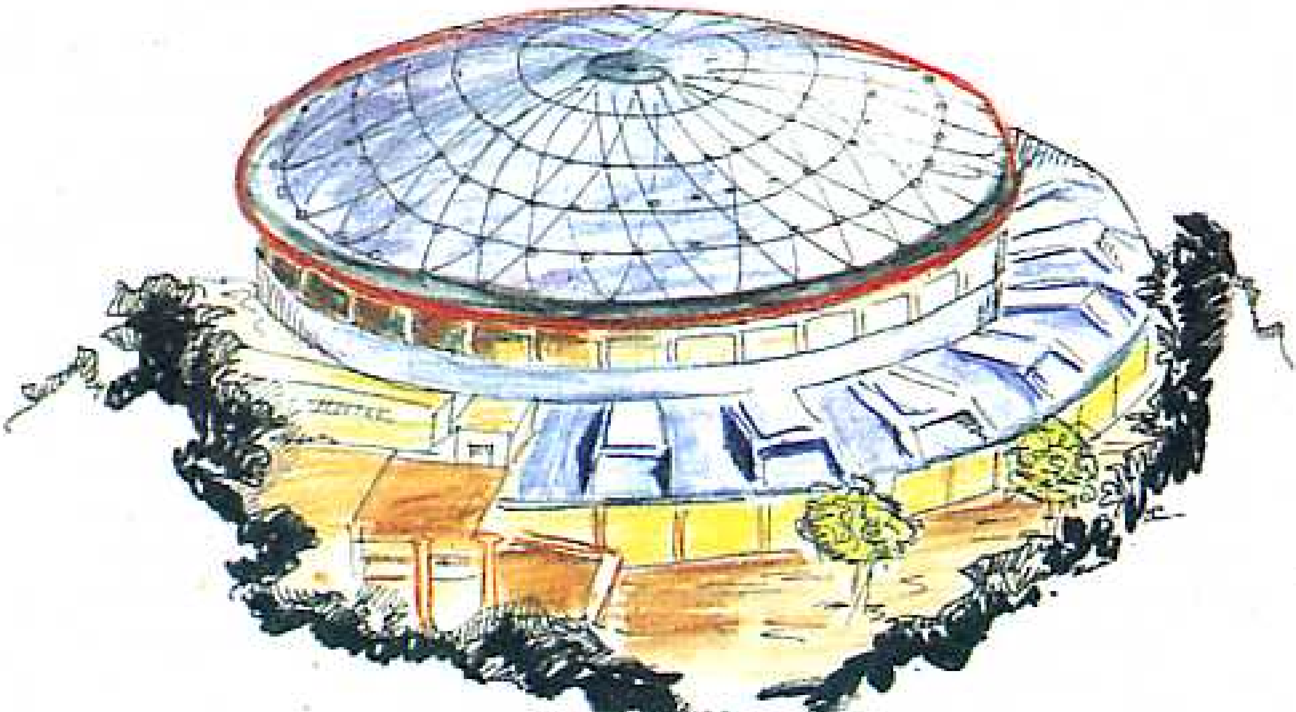

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STUDY OF THE PARASITIC MODE ABSORBERS FOR THE FRASCATI Φ-FACTORY RF CAVITIES

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ABSTRACT

A twin ring electron-positron collider Φ-Factory DAΦNE is in construction at Frascati National Laboratories. The machine is designed to store high current multibunch beams at the energy of 510 MeV. High luminosity through multibunch operation is the main goal of the accelerator. The accumulation of 30 bunches per beam is the first objective. Longitudinal instability is among the most troublesome problems in such a multibunch machine; extraction and damping of the cavity High Order Mode (HOM) wake fields induced by the charged particles is of primary importance. In this article we report about the R&D in progress to couple out and absorb the parasitic HOMs of the DAΦNE accelerating cavities.

1. - INTRODUCTION

The DAΦNE complex consists of two rings colliding beam Φ-Factory with an injection system composed of a 510 MeV e^+/e^- linear accelerator and a damping ring. Due to the high electron-positron current to store in 30 buckets of the DAΦNE rings with a total current of about 1.4 Amps, coupled-bunch instabilities may very likely occur. Also, the single bunch instabilities have to be considered and suitably cured. The interaction of the beam with the accelerator environment has been carefully analyzed by the DAΦNE machine group. Each vacuum component is designed to reduce as much as possible its contribution to the coupling machine impedance, which affects the single bunch dynamics[1]. In particular, the RF cavity, causing a sharp variation in the vacuum chamber cross-section and being source of resonant fields, deserves attention both for single and multibunch dynamics. Therefore, the reduction of the HOM impedances that may overlap the beam spectrum harmonics is mandatory. This is accomplished both by damping the spurious modes and properly shaping the cavity.

2. - THE DAΦNE RF CAVITY PROTOTYPE

The main RF parameters for a 30 bunches operation are given in Table I and Fig. 1 shows the shape of the RF cavity selected among some other RF structures studied and tested in our laboratory. The use of large diameter and smoothly tapered beam tubes [2] allows the parasitic mode fields to propagate through those large pipes; it follows that the HOM impedance average values are about a factor 3÷4 lower than those of a traditionally shaped resonator. In the DAΦNE cavity, only the TM011 mode has high impedance (R/Q = 15.7Ω) and a few modes have R/Q greater than 1 Ω. Due to the large beam tubes, the fundamental mode (FM) shunt impedance is rather low, but high RF voltage is not required in our machine. Also, the resonator has a rounded equator profile to make the multipacting unlikely and ease RF conditioning and operation.

Table I - RF Parameters (30 bunch operation)

RF Frequency	368.26 MHz
Cavity Impedance ($R/Q=V^2/2PQ$)	61 Ω
Cavity Qo	40,000
RF Peak Voltage	250 kV
Cavity Wall Power	13 kW
Synchrotron Beam Power	27 kW
Parasitic Beam Losses	< 1 kW
Cavity-Generator Coupling	≈ 3.0
Klystron Power	150 kW/cw

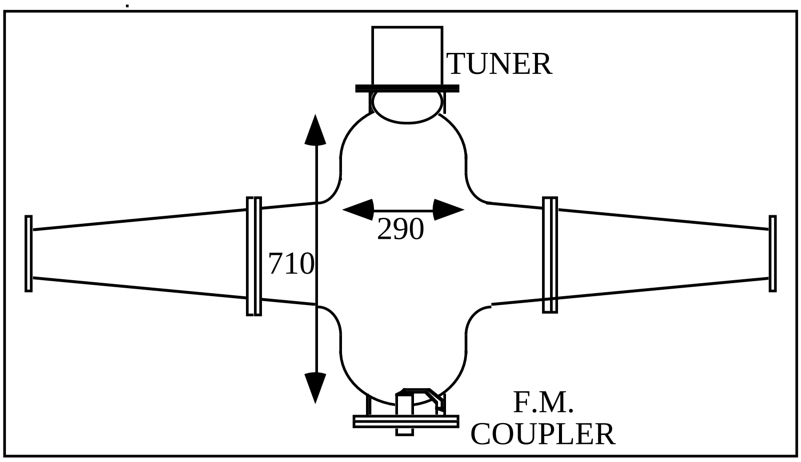

FIG. 1 - The RF Cavity for DAΦNE.

Additional damping of HOM impedances may be achieved by means of waveguides (WG), applied to the cavity external surface, which convey the parasitic electromagnetic fields out and dissipate the power on broadband loads connected to their opposite side. This damping method is also under development in other laboratories[3,4,5]. We have optimized the WG position with a careful examination of the HOM field patterns using the computer codes Oscar2D[6] and Urmel[7]. In DAΦNE, the monopoles are the most troublesome HOMs since they affect the longitudinal beam dynamics. Therefore we have focused our attention to those monopoles with the highest R/Q value (i.e. highest impedance) up to 2.5 GHz which approximately is the beam pipe cut-off frequency of the cavity straight section.

The best WG position is that where the magnetic field intensity of the parasitic modes is higher and can effectively couple the TE10 fundamental mode of the WG itself. A low power cavity prototype made in copper was fabricated and three ridged WG's, as sketched in Fig. 2, were applied to the prototype through slots obtained 120° apart onto the cavity surface to maintain the FM symmetry and also couple some multipole modes. The test cavity model is shown in Fig. 3.

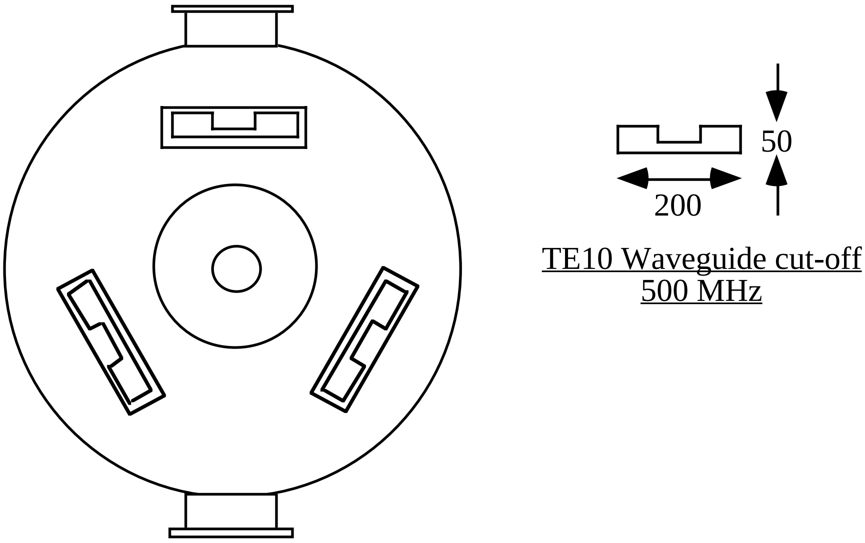

FIG. 2 - Sketch of the cavity lateral view.

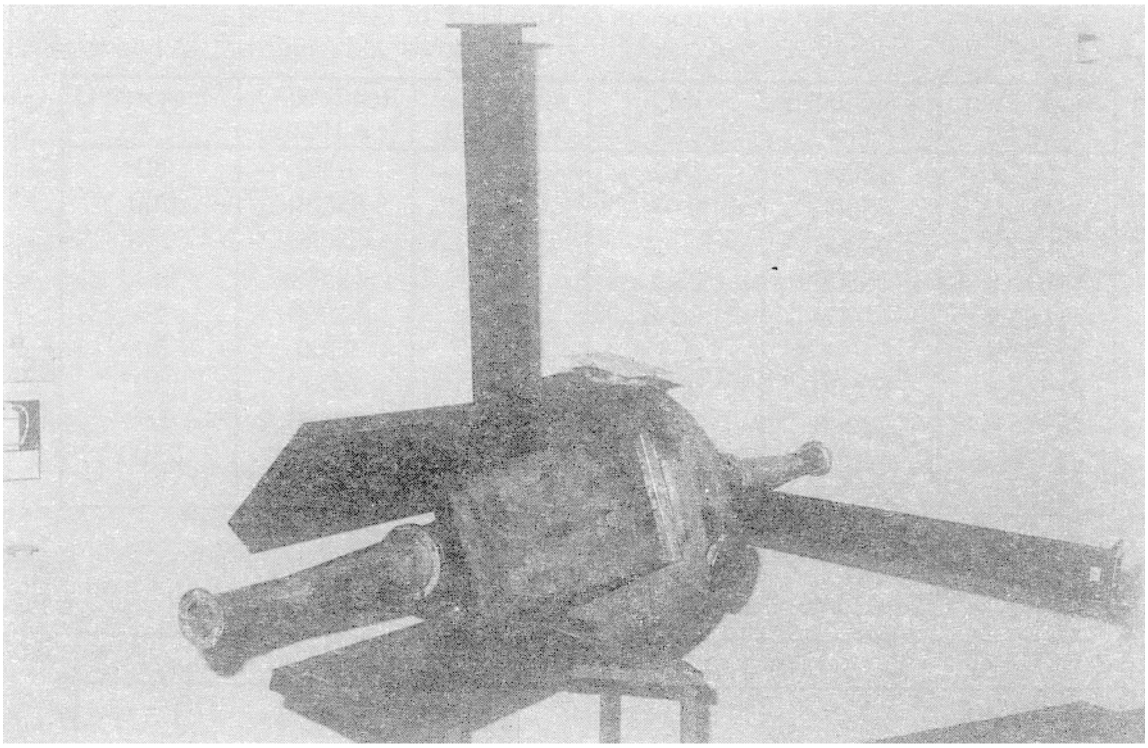

FIG. 3 - The DAΦNE Cavity Prototype.

The WG's are 200x50 mm sized and have the cut-off TE10 at 500 MHz to propagate also the lowest frequency dipole modes. Due to the very compact size of the ridged WG's the FM frequency and Q_o are unperturbed. Two additional WG's with cut-off at 1350 MHz were connected, 90° apart, on each tapered beam pipe to couple higher frequency monopoles and dipoles propagating along the tubes.

High RF loss ferrite tiles (60x60x5 mm, Trans Tech TT2-111R type), whose characteristics and performances are discussed later on in this paper, have been used as broadband load. They are placed onto the WG bottom without any special shaping since their impedance somewhat matches the vacuum impedance.

Table II shows in column 6 the HOM damping of the first 10 monopoles obtained with the cavity model fully equipped with WG's. Column 4 gives the risetime of the longitudinal instability of a 30 bunches beam if no damping were provided and for the worst case of a full coupling of one HOM with an unstable line of the beam spectrum[8]. In column 5, for each HOM, in full coupling, it is given the needed Q to keep the risetime above 100 µsec that is believed may be compensated by the longitudinal feedback system under development for DAΦNE, in collaboration with SLAC/LBL B-Factory group[9]. The prototype measured damped Q's and hence the HOM impedances are well below the maximum permissible value even in the worst and unlikely case of full coupling condition. Since a moderate degradation of the FM is tolerable, we are going very soon to apply to the prototype three 300x50 mm rectangular WG' s in place of the narrower ridged ones. We expect some further improvements of the damping performances due to a better mode coupling. Table III gives the parameters of the highest transverse impedance dipole modes and the obtained damped Q's.

Table II - Cavity Model Parameters & Rise Time of Longitudinal Instability

Mode Freq. [MHz]	Calculated Qo	R/Q [Ω]	Rise Time (full coupl)	Required Q (t = 100µs)	Measured Q
742.6	52000	15.7	9.5 µs	1000	80
791.5	85000	0.01	1.52 ms	85000	700
1020.3	68000	0.004	5 ms	68000	130
1072.8	68500	0.11	220 µs	68500	1700
1185.2	61000	0.24	120 µs	61000	50
1267.8	73000	1.5	29 µs	9700	50
1314.5	60000	0.34	90 µs	44000	50
1366.2	75000	1.37	29 µs	10500	330
1431.5	63000	0.72	48 µs	20000	2500
1463.5	65500	0.06	360 µs	65500	1100

Table III - Cavity Model - Highest R/Q Dipole Modes

Mode	F [MHz]	R/Q' [Ω]	Calculated Q	Loaded $Q_{1,2}$
1-EM-1	568.10	14.0	55000	350/----
1-EM-2	740.84	1.7	58000	100/----
1-MM-1	518.04	5.1	60000	650/580
1-MM-2	703.53	4.8	47000	250/340

3. - FERRITE ELECTROMAGNETIC FEATURES

Some Trans Tech TT2-111R ferrite tiles have been used as waveguide broadband loads in our cavity prototype. In order to better characterize the RF behavior of the ferrite, we measured the most meaningful wave propagation parameters of the material using a Frequency Domain Reflectometry technique based on the HP8753C network analyzer. The measurement sketch is reported in Fig. 4.

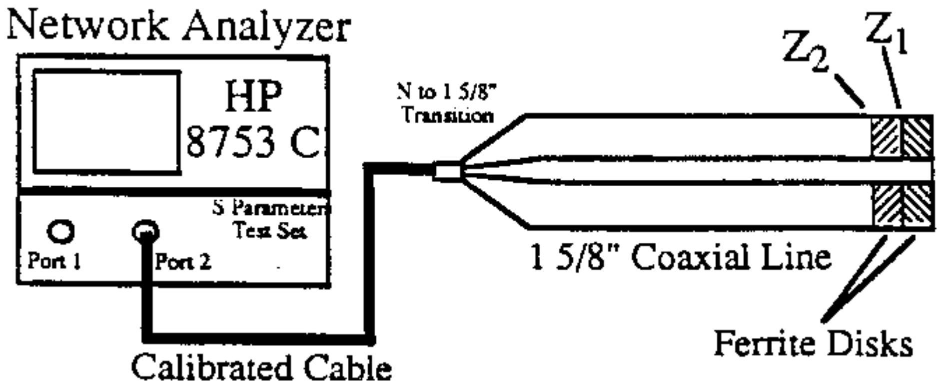

FIG. 4 - Ferrite Measurement Experimental Set-up.

We applied ferrite disks onto the bottom of a shorted 1-5/8" coaxial line and we measured the impedances Z_1 and Z_2 at the discontinuity plane in the case of one and two disk loads. So, if Z_0' is the ferrite characteristic impedance in the coaxial structure, γ the ferrite propagation constant and Δz the tile width, we have:

$$Z_1 = Z_0' \tanh(\gamma\, \Delta z) \qquad\qquad Z_2 = Z_0' \tanh(2\,\gamma\, \Delta z) \qquad (1)$$

By solving the equation (1) for the complex variables γ and Z_0', we get the propagation constant (i.e. the wavelength and the attenuation coefficient) and the characteristic complex impedance $\eta = (\mu/\varepsilon)^{1/2}$ of the medium at any frequency in the range 0.5 to 2.5 GHz. From γ and η we compute also the complex permeability and permittivity in the same frequency range. The curves are reported in Fig. 5.

The results show that ferrite and vacuum characteristic impedances are not much different. It is also noticeable that a single tile layer shows, in the selected frequency range, a better matching to the vacuum impedance than a double layer, which means that the average value of Z_1 is closer to the center of the Smith Chart than Z_2. The VSWR plot for a single and a double tile layer is reported in Fig. 6.

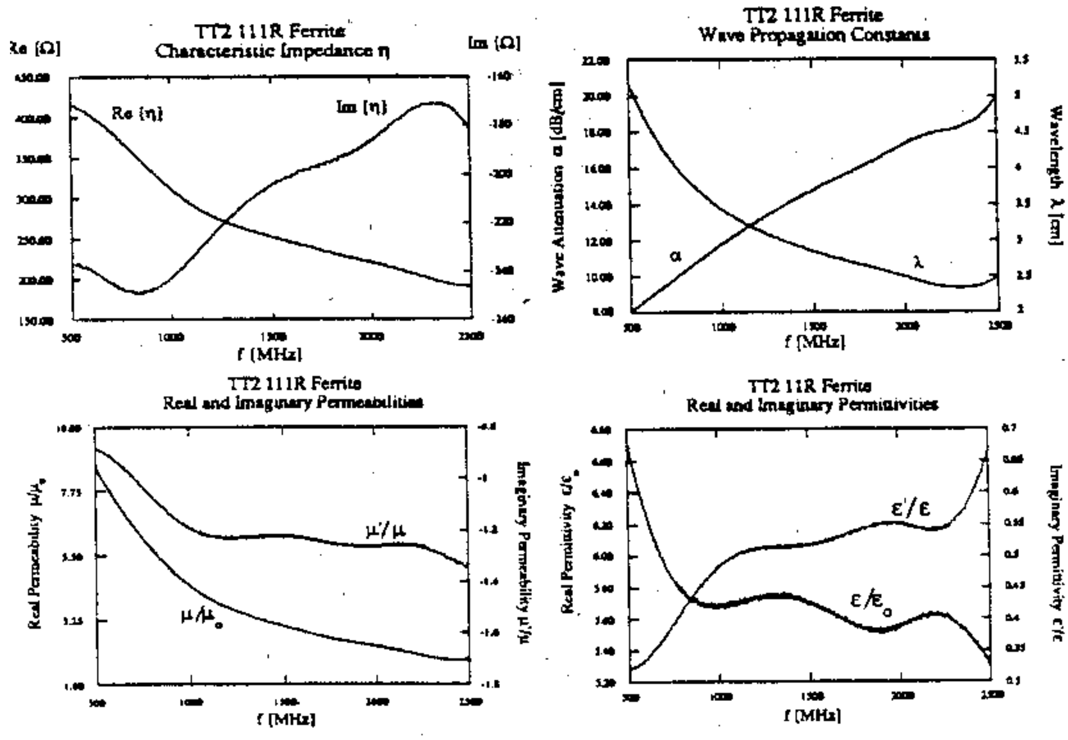

FIG. 5 - E.M. Ferrite Parameters.

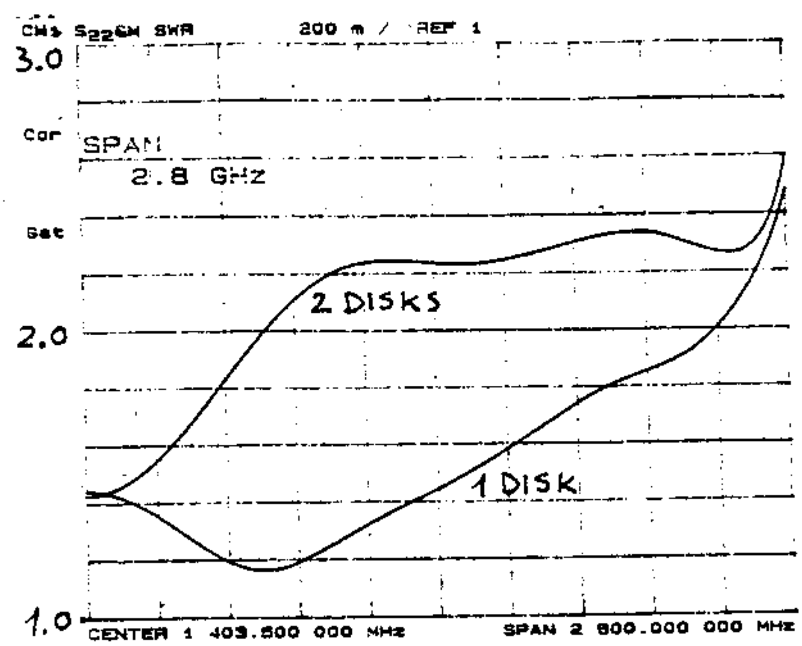

FIG. 6 - Ferrite Standing Wave Ratio Measurements.

4. - ESTIMATE OF HOM POWER DISSIPATION

An estimate of the power delivered by the beam to the cavity HOMs has been carried out to allow thermal and cooling considerations on the absorbing loads.

In a circular machine the beam is always periodic so we can consider the Fourier expansion of the beam current:

$$i(t) = \sum_{n=-\infty}^{+\infty} I_n e^{j2n\pi f_r t} \qquad (2)$$

where f_r is the bunch revolution frequency. The total power delivered to the HOMs is strongly dependent on the cavity monopolar spectrum and it is large when beam and cavity spectra overlap. The computing formula for the total power is:

$$P = \sum_{n=-\infty}^{+\infty} \frac{2\left(\frac{R}{Q}\right)_k Q_k I_n^2}{1 + Q_k^2 \left(\frac{nf_r}{f_t} - \frac{f_k}{n_f}\right)^2} \qquad (3)$$

where each mode is represented by the resonant frequency f_k, the quality factor Q_k and the normalized shunt resistance $(R/Q)_k$. It turns out that for an undamped cavity the overlap probability is very small but the associated power loss might be intolerably high. The situation is somehow reversed for a heavily damped cavity, where the overlap probability is much higher but the power loss may result a moderate value. In our estimates we considered to deal with a damped cavity, so we took the mode frequencies and (R/Q)s from 2D computer simulations and extrapolated the Q values from our prototype measurements. An additional spread of the frequency values inside the ± 0.3 % range was considered to take into account both deformations from 2D geometry that always exist in a real cavity and the frequency drifts due to the tuning operation for matching the beam loading.

The detail of mode dissipations for the case of maximum estimated total power is reported in Fig. 7 and corresponds to an unequal machine filling of 27 bunches over 30. The total power amount delivered to the HOMs is evaluate to be $P \approx 120$ W, which is not a worrying value. To obtain such a moderate value we have to slightly modify the cell geometry in order to tune away the most dangerous longitudinal mode TM011 from the powerful beam harmonic n=240.

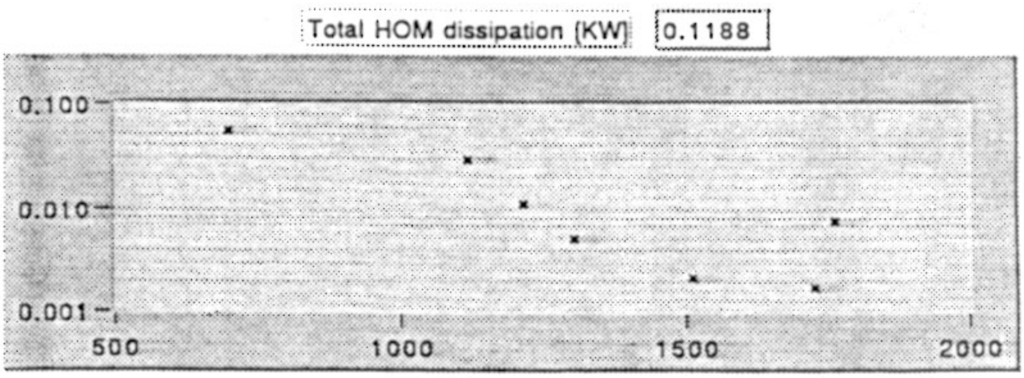

FIG. 7 - HOM Power Loss Estimate.

5. - TEMPERATURE MAP OF THE FERRITE LOAD

The damping of the cavity modes in our prototype was achieved by coupling to the TE10 mode of the ridged waveguide. The power flows in the longitudinal direction with a distribution given by :

$$\frac{dP}{dS} = \frac{1}{2} \text{Re}[\mathbf{E} \times \mathbf{H}^*] = \frac{1}{2} Z_{TE} \left(E_x^2 + E_y^2\right) \qquad (4)$$

where $\mathbf{E} \times \mathbf{H}^*$ is the Poynting' s vector of the TE10 waveguide mode.

To compute the temperature distribution inside the ferrite load of the ridged waveguide we considered a total power normalized to 100 Watts/guide and distributed on the waveguide cross section accordingly to (4). We suppose that all the power was transmitted inside the ferrite and was dissipated over there preserving the transverse distribution and considering constant longitudinal distribution. This preliminary thermal analysis was performed using the Finite Element (FE) ANSYS code[10], assuming a single tile layer load cooled with a 300°K water system from the waveguide bottom.

The resulting temperature map is reported in Fig. 8 and was calculated assuming a 4.5

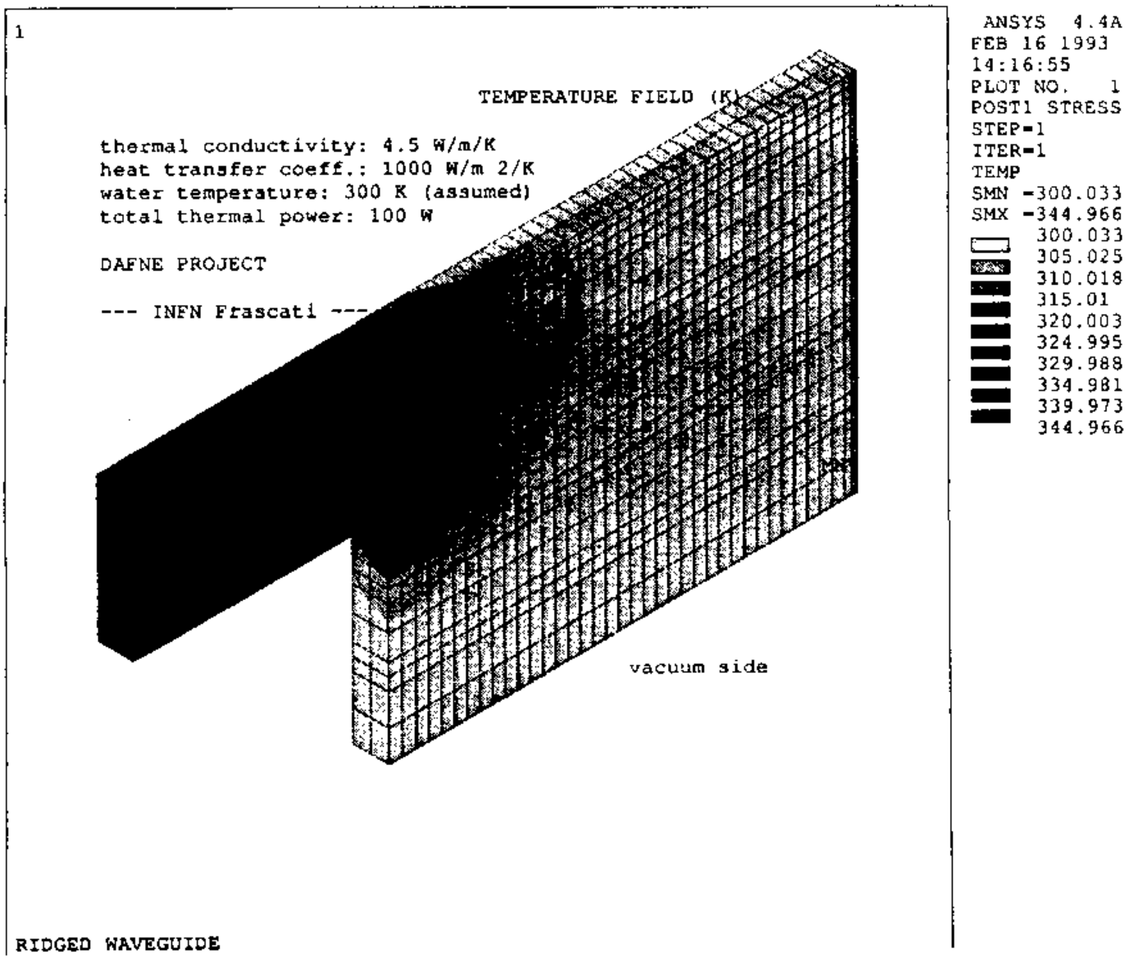

FIG. 8 - Temperature Map of the Ferrite Ridge WG Load for P=100 W.

W/m/°K ferrite thermal conductivity[11] and a 1000 W/m^2/°K heat transfer coefficient for the cooling system. The temperature increase, which is proportional to the power dissipation, seems to be moderate in our case. The situation should be even more favorable for a rectangular waveguide, where the fields are more uniformly distributed. Anyway, mechanical stresses arising from thermal gradients have to be considered in a more accurate FE simulation.

6. - FERRITE VACUUM TESTS

In order to check the vacuum compatibility of the ferrites, some samples were tested in laboratory. Six ferrite tiles were put under vacuum inside a small stainless steel vacuum chamber. The pumping system consists of a 180 l/s dry turbomolecular pump backed with a dry fore-vacuum pump. The total pressure is measured with a Bayard-Alpert vacuum gauge while a quadrupole residual gas analyzer is used to find the residual gas partial pressures with molecular weight from 1 to 100 atomic mass units (AMU). The vacuum chamber may be heated with an external heater up to about 400 °C. Experimental data has been carried out from ambient temperature to 400°C. Each measure consists of a temperature measurement, a total pressure measurement, and a residual gas spectrum. There are not significant differences in total pressure between data measured with and without ferrites, even at high temperature. A more precise evaluation has been done by comparing the residual gas spectra (see Fig. 9).

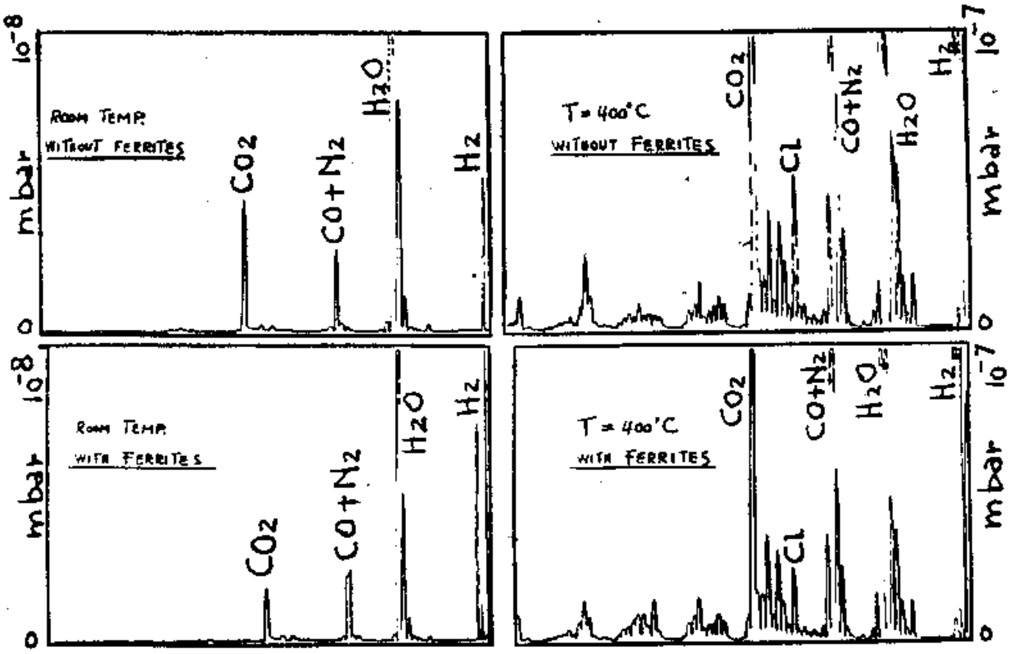

Fig. 9 - Ferrite Residual Gas Spectra.

By checking those spectra, it arises that the TT2-111R ferrites do not emit any gas or compound which may be incompatible to the ultra high machine vacuum (10^{-9} Torr at full beam) and therefore they behave satisfactorily in ultra-vacuum at room temperature as well as at higher temperature.The brazing procedures are still an open field. Looking at the Chalk River Laboratories experience[12] the proposal has been considered of performing some tests on low temperature bonding techniques, in order not to alter the ferrite properties for their use as a damper.

7. - CONCLUSIONS

An RF accelerating cavity with a low HOM impedance content is proposed for the Frascati Φ-Factory. Parasitic mode coupling will be made with waveguides and the absorption of HOM fields may be promisingly performed with high RF losses ferrite compounds even though we are also considering other damping methods, like the use of waveguide to coaxial broadband transitions. The behaviour of ferrites in ultra high vacuum and high RF power regime needs to be further investigated. Also more research is requested to develop reliable brazing procedures.

The fabrication of a high quality low power cavity model is in program. The aim is to carry out more precise RF tests.

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