# The RF Cavity for DAΦNE

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*Abstract*

The achievement of the highest luminosity in the 510 MeV electron-positron Φ-Factory DAΦNE, in construction at Frascati Laboratories, requires a careful design of the RF accelerating cavity, being the main source of High Order parasitic Modes (HOM) which are responsible for multibunch instabilities. Intense R&D has been carried out to choose the cavity resonator which would better cope with those problems. Theoretical studies and simulations of the longitudinal beam dynamics with various cavity shapes have been performed and several HOM extraction and damping techniques have been studied and tested. This report presents the results of these investigations and the laboratory tests of the proposed accelerating RF cavity for DAΦNE.

## I. INTRODUCTION

The very high luminosity of the double ring Φ-Factory DAΦNE, of the order of $10^{32} \div 10^{33}$ cm$^{-2}$·sec$^{-1}$, will be achieved by filling up to 120 buckets per ring with 47 mA per bunch. One of the main problems arising in the beam dynamics concerns the multibunch instabilities caused by the parasitic resonant fields induced by the beam in the RF accelerating cavity. Due to the high current, the instability rise time can be very fast [1], so it is impossible to stabilize the beam with a feedback system alone. An effort has to be made to reduce the shunt impedance of the cavity HOM's such that the feedback can be effective. This task can be accomplished both by properly shaping the cavity and damping the parasitic modes by extracting the relative energy with suitable RF techniques. The parameters of the DAΦNE RF system for an initial operation at 30 bunches are presented in Table 1. The RF power sources permit to eventually upgrade the operation to 120 bunches.

Table 1. RF Parameters for 30 Bunches

| | |
|---|---|
| RF Frequency (MHz) | 368.25 |
| Harmonic Number | 120 |
| Cavities per Ring | 1 |
| Cavity Impedance (Ω) | 61 |
| Cavity Quality Factor | 45000 |
| RF Peak Voltage (kV) | 250 |
| Cavity Wall Power (kW) | 11.5 |
| Current per Beam (Amps) | 1.4 |
| Synchrotron Power Loss (kW) | 27 |
| Parasitic Cavity Losses (kW) | < 1 |
| Cavity-Generator Coupling | ≈ 3.0 |
| Klystron Power (kW) | 150 |
| N° of Klystrons per Ring | 1 |

## II. THE DAΦNE RF CAVITY

A considerable reduction of the characteristic impedance of the cavity HOM's can be obtained by opening the beam tubes at the cavity irises in order to let the higher frequency parasitic modes propagate through them. A taper is then used as a gradual transition from the cavity iris to the ring vacuum pipe. A careful analysis of the longitudinal wake potentials was made with the code TBCI, aiming to reduce the cavity contribution to the machine impedance [2]. A design with no beam tubes and two long tapers was compared with a conventional design having tubes and short tapers. The long taper cavity showed a rather low value of loss factor to the HOM's ($k_{pm}$ = 0.07 against 0.16 V/pC at an rms bunch duration $\sigma_t$ of 100 psec) and a slightly larger R/Q at the fundamental mode (FM). Since the total loss factor for a single bunch passage is:

$$k_{pm} = \sum_{n>1} \left( \frac{\omega_n}{2} \cdot \frac{R_n}{Q_n} \cdot e^{-\omega_n^2 \cdot \sigma_t^2} \right)$$

this means that on the average the R/Q's are substantially decreased. This fact was confirmed by a frequency-domain analysis (done by means of the codes OSCAR2D and URMEL), where the presence of some strong HOM's above the beam tube cutoff was observed in the short tapered, but not in the long tapered structure.

Once the basic long-tapered design was adopted, the next step was the optimization of the cell profile. A "nosecone" shaped resonator can concentrate the electric field in the region of the beam, thus increasing the R/Q and also helps to decrease the R/Q of the 0-MM-1 HOM considerably, while the situation of the 1-EM-1 dipole mode is worsened, because of the abrupt discontinuity due to the noses. In a high-Q "bell-shaped" (rounded) structure, on the opposite, the smooth profile is beneficial for dipole modes, but retains a greater value for the 0-MM-1 mode. We have studied and measured both structures, maintaining the same FM shunt resistance. A comparison shows a preference for the 'nosecone' cavity as regards the 0-MM-1 mode and for the 'rounded' cavity as regards the 1-EM-1 mode. The situation of other HOM R/Q's, up to the beam pipe cutoff, is quite similar for the two shapes. Experimental results show that the strong damping of the 0-MM-1 required to be confortable with a feedback system [3] can be provided in both cases. Thus, there is no reason to choose the 'nosecone' cell as our cavity, while the 'rounded' cell is certainly to be preferred because it is of much easier construction and cooling.

The final shape is shown in Figure 1. In the DAΦNE cavity, only the 0-MM-1 mode has a rather high R/Q value (16 Ω) and for just a few modes R/Q is greater than 1 Ω. Much care was taken to ensure that the higher R/Q HOM's are far away from the most powerful harmonics of the beam spectrum, to avoid resonant enhancement of the parasitic power loss.

The adopted profile makes multipacting unlikely easing the RF conditioning and operation.

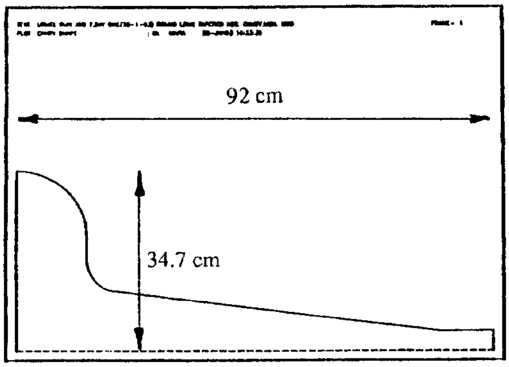


Figure 1. Profile of One Quadrant of the DAΦNE Cavity.

## III. EXPERIMENTAL RESULTS

A copper cavity prototype has been fabricated. Due to mechanical imperfections of the model, the FM frequency is slightly lower than the nominal value. We have improved the HOM impedance damping by opening three rectangular slots onto the central body of the cavity model and connecting three 300x40 $mm^2$ waveguides (WG) with cut-off at 500 MHz. The WG's are placed 120° apart to avoid perturbing the accelerating field symmetry. The WG's have been positioned in order to couple as much as possible the magnetic field peaks of the highest HOM R/Q's. The guides convey the HOM energy out of the cavity in the $TE_{10}$ WG mode. Two additional WG's with cut-off at 1350 MHz have been placed, 90° apart, along the tapered pipes. They couple to some higher frequency HOM's which have there intense magnetic field. Figure 2 shows the cavity prototype tested in laboratory and fully equipped with 5 WG's.

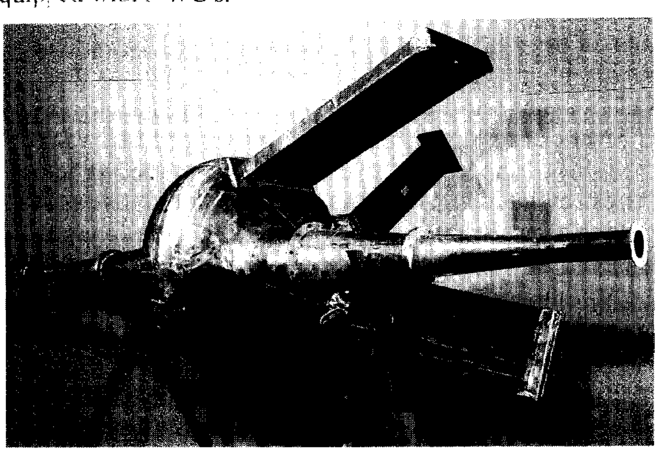

Figure 2. The Low Power Cavity Prototype.

The application of the WG's to the test cavity decreases the FM frequency by 2% and the FM quality factor by 16%. Being 25,000 the cavity model Qo, the WG's external Q is about 180,000. High RF losses ferrite tiles have been applied onto the shorted plane of each WG to dissipate the HOM energy. The ferrites do not require any shaping since their impedance, as shown later on in this article, somewhat matches the 377 Ω vacuum impedance.

Table 2 shows the experimental results obtained by equipping the test cavity with 3+2 WG's and ferrite loads. The damping of the first 8 HOM monopoles is listed together with the FM data. In some cases, the impedance damping is more than 2 orders of magnitude. Such results are very encouraging and let us believe, in accordance with numerical simulations [3], that a feedback system to control the longitudinal beam instabilities is feasible. Table 3 gives the parameters of the highest impedance HOM dipoles and the obtained damping. We plan to perform more precise tests with a high quality electro-formed cavity model.

Table 2. Cavity Model Test Results (Monopoles)

| Mode | Freq. [MHz] | Qo | R/Q [Ω] | Loaded Q | $R_{SH}$ [kΩ] |
|---|---|---|---|---|---|
| 0-EM1 | 357 | 25000 | 61 | 22000 | 1350 |
| 0-MM1 | 747.5 | 24000 | 16 | 60 | 0.96 |
| 0-EM2 | 796.8 | 40000 | 0.5 | 270 | 0.13 |
| 0-MM2 | 1023.6 | 28000 | 0.9 | ----- | ------ |
| 0-EM3 | 1121.1 | 12000 | 0.3 | 600 | 0.21 |
| 0-MM3 | 1175.9 | 5000 | 0.6 | 140 | 0.08 |
| 0-EM4 | 1201.5 | 9000 | 0.2 | 110 | 0.02 |
| 0-EM5 | 1369.0 | 5000 | 2.0 | 300 | 0.6 |
| 0-MM4 | 1431.7 | 2000 | 1.0 | 150 | 0.15 |
| 0-EM6 | 1465.0 | 2000 | 0.1 | 200 | 0.02 |

Table 3. Test cavity HOM Dipole Damping

| Mode | Freq. [MHz] | Qo | R/Q' [Ω] | Loaded Q |
|---|---|---|---|---|
| 1-MM1 | 520.7<br>522.3 | 30500<br>28500 | 5.1 | 400<br>300 |
| 1-EM1 | 569.6<br>569.8 | 31500<br>32000 | 14.0 | 130<br>140 |

## IV. STUDY OF THE HOM DAMPERS

The damping of the HOM energy propagating through the test cavity WG's has been achieved by means of Trans-Tech TT2-111R ferrite tiles placed onto the opposite shorted plane of the guides. The ferrites, based on a Ni/Zn compound, present high RF losses in a broad frequency band and do not require special shaping. The most significant RF parameters have been measured in the frequency domain with a reflectometric technique [4]. We report in Figures 3 and 4 the characteristic impedance and the VSWR versus frequency.

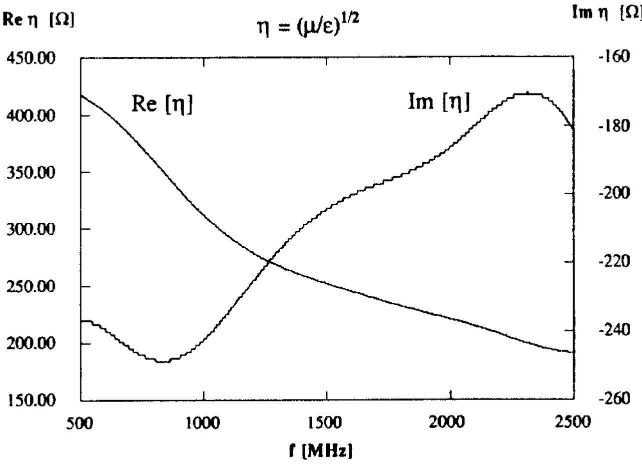


Figure 3. Characteristic Impedance of Ferrite TT2-111R.

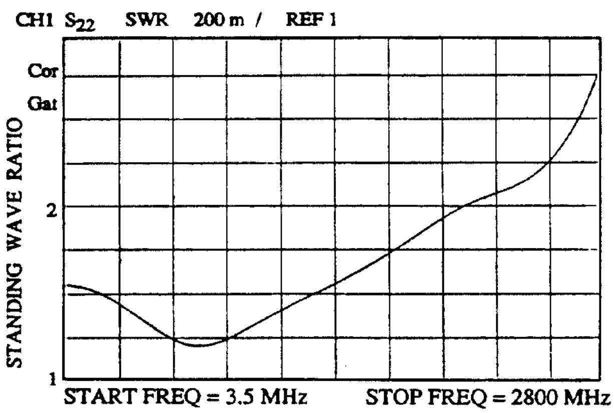


Figure 4. VSWR of Ferrite TT2-111R.

The power transferred from the beam to the cavity HOM's has also been calculated [4] to study the ferrite thermal behavior in ultra high vacuum (UHV) and the needed cooling. With 47 mA per bunch and an asymmetrical machine filling of 27 bunches (instead of 30), required to avoid ion trapping, the HOM power flow is about 150 W per WG. Simulations performed with the code ANSYS [5] assuming a ferrite thermal conductivity of 4.5 W/m/°K and an external temperature of 20 °C, give a maximum temperature of 75 °C for the absorbing material vacuum side. This temperature is well below the 370 °C Curie point. Moderate cooling should then be necessary.

The ferrites have been vacuum tested up to 400°C. They behave compatibly to the UHV since no undesired gas emission has been detected. In the real cavity, the absorbing materials would be applied inside the WG's with a brazing technique that is presently under study.

In alternative to the ferrite load terminations, we are studying a broadband transition from WG to coaxial 1-5/8". A bandwidth of more than 2 octaves (i.e. .5÷2.5 GHz) with VSWR ≤ 2.0 seems feasible. This design would allow to dissipate the HOM power on an external 50 Ω load.

## V. ACKNOWLEDGMENTS


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