THE DAΦNE 3RD HARMONIC CAVITY

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Abstract

The installation of a passive 3rd harmonic cavity in both the e^+ and e^- rings of the Frascati Φ-factory DAΦNE has been decided in order to improve the Touschek lifetime by increasing the bunch length. The implications of the RF harmonic system on the beam dynamics, in particular those related to the gap in the bunch filling pattern, have been carefully studied by means of analytical and numerical tools. A single-cell cavity incorporating a ferrite ring for the HOM damping has been designed through the extensive use of MAFIA and HFSS simulation codes. One cavity prototype has been built and extensively bench tested, while the fabrication of the two final cavities is almost completed. A description of the design and construction activities, and a set of experimental measurements are reported in this paper.

1 INTRODUCTION

The installation of a passive 3rd harmonic cavity [1] in each DAΦNE ring has been decided to increase the Touschek lifetime by lengthening bunches [2], and to weaken the coherent instabilities by increasing the Landau damping due to the non-linearity of the longitudinal potential well.

The most relevant parameters related to the machine longitudinal phase space are summarized in Table 1.

Table 1: DAΦNE parameters

Energy	E	510 MeV/ring
Single bunch current	I_b	20 mA (present operation) 44 mA (nominal)
Maximum total current	I_M	0.8 A (present operation) 1.5 A (mid-term goal) 5 A (nominal)
Synchrotron losses	V_s	9.3 keV/turn
Parasitic losses	V_p	≈2 keV/turn(@ I_b=20 mA)
RF frequency	f_{RF}	368.29 MHz
RF voltage	$_{RF}$	120÷170 kV (present operation) 250 kV (nominal)
harmonic number	h	120
momentum compaction	α	≈ 0.025
natural bunch length (@ $I_b \approx 0$)	σ_{z_0}	≈ 1.4 cm (@ V_{RF}= 120 kV) ≈ 1.0 cm (@ V_{RF}= 250 kV)

The actual DAΦNE bunch length depends on the single bunch current, since the machine runs in the bunch lengthening regime.

This means that bunch lengths exceeding 2 cm are normally obtained in the present standard operating conditions (I_b = 20 mA, V_{RF} = 120 kV).

The implementation of a high harmonic RF system will allow to approach a bunch length value $\sigma_z \approx 3$ cm in the lengthening regime with the main RF voltage larger than the present operational value. Thus the Touschek lifetime will be recovered mainly from the bunch lengthening, but also due to the RF acceptance increase.

The parameters of a 3rd harmonic RF system matching these specifications are summarized in Table 2.

Table 2: DAΦNE 3rd harmonic RF system parameters

3rd harmonic RF frequency	f_{RF_H}	1104.9 MHz
main RF voltage	V_{RF}	200 kV
3rd harmonic RF voltage	V_{RF_H}	57 kV
natural bunch length (@ $I_b \approx 0$, V_{RF}= 200 kV)	σ_{z_0}	≈ 2 cm
bunch length @ $I_b \approx$ 20 mA	σ_z	≈ 2.8 cm
operational beam current	I	0.3 ÷ 1.5 A

Under these specifications we estimate that the Touschek lifetime improvement, with respect to the present operating conditions, will be about 50% [2].

Due to the peculiarity of the DAΦNE parameters (low RF voltage, high beam current), powering the cavity in the passive way appears to be the simplest and the most effective choice. The required harmonic voltage can be obtained with a modest cavity shunt impedance and over a wide range of beam currents. The choice of the harmonic number 3 is a compromise between beam dynamics requirements and constraints related to the space available for the cavity installation.

2 BEAM DYNAMICS REMARKS

The implications of the harmonic voltage on the beam dynamics have been carefully considered. The most worrying issues are the shift of the frequency of the coupled bunch (CB) coherent motion and the effects of a non-uniform filling pattern in the multibunch configuration (bunch trains with gaps in the filling pattern).

The coherent frequency shift of the CB modes for a passive harmonic cavity calls for low R/Q and high Q values. In this case the cavity can deliver the required harmonic voltage over a wide range of stored currents being always tuned far enough from the coherent synchrotron lines located near the revolution harmonics $3h$ and $3h+1$.

The presence of a gap in the bunch filling pattern generates a bunch-to-bunch spread of the parasitic losses. Since the total RF voltage derivative at the bunch center is considerably reduced by the harmonic voltage contribution, the parasitic loss spread produces a large spread of the bunch synchronous phases. The higher is the stored current and the larger is the gap in the filling pattern, the larger is the synchronous phase spread. This effect sets the ultimate current value I_{Max} corresponding to the maximum acceptable spread. Beyond this value the bunch-by-bunch feedback systems loose their synchronism and some bunches may collide too far from the nominal Interaction Point (IP).

Since we normally need a gap of 1/3rd of the ring in the e$^-$ bunch filling pattern to avoid ion trapping, we estimate that in our case $I_{Max} \approx 1.5\ \mathrm{A}$.

The harmonic voltage can be almost completely "switched-off" by tuning the cavity as far as possible from the harmonic $3h$. In order to minimize the coherent effects, it is worth tuning the cavity at $(3h + n + 0.5) f_{rev}$, with the integer n as high as the tuning system allows. This is the so-called "parking option", that can be used to recover approximately the operating conditions obtained before the harmonic cavity installation. In our case n can be chosen in the range from -1 to +2.

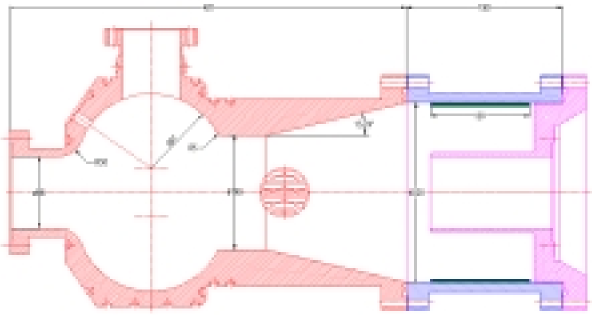

Figure 1: Sketch of the 3rd harmonic cavity

3 DESIGN OF A HOM DAMPED 3RD HARMONIC CAVITY

A mechanical sketch of the DAΦNE 3rd harmonic cavity is shown in Fig. 1. The assembly can be divided into 3 main parts connected together with flanges. In the first part the contour of a rounded cell is recognizable, connected to a short flanged beam tube on the left side and to a longer tapering-out section on the right. On the cell top there is a port for the insertion of a tuning plunger. This cavity has been designed to be passively powered by the beam itself, so that no port for the RF coupler has been foreseen. Three small RF probes have been inserted in the structure to measure the beam induced field allowing the low-level control and diagnostics.

The rounded cell is the volume where the fundamental mode resonates. It is connected through the tapered section to an HOM damper. The damper consists in a ring made of a special ferrite (IB-004) bonded on a flanged stainless steel support with the Hot Isostatic Pressure (HIP) method. This device has been designed and fabricated as one of the HOM dampers for the superconducting cavities of the KEK B-factory [3], the so called SBP (Small Beam Pipe) HOM load. The KEK laboratory kindly supplied us 3 dampers taken from the B-factory spares.

The DAΦNE 3rd harmonic cavity has been designed to incorporate this kind of damper. In this way we could simplify the project considerably, ending-up with a design having basically a 2D symmetry and taking advantage of the good experience of two-years operation of these kind of dampers. The general properties of a rounded cell with large openings well match the requirements of our passive cavity (high Q and low R/Q values).

The only significant adaptation of the SBP HOM load to our requirements is represented by the coaxial shield which avoids direct exposure of the ferrite to the beam charge, which is the third flanged object shown in the assembly of Fig. 1. The shield prevents direct heating of the ferrite that in this case can interact with the beam only through the cavity HOMs. The shield then avoids the risk of degradation of the DAΦNE broadband impedance associated with the direct beam-ferrite interaction. This risk cannot be easily evaluated by means of simulations or analytical estimate.

In spite of the apparent simplicity of the proposed geometry, a huge simulation activity based on MAFIA and HFSS codes had been necessary to define the final dimensions of the cavity. The task of this job was to obtain a strong coupling of all the cavity modes with the damper, except the fundamental one, with a limited total length available for allocating the structure in the ring.

4 EXPERIMENTAL MEASUREMENTS

The fabrication of one cavity prototype and two final devices all made of Aluminium has been decided. The prototype, whose picture is shown in Fig. 2, has been delivered to the LNF at the end of last year, while the fabrication of the two final cavities is almost completed and their delivery is scheduled by the end of June 2001.

Figure 2: Picture of the harmonic cavity prototype

Three tuning plungers (including one spare) made of Copper and fully equipped with bellows, stepping motors and encoders have been fabricated separately and have been already delivered to LNF. Although Copper has a better conductivity, we chose Aluminium for the cavity body fabrication in order to reduce both the cost and the delivery time. This choice implies a reduction of the fundamental mode Q by ≈ 15÷20%.

Table 3: cavity modes (simulations and measurements)

	SIMULATIONS			MEASUREMENTS	
	f[MHz]	Q	R/Q	f[MHz]	Q
M1	1105	23000	26 Ω	1105	18500
M2	1335	12	16 Ω	---	---
M3	1600	27	6 Ω	---	---
M4	1650	55	2 Ω	1650	168
M5	1899	52	4 Ω	---	---
M6	2094	115	7 Ω	2100	224
M7	2270	117	9 Ω	2289	60
M8	2495	167	3 Ω	2466	140
M9	2524	226	10 Ω	2507	278
D1	1089	438	66 Ω/m	1070	450
D2	1244	35	26 Ω/m	---	---
D3	1445	158	22 Ω/m	1400	139
D4	1618	158	29 Ω/m	1560	175
D5	1797	266	37 Ω/m	1725	163
D6	1886	283	24 Ω/m	1865	190

The impedance and Q values of the cavity longitudinal (M=monopole) and transverse (D=dipole) modes, as given by simulations and as measured on the prototype, are reported in Table 3. With the exception of the fundamental mode M1, all the other modes are substantially damped by the ferrite load. Considering the bunch always longer than 2 cm, the HOMs show effective impedances lower than 800 Ω (monopoles) and 25 kΩ/m (dipoles). We believe that this contributions will not change significantly the present scenario of the DAΦNE beam dynamics [4]. On the contrary we expect beneficial contribution to the beam dynamics from the Landau damping which will be strongly emphasized by the non-linearity of the harmonic voltage.

Some modes, calculated with the simulations, where not measurable port-to-port on the prototype. The low Q value of these modes and the presence in the measurements of high polarity modes (quadrupoles, sextupoles, etc.) are possible explanations for this lack. We also performed longitudinal and transverse impedance measurements on the prototype based on the wire method. After a careful interpretation of these measurements we conclude that they confirmed the values reported in Table 3. The fundamental mode shunt impedance ($R_s = V_{acc}^2/2P_d$) is about 0.5 MΩ, a value fully compatible with the Table 2 specifications.

The power required to sustain the harmonic voltage is $P_{fund} \approx 3.5\ kW$. The maximum power delivered by the beam to the cavity HOMs is about the same ($P_{HOM} \approx 3.5\ kW\ \ @I = 1.5A$ into 60 bunches), accordingly with our prudent estimate. The fundamental mode power is dissipated on the cavity walls, while the HOM power is dissipated in the ferrite damper. All this power is supplied through the main RF system and corresponds to an increase of the beam parasitic losses.

5 CAVITY ENGINEERING

The final cavities will be ready by the end of June, while all other equipments (dampers, tuners, vacuum feedthroughs) are already in house. Presently, the SBP HOM loads are undergoing a 60-day baking process at 55 °C, accordingly to a procedure suggested by KEK [5].

The RF power wasted on the cavity walls is limited to only 3.5 KW, but water cooling is still necessary. A plot of the expected temperature along the cell profile for an overrated RF dissipation of 5 KW is shown in Fig. 3. Other 3 separated water circuits will cool the damper, the tuner and the tube connecting the tuner port to the cell.

The passive harmonic cavities will not be installed during the shut-down period of August 2001, since a vacuum opening is not compatible with the machine schedule for the year 2001. The next shut-down (January 2002) is a more convenient period for such installation.

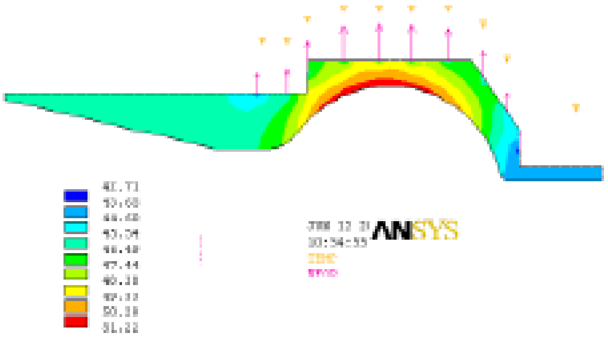

Figure 3: Temperature map along the cell profile

ACKNOWLEDGMENTS

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