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MEASURES TO REDUCE THE IMPEDANCE OF PARASITIC RESONANT MODES IN THE DAΦNE VACUUM CHAMBER

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ABSTRACT

The presence of trapped e.m. fields in any section of the vacuum chamber driving coupled-bunch instabilities is one of the most harmful problems to solve in order to successfully operate multibunch, high-current storage rings. Design and experimental activities aimed to eliminate or weaken the resonant modes in various sections of the DAΦNE vacuum chamber (cavities, kickers, bellows, BPMs, current monitors) are described and discussed here.

1. Introduction

The double ring e^+e^- collider DAΦNE¹⁾ is presently under commissioning at LNF in Frascati (Italy). It is designed to reach a maximum luminosity of $5.3 \cdot 10^{32} \text{ cm}^{-2}\text{s}^{-1}$ at the energy of Φ resonance (1020 MeV in the center of mass).

In order to achieve the required luminosity a large total current, up to 5.2 A, distributed over 120 bunches (maximum) has to be stored in each ring. This gives rise to the problem of the parasitic electromagnetic interaction of the beam with the surrounding vacuum chamber. In particular, the machine performance can be seriously limited by unstable coupled-bunch oscillations excited by the multibunch beam interaction with long-lasting parasitic resonant modes (high order modes-HOM) in the vacuum chamber. Much care has been taken in designing the DAΦNE vacuum chamber elements to minimize the machine HOM content and reduce the impedance of the remaining HOMs in order to avoid excessive beam power loss and increase multibunch instability thresholds.

In this paper we briefly describe the design of the main DAΦNE vacuum chamber components with analysis of their HOM impedance and discuss measures undertaken to eliminate or damp the parasitic resonant modes to a harmless level.

2. RF cavity

The DAΦNE RF cavity is the principal source of the HOMs. The power requirement is quite moderate for the RF cavity. The RF power per ring necessary to compensate the power lost by the beam and that dissipated on the cavity walls is only 100 kW for 120 bunches at 250 kV gap voltage. This allowed us to concentrate our design efforts on the cavity HOM damping ^{2,3}).

The main cavity body has been chosen to have "rounded" profile mainly due to a simpler mechanical realization. Then, the cavity shape was optimized in order to keep the fundamental mode impedance above 3 MΩ to reduce the dissipated power and make the cooling design easier. Much care was also taken to shift the higher impedance HOM frequencies far away from harmonics of the beam in order to avoid resonant enhancement of the parasitic power loss.

The basic ideas to reduce the HOM impedances were to provide a large cavity iris and to apply long tapered beam tubes to let the parasitic modes propagate along them and to couple out the HOM energy by means of waveguides (WG). Figure 1 shows the sketch of the DAΦNE RF cavity.

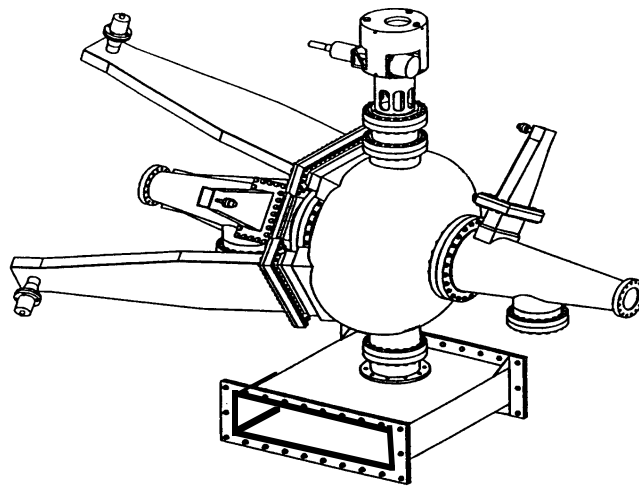


Figure 1. *DAΦNE RF cavity sketch.*

HOM damping is obtained by opening rectangular slots onto the cavity surface and applying at those positions rectangular WGs which can convey out of the cavity the fields of the parasitic modes in the TE₁₀ WG dominant mode.

The DAΦNE cavity is equipped with five WGs. Three WGs are applied, 120° apart for symmetry considerations, onto the central body. Their positions allow, on the average, the best coupling with the magnetic field of the HOMs. In addition, two smaller WGs are placed on the tapered tubes to couple some high frequency HOMs which penetrate along the pipes and have intense magnetic field at that position.

In order to dissipate the HOM power extracted from the cavity, the rectangular WGs are converted in double ridge WGs with a smooth and wideband tapered section which is finally adapted to 50 Ω by a transition to coaxial ⁴⁾. Then, by means of coaxial vacuum feedthroughs, the HOM power can be dissipated onto external 50 Ω loads in air. In this way, the application of dissipating materials in ultra high vacuum (UHV) is avoided.

With the use of the described damping system, the parasitic mode quality factors Q_s of the most dangerous HOMs are reduced, on the average, by two orders of magnitude. In some cases, like for the TM₀₁₁, the Q damping is even stronger. The fundamental mode quality factor decreases only by 12 % due to the application of the WGs.

3. Longitudinal feedback kicker

Despite the HOMs are heavily damped in the RF cavity, the growth time of the unstable modes still can be substantially shorter than the radiation damping time in case of full coupling of the beam spectrum lines with the HOMs. The longitudinal and transverse feedback systems will be used as complementary means to cure the multibunch instability. An overdamped cavity, which avoids the application of absorptive materials in the ultra high vacuum for HOM damping, has been proposed for DAΦNE as a longitudinal feedback kicker ⁵⁾, successfully tested ⁶⁾ and installed in the main factory rings. Figure 2 shows a cut-view of the kicker.

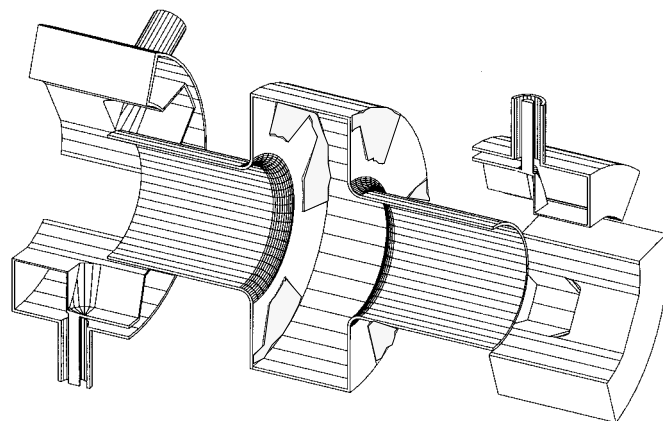


Figure 2. Exploded cut view of DAΦNE longitudinal feedback kicker.

The main cavity body is a 72 mm long pill-box cavity with 100 mm outer radius and beam pipe tubes of 44 mm radius. In order to obtain the large bandwidth necessary to handle all the coupled bunch oscillations, special ridged waveguides are connected to the cavity, placed symmetrically with respect to the operating (fundamental) mode, 3 on each side. The lowest propagating mode of the single ridged waveguide with a 6 mm gap is 690 MHz, much lower than the cavity fundamental mode frequency. This provides a tight coupling to the external devices and low Q of all the cavity modes.

The waveguides are followed by a carefully designed broad band transitions to 7/8'' coaxials capable to withstand more than 1 kW power flow. Ceramic feedthroughs allow in-air connections to the driving amplifiers and dummy loads. The cavity, being broad band, does not need to be tuned nor cooled, since almost all the power is dissipated in the external loads.

Numerical simulations with HFSS code and bench wire measurements have shown a peak shunt impedance of about 750 Ω at the 1.2 GHz operating frequency and a bandwidth of about 220 MHz, i. e. the quality factor of the fundamental mode has been reduced from 22300 to 5.5. It appears that also all the remaining HOMs, both longitudinal and transverse, are drastically damped down to levels which are no longer dangerous for the multibunch instabilities.

4. Transverse feedback kicker

The kicker design consists of an ordinary stripline pair with each stripline electrode creating a 50 Ω transmission line with the kicker tanks. The kicker (shown in Fig. 3) uses a tapered tank in order to reduce parasitic power losses and coupling impedance.

Numerical simulations and measurements have shown that the analytical expressions describe the kicker shunt impedance⁷⁾ and the low frequency real part of the coupling impedance⁸⁾ very much satisfactorily. However, at higher frequencies one has to take into account HOMs which are trapped in the stripline-kicker tank structures.

MAFIA and HFSS simulations of the DAΦNE transverse kickers indicated two narrow parasitic modes at 2.3 GHz and 2.53 GHz, respectively, dangerous for the beam dynamics. Presence of the modes in the kicker tank has been confirmed by the measurements on the prototype. The insertion of two identical rectangular loops intercepting the magnetic field lines of the modes has resulted in their strong damping. The quality factors and shunt impedances of the two modes have been reduced by about two orders of magnitude.

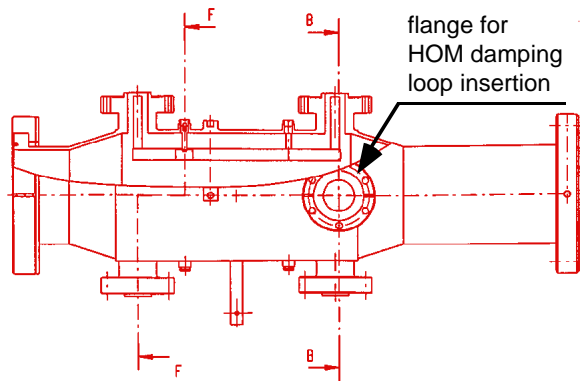


Figure 3. *DAΦNE transverse feedback kicker.*

5. Bellows

There will be eight bellows in each DAΦNE ring which will be placed between the machine arcs and straight sections⁹). These bellows must allow 35 mm longitudinal expansion and 10 mm horizontal offset. Half of the 8 bellows (those downstream the machine arcs) must have a lateral slot in the RF shield in order to let the synchrotron radiation get out.

The beam pipes attached to the bellows have a rectangular cross-section. The bellows screen is used as an electrical continuation of the beam pipes inside the bellows and fits the rectangular beam pipe shape. The screen is made of thin (0.2 mm) strips oriented in the vertical plane and separated by 4 mm gaps. The width of a strip is 5 mm, i. e. wider than the gap between the strips in order to attenuate radiation outside the screen.

The strips are produced by a hot forming method and have a waved shape. This allows the longitudinal expansion. In the working regime the strips are almost straight. The screen is quite flexible in order to supply the necessary horizontal offset.

In order to push the HOM frequencies beyond the bunch spectrum, i. e. to avoid excessive power loss, transverse connections between nodes of the waved strips have been put. In this way we reduce the length of the slots created between each neighboring strips. This means that TM waveguide modes with wavelength $\lambda > 2l$, where l is the reduced slot length (the distance between the transverse connections), can not penetrate outside the screen and excite resonant HOMs. Being placed between the strip nodes, the transverse connections do not change much the flexibility of such a bellows shield.

However, four bellows placed downstream the arc vacuum chambers must have a lateral slot along the screen to let the synchrotron radiation get out. It has been found that some coaxial type HOMs between the outer bellows and inner screen are still left in the structure with the lateral slots.

In order to damp the remaining modes we used the transverse plates in addition to the transverse connections. In order to follow the bellows shape the plates have been chosen to have the "half moon" shape. Figure 4 shows a sketch of the bellows internal shield.

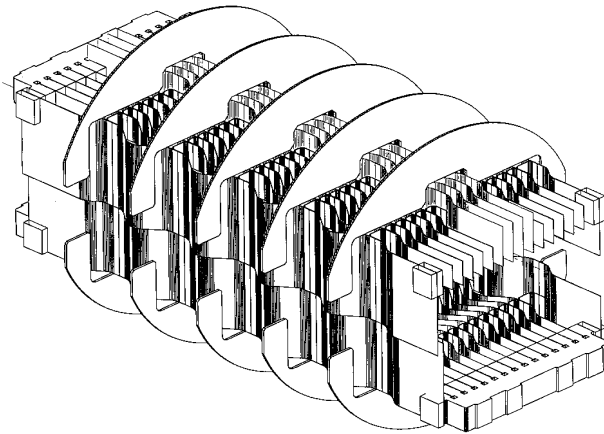


Figure 4. *Sketch of the bellows internal shield.*

In our understanding these plates push the electric fields of the coaxial type modes further from the beam axis thus reducing the coupling of the modes to the beam. The second advantage is that the plates prevent penetration of the TE modes into the outer volume. Third, the plates can be considered as radiators which help to dissipate the lost power. The impedance measurements on the bellows have confirmed the effectiveness of the shield. There are only a few trapped modes left in the shielded bellows. But these modes have rather small shunt impedances which are not harmful for the beam dynamics. Estimates have shown that heating produced in the screen by the beam image currents and possible resonant interaction with the residual HOMs is tolerable¹⁰⁾.

6 . Current monitors

The beam DC current in the DAΦNE storage rings is measured by commercial¹¹⁾ DC current transformers (DCCT). The DCCTs are placed outside the vacuum chambers and special ceramic gaps are foreseen to direct the parasitic vacuum chamber wall current around the transformer cores. The currents flow on the DCCT envelopes used to screen the electromagnetic fields penetrating through the gaps and to provide continuity to the vacuum chamber.

The capacitive break creates a resonant circuit with the external DCCT shield, thus leading to the appearance of parasitic HOMs. The HOMs can potentially drive multibunch instabilities and be a source of power losses. A part of the beam lost power may be absorbed by the ferrite transformer core damaging the device itself.

Figure 5 shows the results of the coupling impedance measurements for the housing of the DAΦNE DCCT without (a) and with (b) the current transformer. As expected, we observe a few strong HOMs, four of them lying at relatively low frequencies. The HOM peaks get smaller and broader with the current transformer. This means that some HOM power is dissipated inside the transformer core and may result in damaging the DCCT. In order to eliminate the dangerous HOMs the ceramic gap has been bypassed by resistors connected in parallel with a total resistance of 1Ω . This is a high enough value to make almost all DC currents still pass outside the current transformer core. At the same time, it appears that the resistor net effectively screens the higher frequency electromagnetic fields. The results of the coupling impedance measurements on the real DAΦNE DCCT confirm that all the HOMs in the frequency range up to 3 GHz are eliminated by the screen (see Fig. 5(c)).

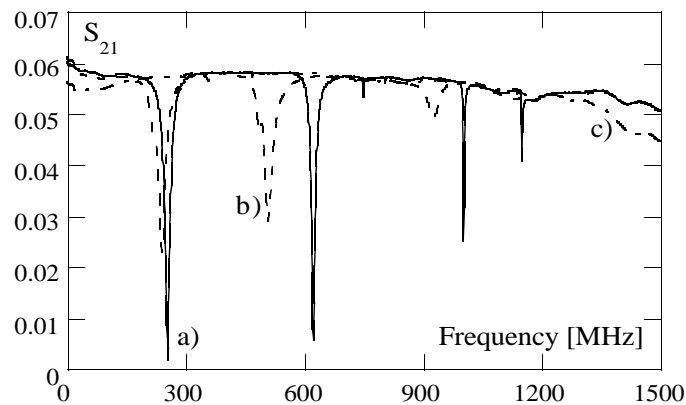


Figure 5. DAΦNE DCCT HOM content measurements.

7. Broad band button BPMs.

The DAΦNE broad-band button electrode¹²⁾ is shown in Fig. 6. BPMs with such buttons are used to measure the individual time and x/y position offset, on a bunch by bunch basis, i.e. without “memory” of the preceding bunch, in the front-end section of the longitudinal and transverse feedback systems.

The button has a diameter of 15 mm and a thickness of 3 mm with the annular gap 1 mm wide. The dielectric material is mainly used to hold the button and creates a short piece of transmission line with a characteristic impedance of 50Ω . A tapered transition has also the characteristic impedance 50Ω and provides matching between the button and the external coaxial connector.

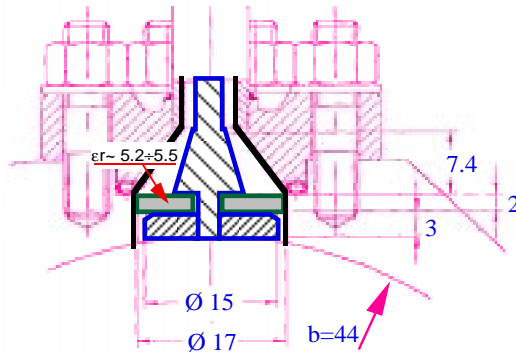


Figure 6. DAΦNE broad band button electrode.

The button has a broad flat response in the frequency range of interest (1-4 GHz) and a transfer impedance value of $\sim 0.5 \Omega$. At the same time the low frequency coupling impedance is relatively small and does not affect beam dynamics considerably.

The first HOM trapped within the button structure is of TE₁₁-type. It is situated beyond the spectrum of 3 cm long DAΦNE bunch and, therefore, does not contribute significant power loss. The HOM is not capable to drive multibunch instabilities. The estimated power flowing into the external termination is less than 1 W.

8. Conclusions

In this paper we have briefly described the design of some DAΦNE vacuum chamber components which were of concern from the HOM content point of view. Here we have paid main attention to the novel design features of these components which allow to avoid excessive power loss, substantially reduce the number of trapped HOMs and, consequently, to damp them. For more details we refer readers to the cited references.

9. References

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