COUPLING IMPEDANCE OF DAΦNE UPGRADED VACUUM CHAMBER

F. Marcellini, D. Alesini, P. Raimondi, G. Sensolini, B. Spataro, A. Stella, S. Tomassini and M. Zobov,
INFN Laboratori Nazionali di Frascati, Frascati, Italy

Abstract

The DAΦNE Φ-factory at INFN LNF has been upgraded in the second half of 2007 with a scope to test a recently proposed scheme of crab waist collisions. The vacuum chamber of the collider has been substantially modified: two new low impedance interaction regions have been designed and installed, the new stripline injection kickers have been implemented, the old bellows have been substituted by the new ones and almost all ion clearing electrodes removed. In the paper we discuss the low impedance design of these new vacuum chamber components and compare bunch lengthening measurements in the modified DAΦNE with simulation results.

INTRODUCTION

DAΦNE is an electron-positron collider working at the c.m. energy of the Φ resonance (1.02 GeV) to produce a high rate of K mesons [1]. The collider complex consists of two independent rings having two common Interaction Regions (IR) and an injection system composed of a full energy linear accelerator, a damping/accumulator ring and transfer lines. Fig. 1 shows a view of the DAΦNE accelerator complex while some of the main collider parameters are listed in Table 1.

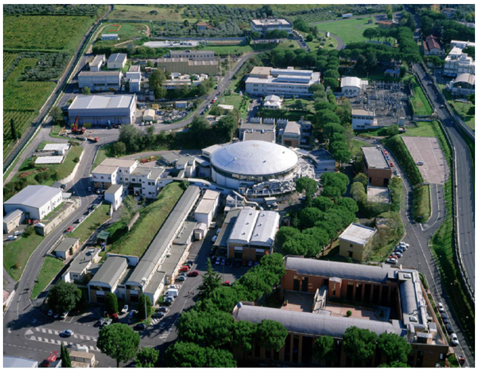

Figure 1: View of DAΦNE accelerator complex.

Since 2000 DAΦNE has been delivering luminosity to three experiments, KLOE [2], FINUDA [3] and DEAR [4]. The KLOE experimental detector surrounded by a superconducting solenoid has been used for a wide variety of physics measurements with emphasis on the kaon decays, and most notably on the issue of CP violation. The second magnetic detector FINUDA is devoted to the study of hypernuclei physics. The small non-magnetic experiment DEAR has been used for the study of the properties of kaonic atoms.

In 2007 DAΦNE was shut down for the SIDDHARTA experiment installation [5] and for relevant collider modifications aimed at testing the novel idea of crab waist collisions [6, 7, 8]. DAΦNE operations with the crab waist scheme started in the very end of 2007 and the first results of the new scheme implementation are reported in [9] at this Conference.

The DAΦNE upgrade required a new magnetic and mechanical layout [10] [11] to exploit “Large Piwinski Angle” and “Crab Waist” concepts. As a result, the collider vacuum chamber has been substantially modified. Relying on our long-term experience in coupling impedance calculations and measurements, all the new vacuum chamber components have been carefully designed and optimized in order to reduce both the broad band and narrow band impedances.

In the first part of this paper we overview designs of the principal new vacuum chamber elements and describe the design solutions aimed at the coupling impedance minimization. In the second part we report the results of bunch lengthening measurements in the DAΦNE upgraded rings that clearly prove the vacuum chamber beam impedance reduction.

Table 1: DAΦNE main parameters (KLOE run)

Energy [GeV]	0.51
Trajectory length [m]	97.69
RF frequency [MHz]	368.26
Harmonic number	120
Damping time, τ_E/τ_x [ms]	17.8/36.0

NEW VACUUM CHAMBER COMPONENTS

The New Interaction Region

The beam pipe is composed essentially by straight tubes without sharp discontinuities, except for the Y-shape section, where the common IR chamber is split in the two separate rings (see Fig.2).

Figure 2: The new IR vacuum chamber layout (half).

HOMs could be trapped in the Y-section and, if the beam interacts with them, problems related to power losses may arise, as confirmed by HFSS simulations. The diameter and the shape of the single pieces of pipes have been designed in order to reduce as much as possible the total number of HOMs, and to keep the frequencies of the residual ones far enough from the beam power spectrum lines. From simulation results [12], this distance is always more than 200 MHz and even if full coupling should occur, the power losses would be less than 200W. Despite such a power seems to be manageable, two cooling channels have been placed at each Y-chamber junction.

The New Injection Kicker

New injection kicker has been realized to have the possibility of using fast high voltage pulsers which minimize the perturbation of the stored bunches. The design of the new kicker [13] is based on a couple of tapered strips in a vacuum chamber with rectangular cross section (see Fig. 3).

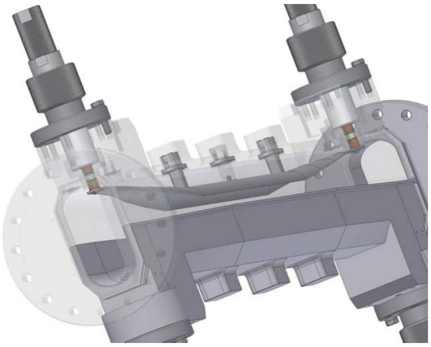

Figure 3: Drawing of the new injection kicker

The stripline tapering allows to reduce the broadband beam impedance of the device and to obtain a better matching of the transition to the external coaxial lines, hence a better damping of possible HOMs. Moreover the cross section of the kicker chamber is now the same of the adjacent beam pipe in the dipole regions and this also contributes to reduce the total beam coupling impedance of the machine. In Fig.4, the longitudinal coupling impedance of the structure has been evaluated with HFSS applying the principle of the wire method.

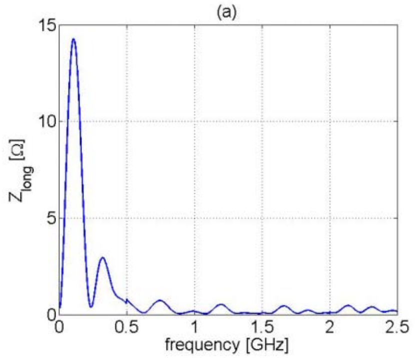

Figure 4: Kicker coupling impedance calculated by HFSS.

The New Shielded Bellows

The new bellows [14] connect pipes having circular cross section with 88mm diameter. The inner radius of bellows convolutions is about 65mm, the outer one 80mm and the length about 50mm. Then a RF shield is necessary to hidden the chamber discontinuity to the beam. The shield has been designed as shown in Fig. 5. Two cylindrical shells made of aluminium are fixed at the bellows ends and assure continuity to the beam pipes except for the gap between them. But even this gap is shielded by a number of adjacent Be-Cu strips placed all around the Al shells. The shape of the strips is preformed as a Ω that gives elasticity to the system.

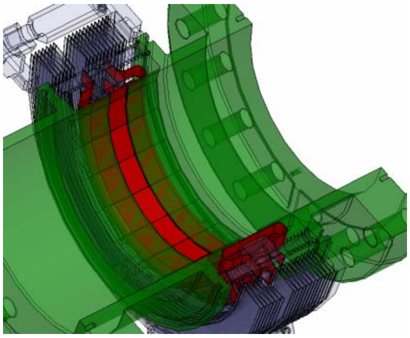

Figure 5: Drawing of the shielded bellows.

The structure has been simulated with HFSS in a frequency range from DC to 6 GHz and no HOMs have been found. The beam coupling impedance has been calculated as well and the result is plotted in Fig.6.

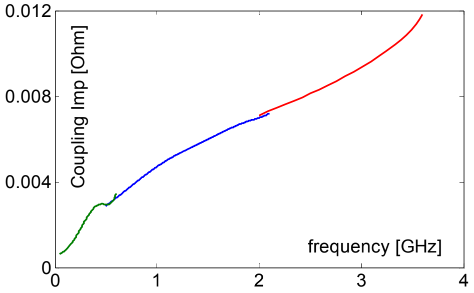

Figure 6: Beam coupling impedance obtained by HFSS.

BUNCH LENGTHENING

The broad-band coupling impedance of the DAΦNE original vacuum chamber is well-known for both the positron [15] and electron rings [16]. Numerical simulations based on the numerically computed wake fields reproduce well the measured bunch length and charge distribution in lattices with negative and positive momemtum compaction factors.

In Fig.7 one can see the bunch length as a function of bunch currents and bunch charge distribution measured by Hamamatsu C5680 streak camera in the DAΦNE electron ring.

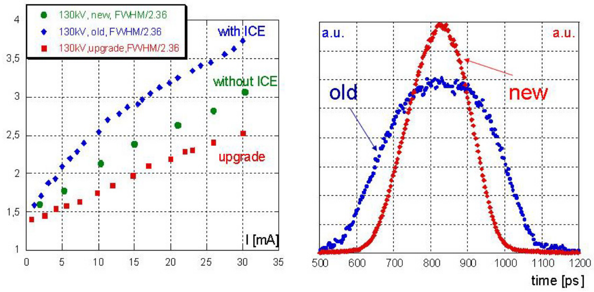

Figure 7: Bunch length as a function of bunch current (left) and bunch charge distribution (right) in the electron ring.

The blue curve corresponds to the bunch length measured in the DAΦNE original vacuum chamber. The first notable impedance reduction of the electron ring has been already obtained after the long ion clearing electrode removal from the collider wiggler sections [17]. Besides the evident bunch lengthening reduction (see the green curve in Fig.7), it has helped to eliminate other two harmful impedance related effects: the single bunch quadrupole instability and single bunch vertical size blow up. This has resulted in about 50% specific luminosity increase during the last run for the FINUDA experiments [18].

The vacuum chamber modifications for the crab waist experiment have brought another big factor in the coupling impedance reduction. As one can see in Fig. 7 by comparing the green and red curves, now bunches in the electron ring are by about 20% shorter with respect to the previous FINUDA run. As it is also shown in Fig. 7 the bunch charge distribution has cardinally changed. In the original vacuum chamber the longitudinal bunch profile had the typical parabolic shape due to bunch interaction with the inductive chamber impedance (the blue curve on the right plot taken at 30 mA per bunch). After the modifications, the distribution is close to a gaussian one with some small asymmetry due to the resistive part of the coupling impedance (the red curve on the right plot).

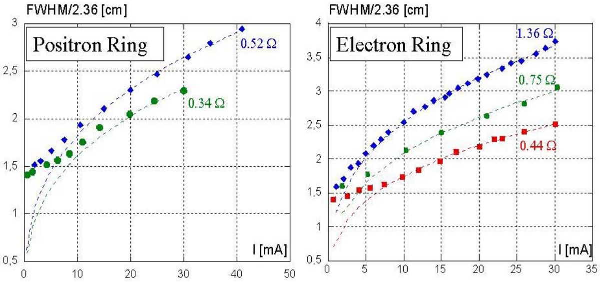

Figure 8. Bunch lengthening positron (left) and electron rings (right)

Looking at the left plot of Fig. 8 we see that also positron bunches are shorter after the vacuum chamber upgrade even though the effect of the bunch length reduction is slightly smaller than that in the electron ring. This is due to the fact that in addition to the similar vacuum chamber modifications made in both rings also the most part of ion clearing electrodes have been removed from the electron ring. At present bunch lengths in both rings are very similar. Some very small observable difference is explained by the presence of few ion clearing electrodes still remaining in the e^- ring.

In order to obtain a quick but rather rough estimate of the impedance improvements after the modifications we can use the following scaling property above the microwave instability threshold valid in the assumption of the purely inductive impedance [19]:

$$\left(\frac{\sigma_z}{R}\right) \approx \left(\frac{2}{\pi}\right)^{1/6} \xi^{1/3} \left(\frac{Z}{n}\right)^{1/3} \quad with \quad \xi = \frac{2\pi I}{heV_{RF}\cos\varphi_s} \quad (*)$$

with R the ring radius, I the bunch current; h the harmonic number; V_{RF} the RF voltage; Z/n the normalized longitudinal impedance, ϕs the synchronous phase.

Assuming that bunches have a gaussian shape, i.e. rms bunch length σ_z is equal FWHM/2.355, we have fit the measured bunch length data (see Fig. 8) with the expression (*). According to this rough estimate the longitudinal coupling impedance of the positron ring has been decreased by about 50% while the reduction of the electron ring impedance is as high as 70%.

Fortunately, the semi-qualitative estimate is confirmed by numerical simulations of the bunch lengthening. By simply scaling the known wake potential used for bunch lenghtening simulations in the original DAΦNE vacuum chamber [15] and performing numerical tracking have given a satisfactory agreement between the measurement data and simulation results, as seen in Fig.9.

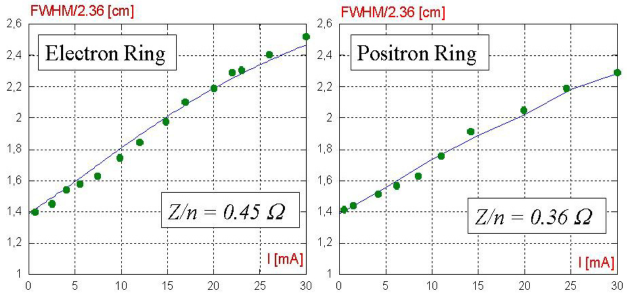

Figure 9. Bunch length in electron and positron rings (dots – measurement data, solid line – tracking results)

CONCLUSIONS

Careful designing of the new vacuum chamber components, required for DAΦNE modifications aimed at testing the crab waist collision scheme, has allowed reducing the coupling impedance of the positron ring by about 50% and that of the electron ring by approximately 70%.

REFERENCES

[1] G.Vignola et al., Frascati Phys.Ser.4:19-30,1996; C.Milardi et al., Frascati Phys.Ser.16:75-84,1999; M.Zobov et al., arXiv:0709.3696.
[2] KLOE Coll., Nucl.Instrum.Meth. A482:363-385,2002.
[3] FINUDA Coll., Proc. HYP2000 (Torino, 2000).
[4] DEAR Coll., Phys.Lett. B535:52-58,2002.
[5] SIDDHARTA Coll., Eur.Phys.J. A31:537-539,2007.
[6] P.Raimondi, 2nd SuperB Workshop, Frascati, 2006.
[7] P.Raimondi, D.Shatilov, M.Zobov, physics/0702033.
[8] M.Zobov et al., arXiv:0802.2667.
[9] C.Milardi et al., this Conference.
[10] S.Tomassini et al., PAC07, pp. 1466-1468.
[11] C.Milardi et al., arXiv:0803.1450.
[12] F.Marcellini, PAC07, pp. 3988-3990, 2007.
[13] D.Alesini et al., DAΦNE Note I-17, 2006.
[14] S.Tomassini et al., TUPP074, this conference.
[15] M.Zobov et al., physics/0312072.
[16] B.Spataro, M.Zobov, DAΦNE Note G-64, 2005.
[17] M.Zobov et al., JINST 2:08002, 2007.
[18] C.Milardi et al., PAC07, pp.1457-1459, 2007.
[19] A.W.Chao, J.Gareyte, Part.Accel.25:229, 1990.