DESIGN AND TEST OF THE CLEARING ELECTRODES FOR e^- CLOUD MITIGATION IN THE e^+ DAΦNE RING

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Abstract

Metallic clearing electrodes have been designed to absorb the photo-electrons in the DAΦNE positron ring. They have been inserted in the wiggler and dipole vacuum chambers and have been connected to external high voltage generators. In the paper we present the design of the devices and the results of the electromagnetic simulations of longitudinal beam coupling impedances. We also present the results of the RF tests on the installed electrodes.

INTRODUCTION

The Frascati Φ-factory DAΦNE is an e^+e^- collider operating at the energy of Φ-resonance (1.02 GeV c.m.) [1]. The main machine parameters in the last run for SIDDHARTA experiment and the crab waist collision scheme test [2] are given in Table 1.

One of the main limitations in the maximum stored current of the e^+ ring has been identified as a horizontal instability due to the e^- cloud effect [3]. To mitigate such instability metallic (copper) electrodes have been inserted in all dipole and wiggler chambers of the machine and have been connected to external dc voltage generators in order to absorb the photo-electrons [9]. Simulations of the e^- cloud density and instability threshold with and without the voltage applied to the electrodes are widely discussed in [4]. With a dc voltage of 500 V applied to each electrode we expect a reduction of such density by two orders of magnitude that will contribute to reduce substantially the source of the instability.

Table 1: DAΦNE Parameters (last 2009 run)

Energy	E [MeV]	510
Machine length	l [m]	96
Max. beam current	I_M [A]	≈2.2(e-)≈1.1(e+)
# of colliding bunches	N_b	110
RF frequency	f_{RF} [MHz]	≈368.67
RF voltage	V_{RF} [kV]	150-170
Harmonic number	h	120
Bunch spacing	T_B[ns]	≈2.7 (=1/f_{RF})
Max Luminosity	L [$cm^{-2}s^{-1}$]	≈$4.5\cdot10^{32}$

ELECTRODES DESIGN AND INSTALLATION

The pictures of the electrodes inserted in the dipole and wiggler chambers are shown in Fig. 1. The dipole electrodes have a length of 1.4 or 1.6 m depending on the considered arc, while the wiggler ones are 1.4 m long. They have a width of 50 mm, thickness of 1.5 mm and their distance from the chamber is about 0.5 mm. This distance is guaranteed by special ceramic supports made in SHAPAL (Fig. 2) and distributed along the electrodes. This ceramic material is also thermo-conducting in order to partially dissipate the power released from the beam to the electrode through the vacuum chamber (see last paragraph). Moreover, the supports have been designed to minimize their beam coupling impedance and to simultaneously sustain the strip. The mechanical drawing of a dipole-wiggler arc with the electrodes is shown in Fig. 3. The distance of the electrode from the beam axis is 8 mm in the wigglers and 25 mm in the dipoles.

The electrodes have been connected to the external dc voltage generators modifying the existing BPM flanges as shown in Fig. 4.

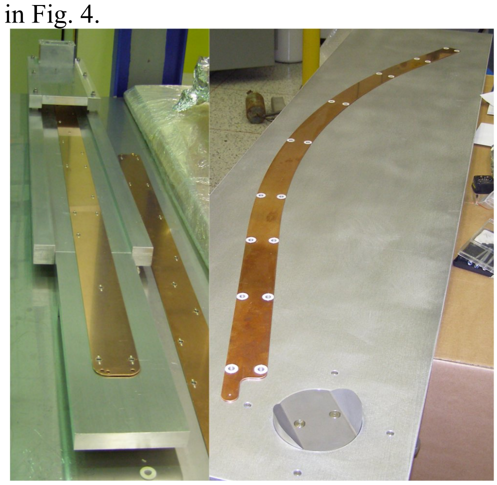

Figure 1: Pictures of the electrodes inserted in the dipole (right) and wiggler (left) chambers.

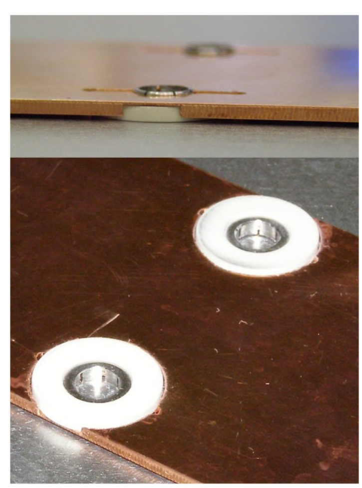

Figure 2: SHAPAL supports for the electrodes.

The electrodes have been inserted in the vacuum chamber in the last January-May 2010 shutdown. The picture of an installed electrode is given in Fig. 5. The electrodes have been inserted in the machine through special plastic supports that allowed inserting the electrodes in the chamber without damaging the chamber and the electrodes themselves. Before and after their installation the electrodes have been tested applying a dc voltage of about 400 V (in air) to check the correct installation and the correct connection of the devices. Measurements with a Network Analyzer have been also done and they will be illustrated in the next section.

A low pass-band RC filter has been inserted between the feed-through and the dc generator in order to decouple the dc generator from the beam induced signal at high frequency.

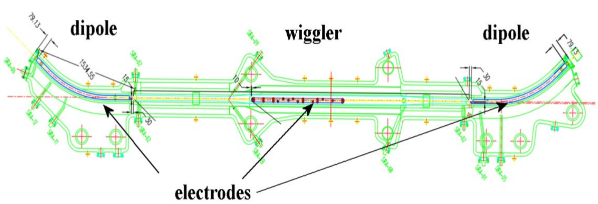

Figure 3: Mechanical drawing of a complete arc with the electrodes.

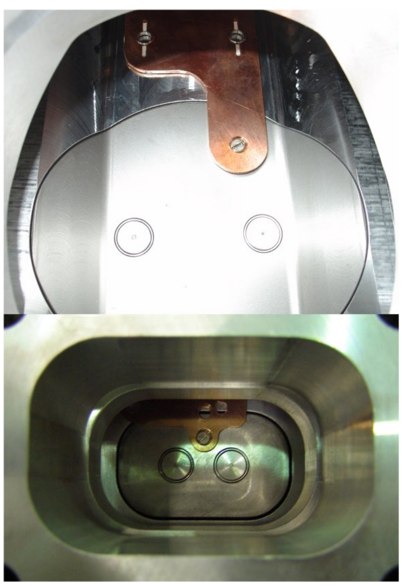

Figure 4: Detail of the electrodes output connection.

ELECTRODE IMPEDANCE EVALUATION AND RF MEASUREMENTS

The electrode impedance consists of two contributions: a resistive wall impedance due to a finite conductivity of the electrode and a strip-line impedance since the strip-line is created between the electrode and the vacuum chamber wall. Here we considered the most critical case of the wiggler electrodes.

Resistive Wall

For a thick wall (electrode) and not very short bunches the loss factor and the dissipated power per unit length due to the resistive wall impedance [5] is:

$$\frac{dk_l}{dz} = \frac{c}{4\pi^2 b\sigma_z^{3/2}}\sqrt{\frac{Z_0\rho}{2}}\Gamma\left(\frac{3}{4}\right)F_0; \quad \frac{dP}{dz} = \frac{(eN)^2 n_b c}{2\pi R}\frac{dk_l}{dz}$$

For the parallel plate case the form factor $F_0 = 1$. This is a good approximation for the very flat wiggler vacuum chamber with 20x130 mm^2 cross section and the electrode width of 50 mm. We have to divide the result by a factor 2 since we have only 1 electrode.

Considering 120 circulating bunches with 20 mA per bunch ($N = 4x10^{10}$), bunch length σ_z of 2 cm, the distance between the beam and the electrode b of 8 mm and the copper electrode with $\rho = 1.7241x10^{-8}\ \Omega m$ we obtain:

$$\frac{dk_l}{dz} = 3.71x10^8\ \frac{V}{Cm} \quad and \quad \frac{dP}{dz} = 5.58\frac{W}{m}$$

Taking into account the electrode length of 1.4 m each electrode should dissipate 7.8 W, or 112 W/m^2 for the 50 mm wide electrode. According to experimental curves reported in [6], such power density would result in electrode heating under vacuum up to 50°-55° C.

Figure 5: Installed electrode in the dipole vacuum chamber.

Strip-line Impedance

In order to obtain wake fields and impedance of the electrode we have used the code GdfidL [7]. The simulations have been performed for a real size strip-line created by the electrode and the vacuum chamber wall with one feed-through placed at one of the electrode ends. Since it is known that the result depends very much on the external loadings and circuits connected to the electrode we have simulated two extreme cases: the perfectly matched electrode and the short-circuited one.

We have traced the wake behind the exciting bunch over 50 m and the resulting impedance was obtained by applying the Fourier transform. The real part of the electrode impedance for both cases is shown in Fig. 6. As can be seen, the impedances are significantly different in these two cases, despite the loss factors are rather similar, -1.87x10^9 V/C (shorted) and -1.56x10^9 V/C (matched). For the matched feed-through the absolute impedance values are low, but the impedance is broad. In this case the loss factor can be used for the power loss evaluation. Since the loss factor is by a factor 3 higher than that of the resistive walls, the lost power will be higher by the same factor. However, we should say that not all the power will be dissipated on the electrode itself. Part of it will be dissipated in the external loadings and on the vacuum chamber walls.

The situation is less predictable for the other (shorted) case. The released power can be much higher in this case if one of the narrow peaks coincides with one of the RF frequency harmonics (strongest beam power spectrum lines). Fortunately, the probability of this situation is rather low. In order to minimize the power losses the electrode length has been chosen in such a way to shift the impedance peaks away from the RF harmonics.

However, in both cases the lost power is not negligible and can result in excessive heating of the electrode. In order to prevent this possible damage, electrode supports are made of thermo-conducting dielectric material (SHAPAL) thus providing heat transfer from the electrode to the vacuum chamber.

The estimated low frequency broad-band impedance of the electrode *Z/n* is about 0.005 Ω, which is substantially smaller with respect to the impedance of the ion clearing electrodes removed from the wiggler sections of the electron ring [8], and should be a small contribution to the total ring impedance.

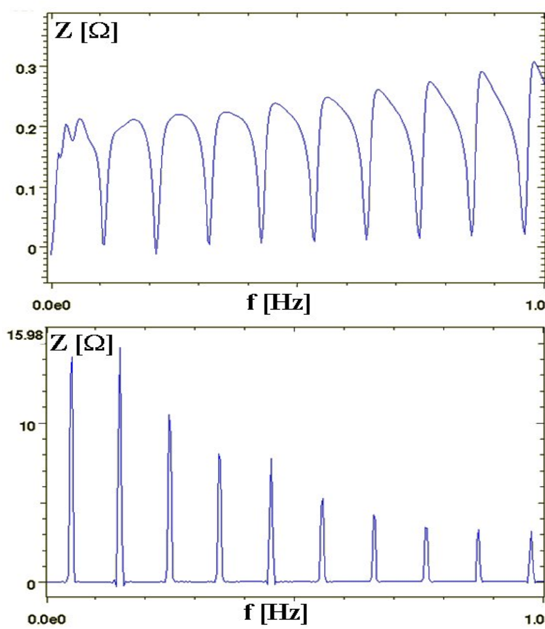

Figure 6: Electrode real impedances for the matched (upper) and shorted (lower) strip.

RF Measurements

RF measurements with a network analyzer have been performed before and after the electrode installation. We have done two types of measurements: reflection coefficient at the feedthrough port and transmission coefficient between one BPM near to the strip and the feedthrough. In both cases it was possible to measure the resonant frequencies of the strip modes and, especially in the second case, it was possible to measure the resonant frequencies also with the presence of the RC low pass-band filter. As an example the first type of measurements is reported in Fig. 7 for the wiggler case. In the second case the measurement is much more noisy because of the presence of the filter and of the small coupling between the BPM and the strip. These measurements allow estimating the resonant frequencies of the strip and, combined with the simulations results, the power released from the beam to the strip and to the external load. Such comparison remarks that we should not expect full coupling between one beam power spectrum line and one of the strip resonances.

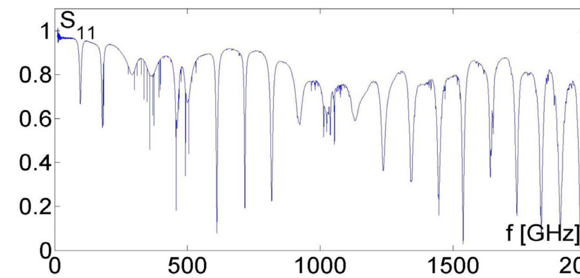

Figure 7: Reflection coefficient at the feedthrough port. The narrowband resonances are the chamber TE resonances.

CONCLUSIONS

Metallic clearing electrodes have been inserted in the wiggler and dipole vacuum chambers of the DAΦNE positron ring to fight the instability due to the e-cloud. The electrodes have been made in copper and have a distance of 0.5 mm from the vacuum pipe. This small distance has been chosen to reduce the beam coupling impedance of the devices. Special ceramic supports sustain the strips. Analytical calculations and electromagnetic simulations have been done to estimate the power released from the beam to the electrodes. We expect a maximum temperature increase of the order of 100°C with a 2A beam for the wiggler electrodes. This temperature increase has been considered acceptable since the electrodes have been heated up to this level without damage and also because it is in the range of operation of all the components (SHAPAL and feed-throughs). The electrodes are connected to external generators that allow reaching dc voltages of about 500-1000 V. RF measurements have been done to precisely measure the resonant frequencies of the electrodes modes.

REFERENCES

[1] G. Vignola et al., PAC93, p. 1993.
[2] M. Zobov et al., Phys.Rev.Lett. 104 (2010) 174801.
[3] A. Drago, C. Vaccarezza and M. Zobov, DAΦNE Technical Note G-67, 2006.
[4] T. Demma et al., this conference.
[5] L. Palumbo, V. Vaccaro, M. Zobov, physics/0309023.
[6] J. Corlett, J. Johnson and D. Lozano, PEP-II-AP-Note-96-22, 1996.
[7] GdifdL v2.1.
[8] M. Zobov et al., JINST 2 (2007) P08002.
[9] Y. Suetsugu et al., NIM-A 598 (2009) 372.