EXPERIMENTAL MEASUREMENTS OF E-CLOUD MITIGATION USING CLEARING ELECTRODES IN THE DAΦNE COLLIDER

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Abstract

Recently the DAΦNE electron-positron collider has started delivering luminosity to the KLOE-2 experiment. For this run special metallic electrodes were installed in all the dipole and wiggler magnets of the positron ring to cope with the effects induced by the e-cloud formation. Experimental measurements have shown an impressive effectiveness of these devices in mitigating the e-cloud impact on the positron beam dynamics. The electrodes allow reducing the vertical beam size and the growth rate of transverse instabilities as well as the tune shifts induced by the electron cloud itself. Moreover frequency shift measurements of the vacuum chamber resonances, switching on and off the electrodes, indicate an evident reduction of the electron cloud density. This paper reports and analyses all the experimental observations and measurements done to suppress the e-cloud induced effects by using metallic 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 present configuration suitable for the KLOE-2 experiment, are given in Table 1. During the last shut-down, strip-line electrodes have been inserted in all dipole and wiggler vacuum chambers of the positron ring and have been connected to external dc voltage generators in order to absorb the photo-electrons [2] overcoming the limitations in the maximum storable positron current due to the e^- cloud driven instabilities [3,4]. The mechanical layout of a dipole-wiggler arc with the electrodes is shown in Fig.1.

Table 1: DAΦNE parameters (KLOE-2 run).

Energy	E [MeV]	510
Machine length	l [m]	96
Max. achieved beam current	I_M [A]	≈ 1.5(e-) ≈ 1(e+)
# of colliding bunches	N_b	100
RF frequency	f_{RF} [MHz]	368.67
RF voltage	V_{RF}[kV]	≈200
Harmonic number	h	120
Bunch spacing	T_B[ns]	2.7 (=1/f_{RF})
Max achieved Luminosity	L [$cm^{-2}s^{-1}$]	≈$1.5\cdot10^{32}$

The e-cloud electrodes consist of Cu strips, having 1.5 mm thickness, 50 mm width and variable length (1.4 m, 1.5 m and 1.6 m) depending if they are installed in the wiggler, in the long magnet or in the short magnet vacuum chamber respectively. They are equipped with dielectric (shapal) contacts providing a ~ 0.5 mm distance with respect to the Al beam pipe. Test with the beam have been done applying an external dc voltage up to 250 V. The electrodes effectiveness in absorbing the e-cloud has been verified by several measurements, as illustrated in detail in the following sections.

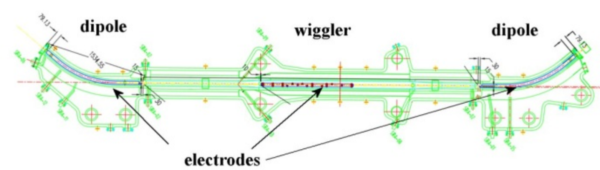

Figure 1: mechanical drawing of an arc with the electrodes.

SHIFT AND SPREAD OF BETATRON TUNES

The horizontal tune shift measurements with electrodes on and off are given in Fig. 2 for a 550 mA positron beam (not in collision). The image is taken from a spectrum analyser (Tektronix RSA3303A) connected to a button pickup. The frequency shift of the horizontal tune line switching off all electrodes is ≈20 kHz which correspond to a difference in the horizontal tune of ≈0.0065.

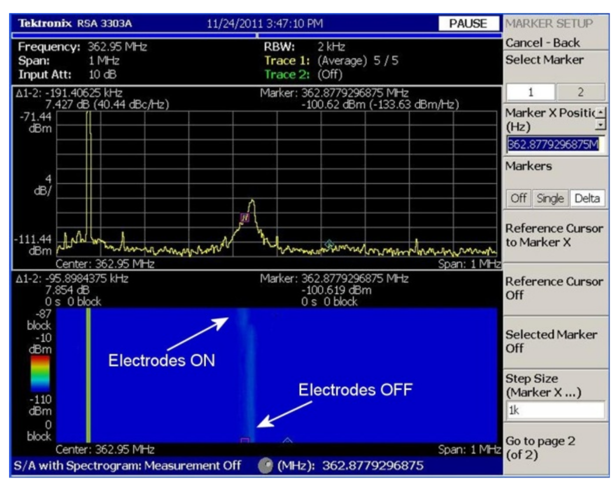

Figure 2: horizontal tune shift measured with 550 mA of positron beam. The image is taken from the spectrum analyser connected to one button pickup.

Off-line analysis of the signals acquired by the bunch-by-bunch transverse feedbacks [5] allows measuring the fractional tunes of each bunch along the batch [6]. Thus providing a very powerful tool to observe the tune shift modulation along the bunch train. Results are given in Fig. 3 for the horizontal plane (bunch #1 is the first in the batch). In this case the measurements have been done

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turning off the four wigglers electrodes and two (over eight) dipole electrodes. With this measurement it is has been possible to observe the tune shift modulation along the train. The horizontal tunes increase in the first part of the train where the e-cloud density grows up and reaches a steady state regime after ≈20 bunches. The tune spread between the head and the tail of the train is ≈0.006 with electrodes off, and ≈0.003 with electrodes on. The average tune shift of the whole batch is about ≈0.004, and it is in good agreement with the global horizontal tune shift measured by the spectrum analyzer, also considering that, in the previous case, all electrodes were switched off. The average tune shift and the tune spread, measured in the vertical plane [6], are a factor ten lower than the corresponding values in the horizontal one, both with electrodes on and off.

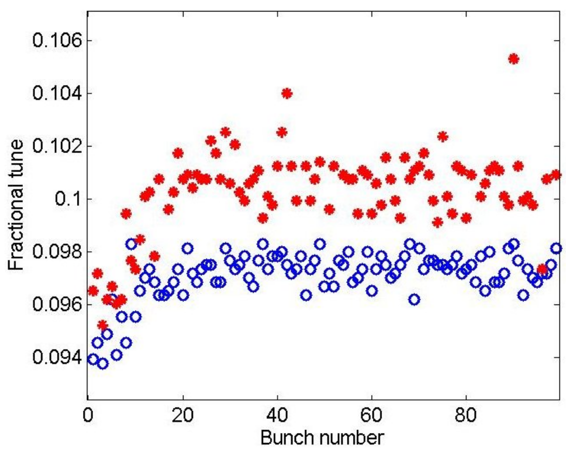

Figure 3: horizontal fractional tune as a function of bunch number (blue curve: electrodes ON, I_B=550mA; red curve: electrodes OFF, I_B=600mA).

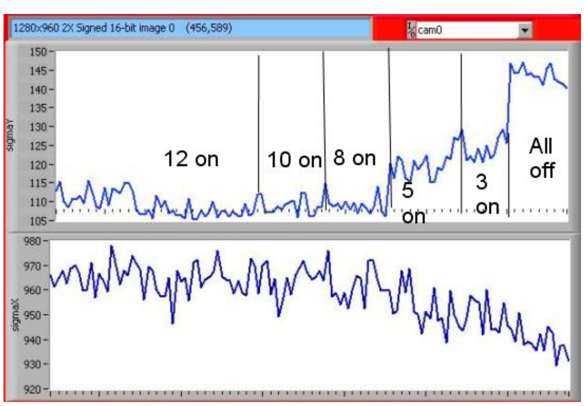

Figure 4: Beam dimension (in μm) at the SLM turning off, progressively, all electrodes.

TRANSVERSE BEAM DIMENSION VARIATION

The transverse beam dimensions (in μm) measured at the synchrotron light monitor (SLM) turning off, progressively, all electrodes are given in Fig. 4. The beam vertical size goes from less than 110 μm with electrodes on to more than 145 μm with electrodes off. Also in this case the beam was not colliding.

GROWTH RATES OF THE HORIZONTAL INSTABILITY

Growth rates measurements of the coupled bunch instabilities can be performed by means of the bunch by bunch transverse feedbacks. The results of the measurements in the horizontal planes are given in Fig. 5 where the growth rates (in ms^{-1}) have been measured as a function of current and for different electrode voltages. With electrodes off the growth rate at 650 mA exceed 50 ms^{-1} and the measurements above this current becomes quite difficult since the beam is strongly unstable. With electrodes on these growth rates are strongly reduced and it is possible to store a higher stable current.

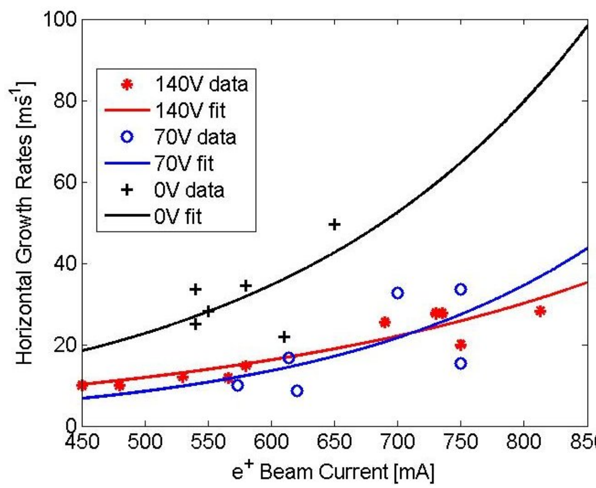

Figure 5: growth rates of the horizontal instability.

FREQUENCY SHIFT OF VACUUM CHAMBER RF RESONANCES

The e-cloud plasma can interact with RF waves transmitted in the vacuum chamber changing the phase velocity of such waves. Such measurements have been successfully done on other machines [7]. A similar approach can be used in case of resonant waves in the vacuum chamber. Even in this case the e-cloud changes the electromagnetic properties of vacuum and this can result in a shift of the resonant frequencies of vacuum chamber trapped modes. In principle, from these shifts it is possible to evaluate the e-cloud density [8]. Resonant TE-like modes are trapped in the DAΦNE arcs and can be excited through button pickups. The lower modes have frequencies between 250 and 350 MHz. A first measure of these resonant modes has been done at DAΦNE for several beam currents with electrodes on and off. The analysis of this data, up to now, gave the following results: (a) all modes have a positive frequency shift as a function of the positron beam current and, with 800 mA, it is between 100 and 400 kHz depending on the modes we are considering; (b) for almost all modes we can partially cancel the frequency shift switching on the electrodes; (c) the quality factor of the modes decreases with positron current. The fact that for some modes the shift does not depend on the electron voltage could depend by the fact that these modes are localized in different places of the arc and also in regions not covered by electrodes. For instance the transmission coefficient between two button pickups in the arc chamber is given in Figs. 6a and 6b for two different modes. The mode of Fig. 6a has a positive frequency shift that does not change with electrode voltage while the mode in Fig. 6b corresponds to the case of a mode with frequency dependent to the electrode voltage. Appling the formula given in [8] it is possible to estimate an average e-cloud density of about (1-5)$\cdot 10^{11}$e/m^3. An identification of resonant mode location is still in progress.

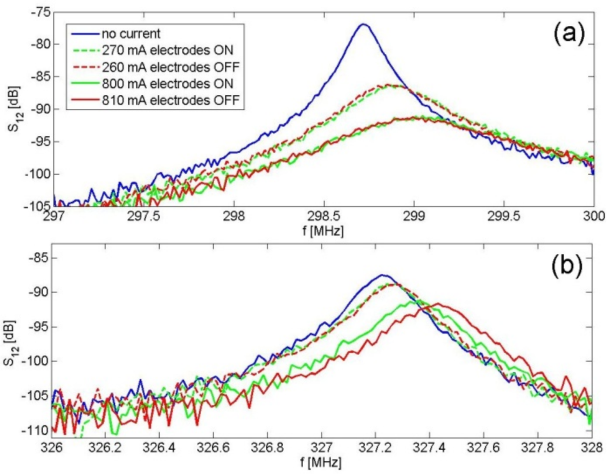

Figure 6: transmission coefficient between two button pickup in the arc chamber for two different resonant modes.

ELECTRODES CURRENT ABSORBTION

The voltage generators connected to the electrodes absorbs the photo-electrons. In the present layout one voltage generator is connected to three electrodes of one arc (i.e. one wiggler and two dipoles). The current delivered by the generator has been measured as a function of the generator voltage and for different beam currents. The result is given in Fig. 7. It is possible to explain the measured current profiles with the following simple model. Let us assume that the current supplied by the generator (I) is proportional to the product between the e-cloud density (n_{e-}) and the electric field around the electrode (i.e. to the dc voltage V_{DC}), it means $I \propto V_{DC} \cdot n_{e-}$. The e-cloud density is proportional to the difference between the beam electromagnetic field (i.e. to the beam current I_B), and to the external field (i.e. V_{DC}), it means $n_{e-} \propto I_B - \beta V_{DC}$. Combining the two previous relations we obtain that $I \propto V_{DC} \cdot I_B - \beta V^2_{DC}$, This equation reproduces the quadratic behaviour evident in Fig. 7. The e-cloud is completely absorbed when $I \approx 0$. In all other situations there is still an e-cloud density. Fitting these curves and scaling their behaviour up to currents >1A, one discover that a voltage of the order of 250 V is no longer adequate to completely absorb the e-cloud when I_B>1A. So the applied voltage has to be increased.

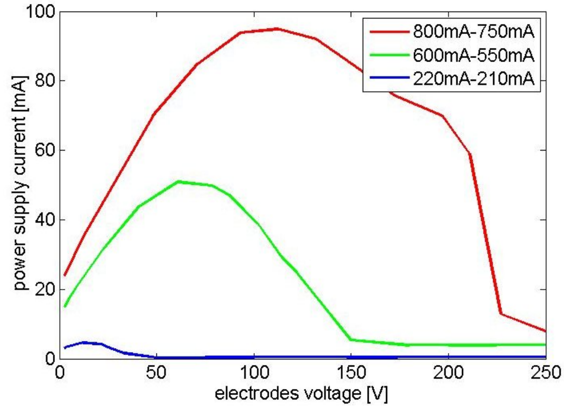

Figure 7: current supplied by the dc voltage generator as a function of the applied voltage and beam current.

CONCLUSIONS

Special metallic electrodes have been recently installed in the vacuum chamber of all dipoles and wigglers of the DAΦNE positron ring. They were expected to absorb the e-cloud that limited the positron beam dynamics and, in turn, the collider performances. Experimental measurements of the effectiveness of the electrodes in the mitigation of the e-cloud effects have been shown. The electrodes allow reducing the vertical beam size increase, the growth rate of transverse instabilities and the tune shifts induced by the e-cloud. Frequency shifts measurements of the vacuum chamber resonances switching on and off the electrodes have also been done. This measure allows calculating, to the first order, the e-cloud density and the effects of the clearing electrodes. In the paper we have also shown the measure of the current delivered by the voltage generators that is related to the effectiveness in absorbing the e-cloud.

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REFERENCES

[1] G.Vignola et al., PAC93, p.1993.
[2] Alesini et al., proc. IPAC12, 2012, Kyoto, Japan.
[3] A.Drago, C. Vaccarezza and M. Zobov, DA□NE Technical Note G-67, 2006.
[4] T.Demma, et al.,proc. of PAC09, Vancouver, Canada.
[5] A.Drago, et al. proc. IPAC 11, San Sebastián, Spain.
[6] A.Drago, et al., BIW12, Newport News; arXiv:1204.5016v1 [physics.acc-ph], 23 Apr 2012
[7] S. De Santis, J. M. Byrd, F. Caspers, et al, Phys. Rev. Lett. 100, 094801 (Mar. 2008).
[8] J.P. Sikora, et al., this conference.