A SIMULATION STUDY OF THE ELECTRON CLOUD INSTABILITY AT DAFNE*

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Abstract

A strong horizontal instability has been observed in the DAFNE positron ring since 2003. Experimental observations suggest an electron cloud induced coupled bunch instability as a possible explanation. In this communication we present a simulation study of the electron cloud coupled bunch instability for the DAFNE positron ring, performed with the code PEI-M, and compare the numerical results with experimental observations.

INTRODUCTION

After the 2003 shutdown for the FINUDA detector installation, and some optics and hardware modifications, the appearance of a strong horizontal instability for the positron beam at a current $I \approx 500mA$, triggered the study of the e-cloud effect in the DAFNE collider. Experimental observation that seems to provide an evidence that the electron cloud effects are present in the DAFNE positron ring can be summarized as follow: a larger positive tune shift is induced by the positron beam current [1]; the horizontal instability rise time cannot be explained only by the beam interaction with parasitic HOM or resistive walls and increase with bunch current [3]; the anomalous vacuum pressure rise with beam current in positron ring [4], bunch-by-bunch tune shifts measured along the DAFNE bunch train present the characteristic shape of the electron cloud buildup [5]. There are also indications that wigglers play an important role in the instability, since the main changes after the 2003 shutdown were the modification of the wiggler poles, and lattice variation which gave rise to an increase of the horizontal beta functions in wigglers [6]. Recently the horizontal feedback for the DAFNE positron ring has been successfully upgraded [2] by doubling the entire system and allowing to operate the machine at a positron current higher than $1A$.

To better understand the electron cloud effects and possibly to find a remedy, a detailed simulation study is undergoing [8], [9]. In this communication we present recent simulation results relative to the coupled-bunch instability induced by the electron cloud buildup in the arcs of the DAFNE positron ring. When possible simulation results are compared to experimental observation. Conclusions follow in the last section.

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ELECTRON CLOUD INDUCED COUPLED-BUNCH INSTABILITY

Once the electron cloud is formed, the beam passing through the cloud interacts with it. The motions of bunches become correlated with each other if the memory of a previous bunch is retained in the electron cloud -i.e., a small displacement of a bunch creates a perturbation of the electron cloud, which affects the motions of the following bunches, with the result that a coupled-bunch instability is caused. A complete discussion of the electron cloud induced multi-bunch instability formalism is outside the aim of this paper . The reader is referred to [10] for a detailed presentation of the subject. Experimental observations [1]-[6] show that the horizontal instability affecting the DAFNE positron beam is a multi-bunch instability. The observed oscillation mode of the instability is always a very slow frequency mode and can be identified as the -1 mode, i.e., the mode that has a line closest to the frequency origin (zero frequency) from the negative part of the spectrum. The same behaviour has been observed even after the solenoid installation [2]. For this reasons the attention has been focused on the interaction of the beam with the cloud in wigglers and bending magnets where the solenoids are not effective.

Tracking of the Coupled-Bunch Instability

A positron bunch can be characterized by its transverse and longitudinal position (dipole moment) as a function of s, ignoring the internal structure of the bunch. Interactions between bunches and electrons in a cloud are determined by the transverse and longitudinal profiles of the bunches. The profiles are assumed to be Gaussian with standard deviation determined by the emittance and the average beta function in the transverse and longitudinal directions. The motion of each bunch is determined by the transformation representing lattice magnets and the interactions with electrons, while the motions of the electrons are determined by the interactions with the bunches, space charge forces between the electrons, and any magnetic field. The equations of motion are written as

$$\frac{d^2\mathbf{x}^p}{ds^2} + K(s)\mathbf{x}^p = \frac{r_e}{\gamma}\sum_{e=1}^{N}\mathbf{F}(\mathbf{x}^p - \mathbf{x}^e)\delta_p(s - s^e) \quad (1)$$

$$\frac{d^2\mathbf{x}^e}{ds^2} = 2r_ec^2\sum_{p=1}^{N_p}\mathbf{F}(\mathbf{x}^e-\mathbf{x}^p)\delta_p[t-t^p(s^e)] + \\ + \frac{e}{m_e}\frac{d\mathbf{x}^e}{dt}\times\mathbf{B} - 2r_ec^2\frac{d\Phi}{d\mathbf{x}} \qquad (2)$$

where subscripts p and e of $\mathbf{x}$ denote positron and electron, respectively, r_e is the classical electron radius, m_e is the electron mass, c is the speed of light, e is the electron charge, Φ is the electric potential due to electrons, δ_p is the periodic delta function for the circumference, and $\mathbf{F}$ is the Coulomb force in two-dimensional space given by the Bassetti-Erskine formula [11].

Simulations for DAFNE

Table 1: DAFNE Beam and Pipe Parameters Used as Input for PEI-M Simulations

parameter	unit	value
bunch population N_b	10^{10}	2.1
number of bunches N	–	120
missing bunches N_{gap}	–	0
bunch spacing L_{sep}	m	0.8
bunch length σ_z	mm	18
bunch horiz. size σ_x	mm	1.4
bunch vert. size σ_y	mm	0.05
chamber radius R	mm	45
hor./vert. beta functions β_x/β_y	m	4.1/1.1
hor./vert. betatron tunes ν_x/ν_y	–	5.1/5.17
primary electron rate $d\lambda/ds$	–	0.0088
photon reflectivity	–	100%
maximum SEY δ_{max}	–	1.9
energy for max. SEY E_{max}	eV	250

To estimate the multi-bunch instability induced by the electron cloud in the arcs of the DAFNE positron ring the code PEI-M [12],[13] has been used. The code computes the transverse amplitude of each bunch as a function of time by solving equations (1), and (2), while evolving the build-up of the electron cloud self-consistently. To save computation time, the Poisson equation for the space charge potential is solved only once for zero beam amplitude, and is used as a constant field in tracking simulation. The beam and chamber parameters used in the simulation are collected in Table 1. A uniform vertical magnetic field $B_z = 1.7$ T was used to model the motion of the electrons both in wigglers and dipoles, and a circular chamber of radius $R = 45mm$ is used instead of the real chamber geometry in order to solve analytically the Poisson equation for the space charge potential Φ . In these tracking simulations, the motion of bunches filling the DAFNE positron ring while interacting with the cloud is followed for 500 turns. The instability mode spectrum is obtained by taking the Fourier transform of the transverse amplitude of each single bunch as computed by the code, and the grow-rate is obtained by an exponential fit to the beam signal envelope. In Figure 1 is shown a snapshot of the electron cloud distribution in the transverse x-y plane, as obtained bu the simulation code at the end of the first bunch train turn, assuming a uniform illumination of the beam chamber walls. The two stripes structure, typical of e-cloud distribution in strong bending field, is clear. In Figure 2 are reported the beam signal (the horizontal position of each bunch as a function of time expressed in turns), the beam signal envelope, and the mode spectrum obtained for a bunch train of 120 equi-spaced bunches filled with a beam current of 1.2 A. It is clearly seen that the most unstable mode, obtained by the simulation is mode 114, corresponding to the -1 mode.

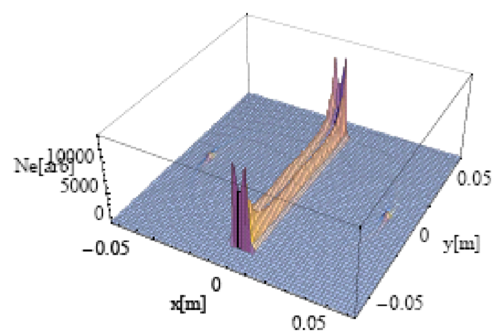

Figure 1: Typical electron cloud distribution in the transverse x-y plane. The number of electrons in an arbitrary unit is plotted in the vertical axis, as obtained by PEI-M after the first bunch train passage in a DAFNE arc bend.

Experiments on coupled-bunch instabilities have been extensively performed using the DAFNE fast feedback system to perform grow-dump measurements [1],[3],[2]. Measured grow-rate are compared to simulation results in Table 2 for different beam currents, showing a good agreement.

Table 2: Measured and Simulated Instability Growth Rate for Different Beam Current

Measurement		Simulation	
$I[mA]/nb$	τ/T_0	$I[mA]/nb$	τ/T_0
1000/105	73	1200/120	100
750/105	56	900/120	95
500/105	100	600/120	130

CONCLUSIONS

Coupled-bunch instability simulations are in good agreement with the experimental observations, and indicate that the observed horizontal instability is compatible with a coupled bunch instability induced by the presence of an electron cloud in the arcs of the DAFNE positron ring. Work is in progress to include more realistic models for

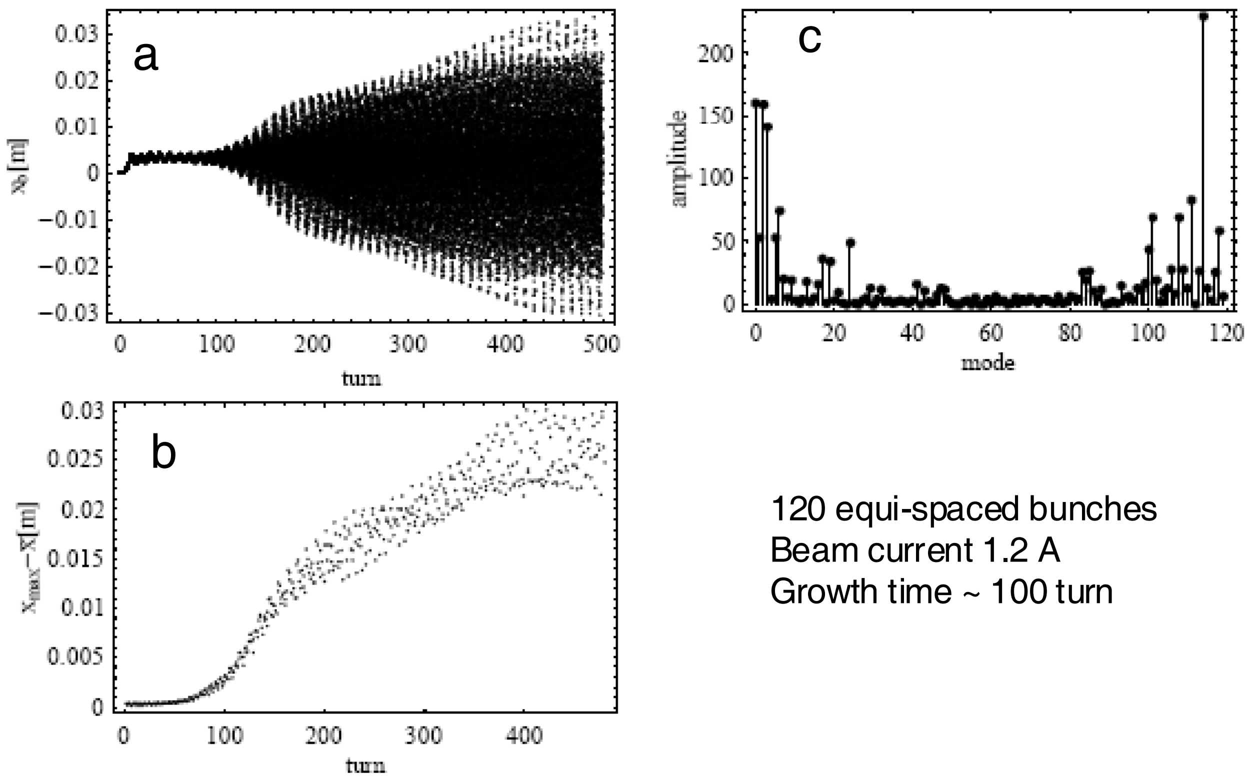

Figure 2: Beam signal (a), beam envelope (b), and mode spectrum (c) for a completely filled DAFNE bunch train.

the space charge potential and the chamber boundaries in the simulation code.

REFERENCES

[1] C. Vaccarezza, et al, ECLOUD04, Napa Valley proc.

[2] A.Drago et al., TH5RFP057 these Proceedings.

[3] A.Drago et al., Proceedings of PAC05, p.1841.

[4] C.Vaccerezza et al., Proceedings of PAC05, p.779.

[5] A.Drago, proc. of the 40th ICFA Workshop on High Luminosity e+e- Factories.

[6] A.Drago et al., DAFNE Tech. Notes, G-67.

[7] A.Drago et al., TH6REP072 these Proceedings.

[8] T.Demma et al., Proceedings of EPAC08, p.1607.

[9] T.Demma, ICFA Beam Dynamics Newsletter n.48 (2009), pp.64-71.

[10] S.S.Win et al., Phys. Rev. ST Accel. Beams 8, 094401 (2005).

[11] M. Bassetti and G. Erskine, CERN Technical Report No. ISR TH/80-06, 1980.

[12] K. Ohmi, Phys. Rev. Lett. 75, 1526 (1995).

[13] Y.Cai et al., Phys. Rev. ST-AB 7, 024402 (2004).