

DUST MACROPARTICLES IN HERA AND DORIS

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Abstract

Charged dust macroparticles are considered as sources of sudden beam lifetime breakdowns detected in many electron storage rings. This phenomenon is still observed in HERA, although the distributed ion pumps, which were previously identified as dust particle sources, have been removed. We report on observations of trapped dust during the last period of electron operation and present a detailed model of dust macroparticle dynamics in HERA and in DORIS with particular emphasis on stability and possible trapping processes.

INTRODUCTION

Sudden breakdowns of electron beam lifetime have been reported from many storage rings [1]-[7]. This phenomenon is ascribed to the trapping of highly ionized macroparticles of micrometer size. A detailed model of dust trapping has been developed in [3, 4, 5]. Although the theory provides a reasonable scenario for the observed lifetime disruptions some aspects lack a satisfactory explanation. In particular, thermal stability of such particles is incompatible with high currents as operated in B factories [7] and more generally the source of dust and the mechanism of capture is unknown.

Earlier periods of electron operation at HERA and DORIS have been affected by severe beam lifetime breakdowns [8]. Integrated ion-getter pumps have previously been identified as potential sources of dust particles [6, 9]. Since then the vacuum systems of both storage rings have changed significantly and most of the ion-getter pumps have been replaced. The remaining pumps of this type in HERA are placed below the vacuum vessel except for those in spin rotator sections where they are placed above the vacuum chamber, however, with a 90° elbow and an additional filter to protect the vacuum chamber. Those in DORIS are placed inside the bending magnet vacuum vessels. Notwithstanding these improvements, sudden drops in beam lifetime during electron operation are still observed (see figure 1) and the electron beam lifetime still represents an issue.

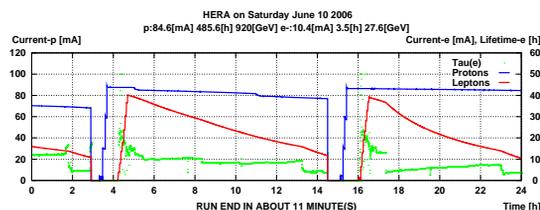


Figure 1: Overview of HERA operation. The last run exhibits a breakdown of beam lifetime typically ascribed to dust trapping.

We report on observations of beam lifetime breakdown most likely caused by dust trapping during the last periods of electron operation at HERA and from the electron test run at DORIS [10]. We invoke the theory of dust trapping for computer simulations and present results from tracking performed with various initial conditions and at different beam currents and filling patterns. We consider particles consisting of SiO₂ since those are thermally most stable and this material has been found in the vacuum pumps.

MODEL

Dynamics and Stability. The dust particle moves in the periodically time dependent potential of Gaussian bunches determined by the filling pattern and the potential of gravity. The beam force is modelled as delta function kicks. In the vicinity of the beam we use the Basseti-Erskine form of the field while for the far field we use a point charge approximation. For the benefit of closed expressions for the asymptotic field of the beam and the dust particle including mirror fields we choose the simplified geometry of two infinite perfectly conducting parallel planes as (vertical) aperture limitations. We consider the full twodimensional transverse dynamics but neglect the longitudinal.

Retaining the full time dependency allows to address aspects of stability in conjunction with the filling pattern. A *critical mass to charge ratio* above which all dust particles are expected to be stable is known from linear stability analysis. Below this critical value there are alternating regions of stability and instability until for very small values all particles are expected to be unstable. In many storage rings the dust particle frequency of oscillation is much smaller than the revolution frequency thereby smoothing the effective potential and the dependency on the filling scheme is spurious. Our tracking results indicate that the frequency of oscillation is at least of the same order of magnitude as the revolution frequency in HERA. The particles move harmonically within the linear region of the beam force. Hence, a dependency on the filling pattern is not ruled out.

Charge, Temperature and Beam Lifetime. The dust macroparticle is assumed to be initially ionized by (scattered) synchrotron radiation. An initial charge of 10 to 100 times the elementary charge is enough to drag the particle from near the chamber wall into the beam. Once the particle reaches the vicinity of the beam it becomes highly ionized due to collisions with beam electrons.¹ This ionization competes with a discharging process due to field enhanced thermal ionization of evaporated neutral atoms where the

¹The effect of synchrotron radiation is negligible compared to the ionization by the beam.

electrons are captured by the positively charged dust particle. This process is strongly temperature dependent. The particle is heated due to energy deposition of beam electrons and is cooled by thermal radiation. The heating rate is considerable and the dust particle reaches temperatures above 1500 K within a few milliseconds. This heating rate entails thermal instability of dust particles in storage rings operated at high beam currents unless the particle oscillates at large amplitudes [7]. Cooling due to thermal radiation deviates from pure black body radiation and is more accurately described by Mie theory.

The dominant process determining the beam lifetime in case of a trapped dust particle is loss of off-energy electrons. The beam electrons loose energy primarily due to bremsstrahlung in the field of the nuclei. The cross section for this process is given by the Bethe-Heitler formula. Another process influencing the beam lifetime is bremsstrahlung in the field of the dust particle itself, a process baptized duststrahlung in [5]. It becomes important for highly charged macroparticles.

RESULTS FROM SIMULATIONS

Simulations of dust trapping have been performed exploring the influence of various initial conditions and different beam parameters on the trapping process. Figures 2 and 4 summarize tracking runs for a particle of characteristic size ($0.7 \mu\text{m}$). The corresponding dust particle charge and temperature as well as the resulting beam lifetime² are depicted in figures 3 and 5.

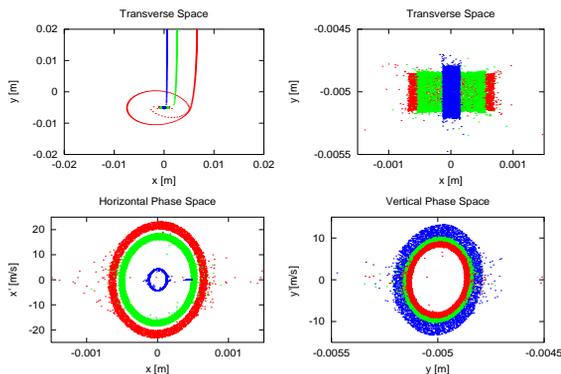


Figure 2: Tracking of a $0.743 \mu\text{m}$ SiO_2 dust particle released at a distance of 0.1mm from the top of the beam pipe and at different horizontal positions. The beam has a vertical offset of -5mm and the current assumed is 45mA filled in 150 bunches. The beam size is $\sigma_x = 1.2\text{mm}$ and $\sigma_y = 0.35\text{mm}$.

The tracking runs show stable particle capture for a large range of initial conditions and beam parameters. The temperatures reached by the macroparticles are comparable to the melting point so that the problem of thermal stability

²An initial beam lifetime of 12 hours is assumed. This is typical for HERA electron operation.

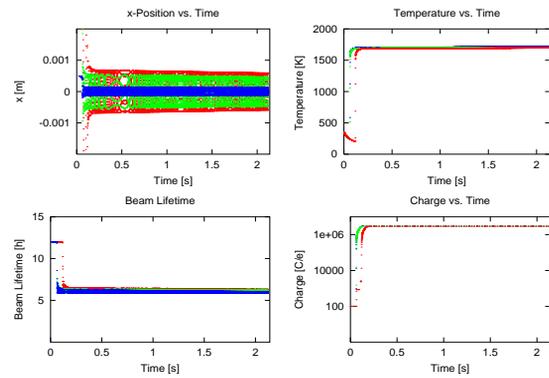


Figure 3: Dust particle parameters and beam lifetime for the tracking depicted in figure 2.

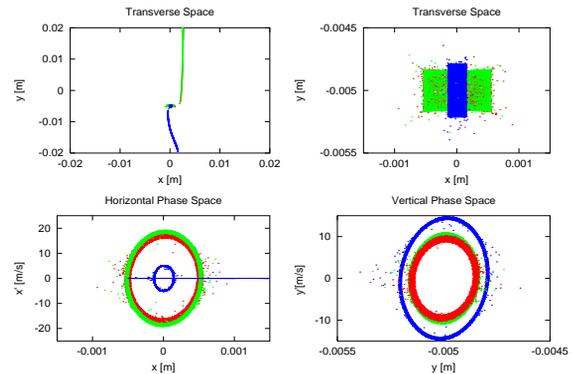


Figure 4: Tracking of a $0.743 \mu\text{m}$ SiO_2 dust particle released at a distance of 0.1mm from the top of the beam pipe and with a beam current of 45mA in 150 bunches (red) and 42mA in 180 bunches (green). The results for a particle of the same size released at a distance of 0.2 mm from the bottom of the beam pipe are plotted in blue. The beam current is again 45mA in 150 bunches. The beam size is as in figure 2.

is still an issue. No stable large amplitude oscillations as advocated in [7] have been found in the parameter regime tested. Even when starting with considerable initial velocity the resulting amplitude is quickly damped below one sigma. Tracking runs with different particle sizes exhibit no dependency on the filling pattern although the particle motion evolves almost entirely in the linear regime of the beam force. The dynamically arising mass to charge ratios lie above the critical value of stability.

HERA AND DORIS

HERA Electron Operation. HERA luminosity operation using electrons was taken up in December 2004. After a start-up phase HERA was operated with 120 bunches filled until February 2005 and then switched to 150 bunches.

Figure 6 shows the average lifetime of the electron beam in HERA in 2005. Points marked in magenta represent runs with sudden breakdowns of beam lifetime. The aver-

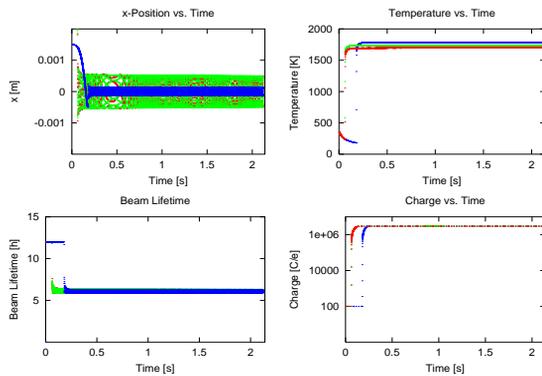


Figure 5: Dust particle parameters and beam lifetime for the tracking depicted in figure 4.

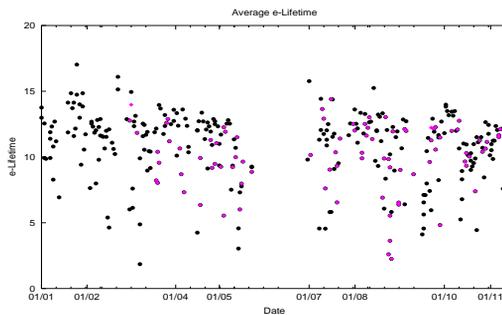


Figure 6: Average electron lifetime in the period of electron operation 2005. Points in magenta mark runs with sudden breakdowns of beam lifetime. Operation with mirror tunes in June 2005 is excluded from this figure.

age lifetime of runs exhibiting a lifetime breakdown lies in most cases well within the typical range of the average lifetime reflecting the fact that the electron lifetime problem has only moderately occurred in this run period. Evaluating the data more closely it can be observed that lifetime events are likely to occur in series and in particular after opening and reassembling the vacuum system. The absence of lifetime breakdowns in the first six weeks of operation in 2005 can probably be traced to the moderate intensity filled in 120 bunches. A correlation between the current filled and the average beam lifetime is plotted in figure 7. Runs exhibiting sudden breakdowns of beam lifetime are rare below a current of about 33mA. However, this does not imply that such breakdowns are bound to happen at intensities above a certain threshold. Indeed, lifetime events have been observed at currents well below 20mA! This is unexpected but not in contradiction with simulations where the trapping process shows no significant dependency on the beam current.

Electron Test Run at DORIS. To investigate the current conditions of running DORIS with electrons the operation has been switched from positrons to electrons in the time from the 4th to the 16th of August 2005 [10]. After an initial period of 4 days with frequent high beam losses the

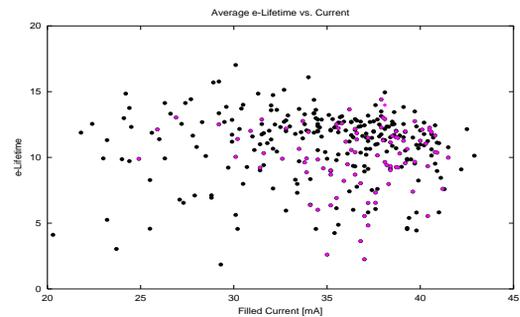


Figure 7: Average electron lifetime plotted versus the current filled. Points in magenta mark runs suffering from breakdowns of beam lifetime.

conditions stabilized at loss rates in the range of 5 to 15 % per hour³ with a mean value of 10 %. This loss rate is about 40 % larger compared to positron runs.

Different filling patterns have been tested to investigate a correlation with the rate of lifetime events. This includes operation with 2, 5 and 10 bunches separated by different gaps, from half ring empty to equally distributed. No significant effect on the beam lifetime has been observed during these tests. This is in accordance with expectations since the revolution frequency in DORIS is high compared to the expected oscillation frequency of dust particles.

In summary, the test run demonstrates that the conditions for electron operation have improved since earlier periods. This is likely to be correlated with the improvements in the vacuum system, but still frequent lifetime reductions have been observed resulting in a reduced performance.

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³The loss rate has been normalized to the full current of 140 mA assuming a linear rise of the vacuum pressure with the stored current.