THE ELECTRON BEAM LIFETIME PROBLEM IN HERA

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Abstract

The electron beam lifetime in the HERA storage ring is not only uniformly lower than the positron beam lifetime, but the electron beam lifetime curves display complicated structures not present in the smoothly behaved positron beam lifetime curves. Summaries of characterising quantities are presented for large numbers of runs in 1993 and 1994, enabling the identification of trends in the beam lifetime behaviour.

The lifetime reduction seems to be due to many discrete lifetime reduction events. The lifetime achieved at given current depends in a complicated (and stochastic) manner on the filled current, energy and integrated ion getter pump voltage. The properties of the lifetime problem are overwhelmingly consistent with the capture of material by the electron beam (most likely dust particles of size 0.1-1μm) which – being then highly positively charged – scatters beam electrons. The source of this material, or the mechanism of its liberation from the chamber or pump walls, is not entirely understood.

Moves towards curing the electron beam lifetime problem are discussed.

I. INTRODUCTION

The lifetime τ of a particle beam of current i at any instant is given by the local exponential decay law $\mathrm{d}i/\mathrm{d}t = -i/\tau$. The lifetime of leptons in the storage ring HERA is expected to be limited by bremsstrahlung from residual gas, and is expected to increase smoothly with reduced current, i.e.with reduced synchrotron radiation induced gas desorption.

In August 1994 positron operation was introduced at HERA, with a notable improvement in the beam lifetime. Similarly, for the DORIS storage ring the switch from electron to positron operation in March 1994 yielded a significant improvement in the operation. In Fig. 1 we see examples of electron and positron runs from HERA. Unexpected jumps and variations can be clearly seen in all electron lifetime curves, whereas the smooth lifetime behaviour for positrons is determined by residual gas. This limitation of the electron lifetime is known as the *electron beam lifetime problem*, and is believed to occur in certain other electron machines in a similar manner.

We present here a brief summary of the major symptoms and properties of the problem in HERA, and discuss moves towards its cure. For an extensive investigation and interpretation of HERA lifetime curve data see [1], [2]. For a discussion of simulations of the dynamic and thermal stability of dust particles of various composition trapped in the HERA electron beam see [3], [4].

II. CHARACTERISTICS OF THE PROBLEM

In Fig. 2 the run-by-run sequence of HERA electron and positron beam lifetimes from March 1994 to August 1994 are shown at various beam currents. The positron runs were very smooth, and the lifetimes achieved from one run to another were very reproducible; variations in the positron lifetimes are almost entirely due to variation in chamber pressure during a vacuum pump assessment programme. The electron lifetimes, however, are much poorer, and vary greatly both within each run and from run to run. A satisfactory explanation of the phenomenon must not only explain these data, but must also explain properties of the beam *lifetime curves* that recur, and it must be consistent with experimental observations of the effect of varying the ion pump voltages, the energy, and the filling current.

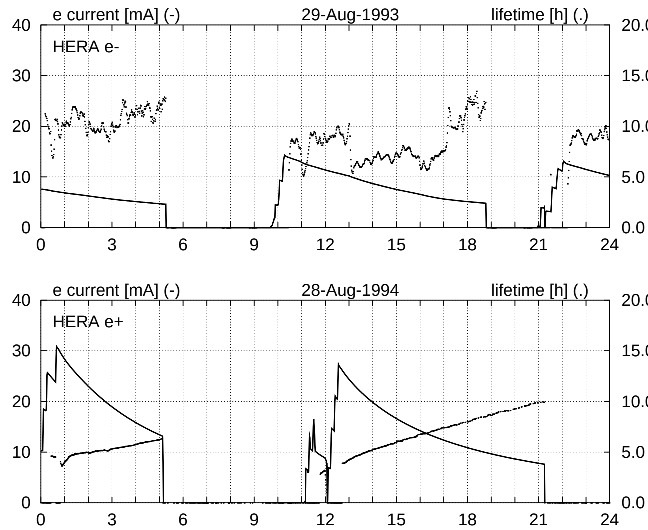

Figure 1. The current in mA (left scale) and and lifetime in hours (right scale) for a typical HERA $e^-$and e^+runs is shown. It is clear that the beam lifetime behaviour for electrons departs from that expected due to residual gas alone.

A. Properties of lifetime curves

The captured dust particle hypothesis in its simplest form predicts abrupt changes in the beam lifetime as particles are captured by (or lost from) the beam. Sudden increase and decreases are seen, however examination of the lifetime curves reveals complicated structures not present under positron operation, including oscillations, increases, and decreases with timescales from minutes to hours. In general, the electron beam lifetime behaviour in HERA is difficult to quantify. Some of the more curious observations are presented:

The electron beam lifetime often drops towards or at the end of the ramp from 12GeV to 27GeV. In Fig. 3 we see an example of the lifetime variations during the ramp from 12GeV to 27GeV. Synchrotron radiation may play a role in the electron lifetime problem.

In Fig. 4 we see a gradual decrease in the lifetime over the first one or two hours of the run (after the rapid ramp from 12GeV

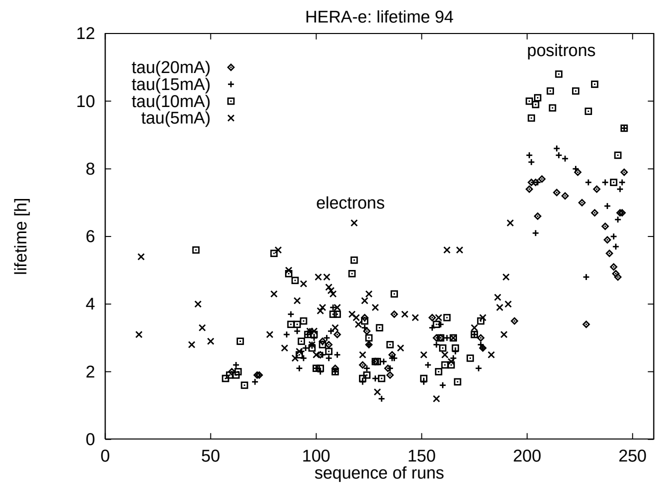

Figure 2. HERA electron and positron beam lifetimes in from March to August 1994 at current values i = 5, 10, 15, and 20 mA. The run for run sequence is shown.

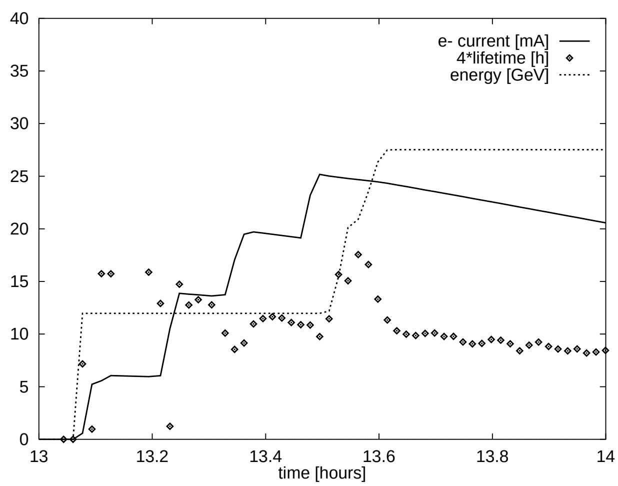

Figure 3. An example of the HERA electron beam lifetime development during the ramp from energy 12GeV to 27GeV for electrons. The current, lifetime and energy are shown against the time in hours. The electron beam lifetime tends to peak during the ramp and then drop.

to 27GeV has been performed). This effect can be seen in over 50% of the electron beam lifetime curves in 1994 and frequently in 1993. Similarly, gradual *increases* in the lifetime are often observed at low current values.

There is a strong correlation between the filled current and the degree to which the lifetime is limited later in a run (Fig. 5). As argued in [2], the statistical distribution is consistent with a discrete many-event model, whereby the probability of a particular lifetime reduction event occurring increases with filled current, and up to 10 lifetime reduction events occur for high current fillings. At very low current fillings lifetime reduction events are unlikely, so that positron beam lifetimes are often obtained. The behaviour seen in Fig. 1 is typical of smaller current fillings, and is perhaps due to the capture and escape of one or two dust particles, whereas for higher current fillings such as Fig. 4

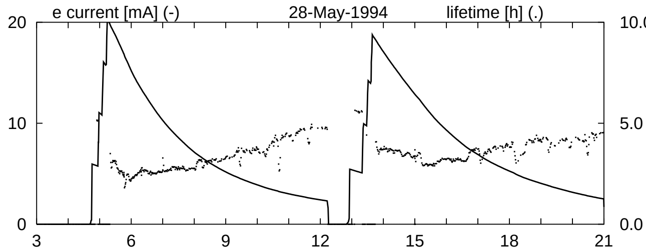

Figure 4. The electron lifetime frequently decreases gradually at the beginning of a run.

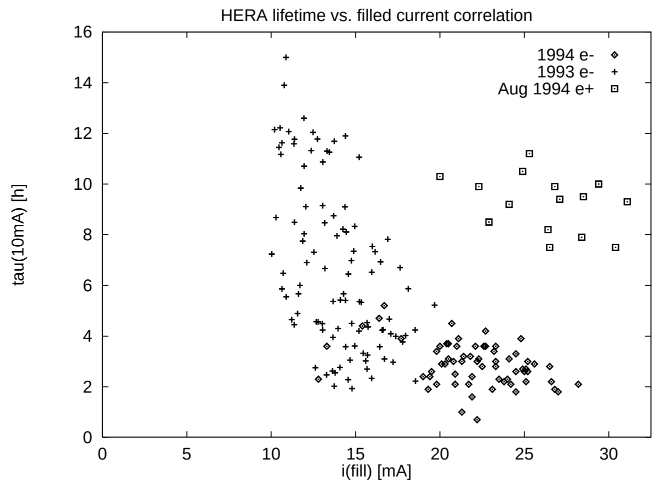

Figure 5. The lifetime in hours at beam current 10mA is plotted against the filled current for HERA electron runs in 1993 and 1994, and for positron runs in August 1994.

the lifetime reduction is more severe, and the lifetime does not recover at low current to values obtainable with positrons.

B. Results of experimental investigations

Many experimental observations are consistent with the capture of a micro particle of size $\leq 1\mu m$ or of a small number of particles with equivalent total mass:

The lifetime problem is independent of the tunes $Q_{x,y,z}$, and the incoherent tunes do not change during sudden drops in the lifetime; Electron loss monitors show that sudden drops in the lifetime are accompanied by strong local loss-rate increases (see Fig. 6, [5]); Spikes briefer than a few milliseconds and events of a few seconds duration – which may be due to the brief capture of dynamically unstable dust particles – are often seen in the bremsstrahlung detectors at the experiments H1, ZEUS and at the HERA polarimeter during electron runs.

The integrated ion pumps of HERA are strongly implicated in the HERA electron beam lifetime problem, which is known to be more severe at high integrated ion pump voltages. Indeed irreversible electron beam lifetime reductions have been induced in both PETRA and DORIS by momentary increases of the pump voltages. A significant improvement in the lifetime was achieved in 1992 by the removal of a single culprit pump. Arcing in the ion pumps has been observed at high voltages and is promoted by the presence of strong synchrotron radiation. It has been proposed that such arcing could throw dust particles

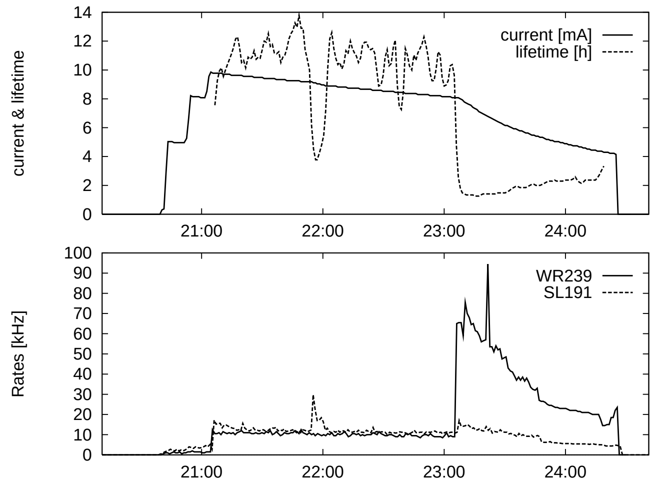

Figure 6. Lifetime reduction events correlate well with losses seen in the HERA electron loss monitors. In the above example from 11 Oct 1994 the brief disruption of the lifetime and current at time 21:55 is seen in loss monitor SL191, and the irreversible disruption at 23:05 is seen in monitor WR239.

into the vacuum chamber. The details of how the beam, synchrotron radiation, and the pumps interact in the complicated physical environment of the vacuum chamber to cast material into the beam are not understood.

III. TOWARDS A CURE

A. Beam excitation

It has been observed that transverse beam oscillations at various frequencies can beneficially affect the reduced electron beam lifetime in HERA. A computer simulation of a $1\mu m$ trapped dust particle indicates that the lifetime can be significantly improved by targetted transverse excitation of the beam (see Fig. 7). A dust particle trapped in the non-linear potential due to a Gaussian beam electron profile will have a well-defined oscillation frequency only for oscillation amplitudes small compared with the beam width. To obtain effective increase of the simulated dust particle's oscillation amplitude the beam excitation frequency must be swept from above the dust particle's `linear-region' oscillation frequency in the kHz range. Trials of this method are to be performed in June 1995 by controlled sweeping of a transverse feedback kicker, to see whether irreversible improvement of the lifetime can be obtained.

B. NEG pumps

Although the lifetime problem appears worse for high ion pump operation voltages, the reduction of the pump voltage from the usual 5kV to very low values is not a satisfactory solution, since measurements during positron operation showed that the chamber pressure obtained under 3kV pump voltage itself delivers unsatisfactory beam lifetime. The trial installation and assessment of `zero-voltage' non-evaporative getter (NEG) pumps has been planned for the 1995/1996 winter shutdown. The HERA electron loss monitors permit measurement of the removal of lifetime reduction events in a region installed with NEG pumps.

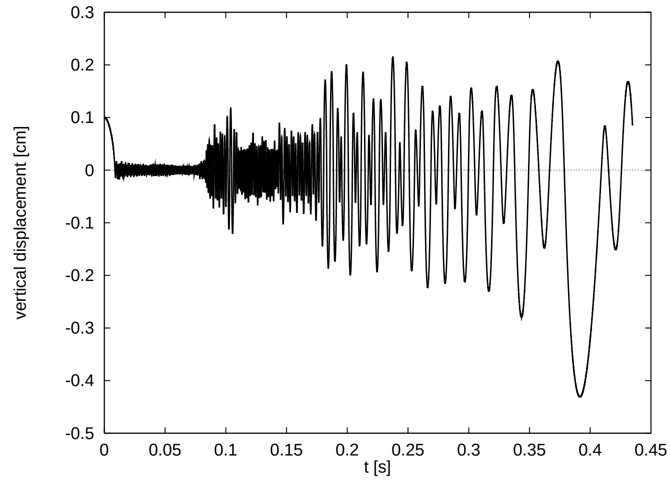

Figure 7. A simulation of the expulsion of a trapped $1\mu m$ dust particle from the HERA electron beam by sweeping a transverse beam kick through kHz frequencies.

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