HOW MUCH PUMPING DOES AN ELECTRON STORAGE RING *REALLY* NEED?

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Abstract

HERA was designed for the collision of protons with electrons and positrons. For the physics program it is essential that the collider experiments can take data with both sorts of leptons. In contrast to operation with positrons, which is unproblematic, running with electrons is characterized by a drop of the lifetime while the energy is ramped from 12 to 27.5 GeV. This beam lifetime instability is related to the operation of the integrated ion sputter pumps. The problem should be solved now after the exchange in the Winter shut down 1997/98 of the integrated dipole ion sputter pumps for passive NEG-pumps.

During machine shifts at the end of the ‘97 run the high voltage of all dipole pumps in the electron storage ring was switched off to imitate NEG-pump operation. The remaining nominal pumping speed in the arcs was about 15 %. Surprisingly during subsequent runs with electron currents of up to 40 mA, improved lifetimes of about 5 hours were observed. The results of the operation with electrons are presented in detail, together with possible consequences for the vacuum systems of future electron storage rings.

1 INTRODUCTION

The **H**adron **E**lectron **R**ing **A**ccelerator HERA is a double ring accelerator complex at DESY in Hamburg. Electron and proton storage rings have been built in a common tunnel fifteen to twenty meters under ground. The tunnel consists of four straight sections connected by four arcs. Underground experimental halls are located in the middle of each straight section. A simplified survey of the complex including the pre-accelerators is shown in Figure 1. HERA was conceived as an electron-proton collider [1]. Two of the four interaction regions are laid-out for colliding beam detectors. The high energy physics experiment H1 is located in the hall North, and the experiment ZEUS in the hall South.

Recently, the two other straight sections have been modified to accommodate internal target experiments. HERA-B will study B-mesons produced in the collisions of halo protons with wire targets. At hall East an internal gas target and a pair of spin rotators were built for the experiment HERMES into the electron machine. One can see in Figure 4 the change in the positron beam lifetime due to the internal helium target; the effect of the target used at the time was between 30 and 50 hours.

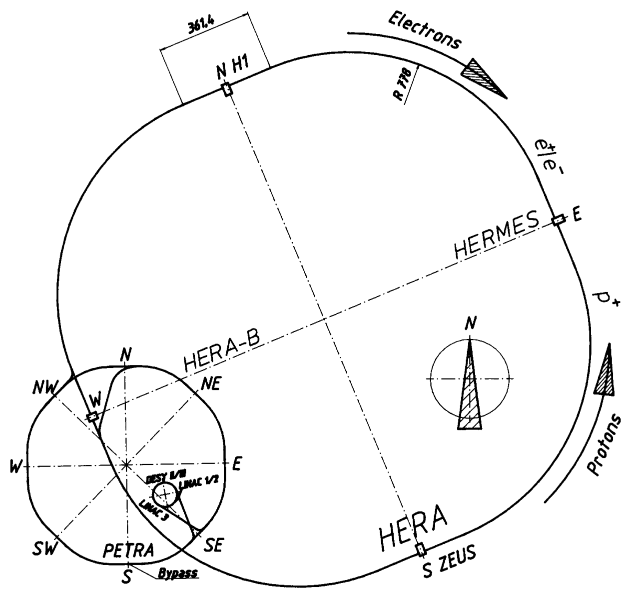

Figure 1: Layout of the electron proton collider HERA.

	e^+ / e^-
Circumference C	6335.82 m
Injection momentum p_0c	12 GeV
Design momentum pc	30 GeV
Number of bunches N	210
Number of buckets N_B	220
Average beam current I	58 mA
Length of straight sections L	4×361.4 m
Length of a half cell l	11.755 m
Length of the dipole yoke l_D	9.135 m
Length of the quadrupole yoke l_Q	0.76 m

Table 1: Main parameters of HERA electron machine.

The magnets of one half cell of the electron machine are assembled in a module [2]. The four arcs consist of four hundred modules. They have been prepared outside of the tunnel, including the vacuum system. A single vacuum chamber spans the total module length. The chamber is brazed of various 4 mm profiles made of the copper alloy CuSn2 [3]. The water-cooled chamber walls absorb synchrotron light more efficiently than aluminium and therefore the radiation shielding problem is reduced. Any additional lead shielding needs no special cooling arrangement. The vacuum system is mainly pumped by integrated ion sputter pumps that use the field of the dipole and quadrupole magnets. The beam pipe has a cross section of $80\ \mathrm{mm} \times 40\ \mathrm{mm}$.

Figure 2 shows the cross section of a dipole vacuum chamber. A longitudinal brazed channel for the pump extends over the whole length of the bending magnet. The quadrupole magnets are equipped with similar pumps located on top and bottom of the beam pipe. Both integrated pump types are designed to give a maximum linear pumping speed of about 30 l/s m. The vacuum system of the straight sections is made mainly from the same copper profiles.

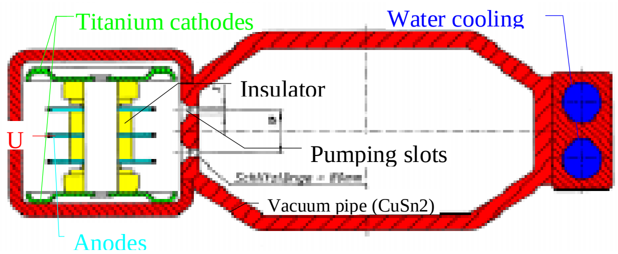

Figure 2: Cut through a HERA dipole vacuum chamber with an integrated ion sputter pump.

2 ELECTRON BEAM LIFETIME

In HERA the operation with electrons is much different from the operation with positrons [4,5]. In 1993, the first year of HERA luminosity operation, a maximum total beam current of only about 3 mA at 27.5 GeV was possible [6]. At higher values the lifetime dropped below one hour. During machine shifts at the end of the '97 run two striking dipole chambers with integrated ion sputter pumps were identified in the spin rotator section East [7]. The beam pipes were replaced by chambers without pumps. This modification allowed operation in the following year at higher currents with improved beam lifetimes. Nevertheless the lifetime could still not be explained by the residual gas pressure. In Figure 3 is shown the electron current and beam lifetime during luminosity operation at the beginning of the year 1994.

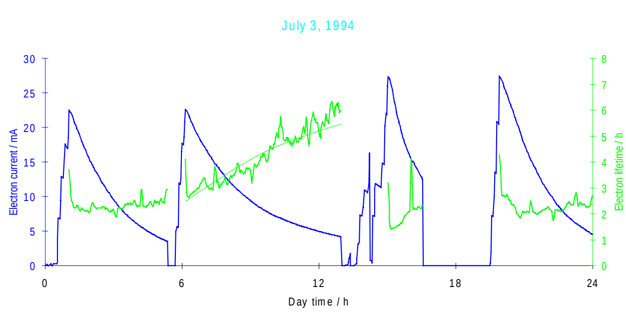

Figure 3: Luminosity operation with electrons in 1994.

Up to July 1994 data had been taken with electrons. Afterwards luminosity operation was continued with positrons. Immediately after the change of the polarity the lifetime of the positron beam was much higher than that with electrons. Through this the integrated luminosity could be improved [8].

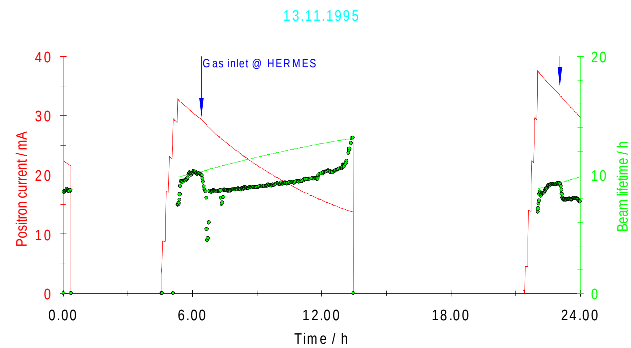

Figure 4: Change in e^+ lifetime due to the helium target.

Figure 4 shows the beam lifetime versus positron current during luminosity operation. The gas was switched off at the beginning and end of the run. One expects that the total lifetime τ depends on the current i as:

$$(1) \qquad \frac{1}{\tau} = \frac{1}{\tau_0} + \frac{1}{\tau_{He}} + \frac{i}{\lambda},$$

where τ_0 is the beam lifetime for small currents and τ_{He} the fraction used by the internal helium target at HERMES. λ over i is the beam current dependent lifetime. Due to a cleaning effect the parameter λ decreases with increasing circulating charge (total dose). This can be described by the following empirical formula:

$$(2) \qquad \lambda = const \left(\frac{D}{D_0} \right)^{\alpha},$$

where $D = \int idt$ is the circulating charge. The beam current dependent pressure rise has been measured in the HERA electron machine, from which α=0.875 was determined. In the year 1995 the HERA electron machine accumulated a circulating charge D of 43 Ah. After that time the synchrotron light desorption coefficient λ obtained by fitting runs was 700 mAh (see Table 2). This value is consistent with that expected from Eq. (2).

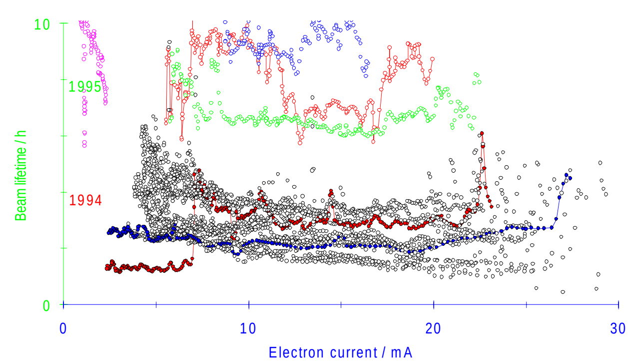

Figure 5: Beam lifetime versus electron current.

Figure 5 shows the electron beam lifetime versus current during luminosity operation in 1994 and during machine shifts in 1995 with some dipole pumps switched off. During normal electron luminosity operation and for higher beam intensities the lifetime drops to values between two and four hours during or shortly after the energy is ramped from 12 to 27 GeV and then remains nearly constant. Thus neither the lifetime behavior of Eq. (1) nor the cleaning effect described by Eq. (2) has been observed during electron operation.

The current understanding of the lifetime problem with electrons is as follows: During operation the integrated ion sputter pumps in the main dipoles release micro particles that can be positively ionized by the circulating beam. The negative potential of the electron beam traps the particles and the beam lifetime is reduced by bremstrahlung. The probability for trapping a micro particle depends on the beam intensity and the energy. The observation that breakdowns can be triggered by switching the high voltage of the pumps supports this model. Loss measurements [7] were performed with electrons in 1995, during which a problematic section was found. The high voltage of the dipole pumps in this section was switched off, and afterwards, runs with electron currents up to 20 mA with improved lifetime were observed, Figure 5. The performance could be improved, but the lifetime of the operation with electrons was not as good as with positrons.

During the winter shut-down 1995/1996 this vacuum section was equipped with NEG strips. The remaining pumps were exchanged for NEG, in 1997/98.

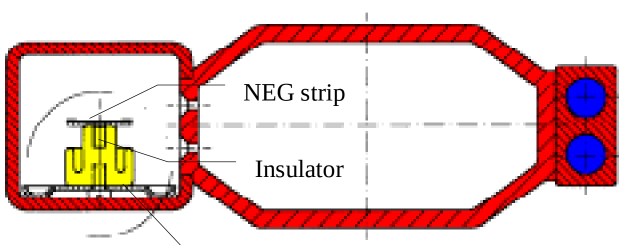

Figure 6: Cut through a HERA dipole vacuum chamber with an integrated **N**on **E**vaporable **G**etter-pump.

Figure 6 shows a cut through a dipole vacuum chamber with an integrated NEG-pump. NEG pumps are sorption pumps for active gases and ultra high vacuum. The getter material is an aluminium zirconium alloy that is pressed onto a constantan strip. It can be activated after venting and regenerated at a minimum pumping speed by electrical heating. For pumping of inert gases ion getter pumps are necessary.

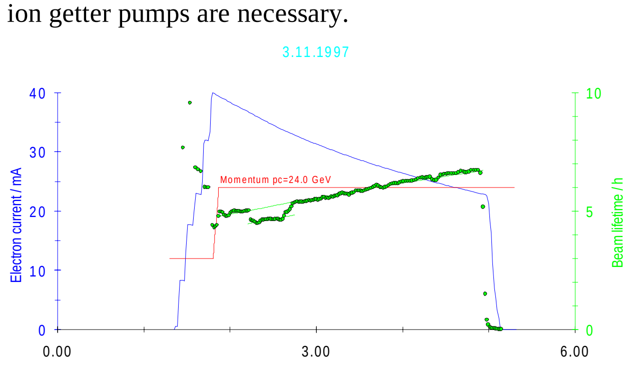

Figure 7: Electron operation with dipole pumps off.

During machine shifts at the end of last year the high voltage of all dipole pumps in the electron storage ring were switched off to imitate the NEG-pump operation. The remaining nominal pumping speed in the arcs was about 15 %. Surprisingly, during subsequent runs with electron currents of up to 40 mA, improved lifetimes of about 5 hours were observed (see Figure 7). In a first order approximation one would expect a factor of ten smaller lifetime. Half of the pumping capacity remained after switching off the high voltage. This could be explained by the pumping capacity of the sputtered titanium and of the cleaned surfaces of the chamber walls.

Operation	e^+	e^+	e^-
HV Dipole pumps	On	Off	Off
τ_0 / h	17	12.2	15.3
λ / mA h	700	311	274

Table 2: Comparison of lifetime parameters for different operation modes.

3 CONCLUSION

The "HERA problem" with the strange behavior of the electron lifetime isn't understood completely but we are confident that it will be overcome by the use of mainly passive vacuum pumps. The lifetime of a stored electron beam in HERA could be improved by switching off the high voltage of the integrated dipole pumps. After switching off all dipole pumps around the machine the lifetime of the electron beam was nearly as high as that expected for positrons. "How much pumping does an electron storage ring REALLY need?" The answer is that an electron storage needs minimal passive pumping if the vacuum system is leak tight and well beam cleaned.

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