ELFE@DESY: SLOW EXTRACTION FROM HERA

M. Gentner, D. Husmann,
Bonn University, Physics Institute, Nussallee 12, 53115 Bonn, Germany
P. Nghiem, J. Payet, A. Tkatchenko,
Laboratoire National Saturne, CE Saclay, 91191 Gif-sur-Yvette Cedex, France

Abstract

The feasibility of the conversion of the HERA electron ring into a pulse stretcher for a 15-25 GeV injector linac has been studied. Such an injector would be available if a linear collider will be built at DESY. The linac pulses will be stretched to a c.w. beam by slow extraction from HERA. This paper describes the proposed extraction scheme and gives estimations of the stretcher performance in terms of duty factor, emittance and energy spread of the stretched beam.

1 THE ELFE@DESY PROJECT

ELFE (*E*lectron *L*aboratory *F*or *E*urope) is proposed as a 15-25 GeV, 30 μA c.w. electron beam facility for nuclear physics experiments[1]. In the past different approaches have been studied to provide such a beam, e.g., a polytron or a recirculating linac[2].

A new approach has been proposed during the conceptual design studies of a DESY linear collider[3]. If a 500 GeV linear collider linac will be installed at DESY, the first section of this linac could be used to inject a 15 to 25 GeV beam into the HERA electron ring. The ring would then act as a stretcher for the short linac pulses (in the case of TESLA the pulses are 800 μs long at a repetition rate of 10 Hz) to create a quasi-continuous beam. Figure 1 shows the schematic layout of this facility.

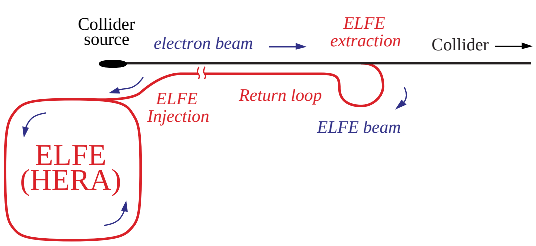

Figure 1: ELFE@DESY schematic layout

The overall feasibility of the conversion of HERA into ELFE@DESY has been discussed in[4]. The main result of that paper is that *ELFE@DESY appears to be feasible*. There are various problems to make the facility work. For example the linac pulses have to be fitted into the HERA circumference, which needs a complex injection scheme.

Furthermore the ring has to be capable to hold currents up to 150 mA to stretch the injected charge to a 30 μA c.w. beam. To counteract the arising collective instabilities a good feedback system has to be installed[5].

And, also very important, a mechanism has to be applied which can ensure the extraction of a constant current from the ring. Details of the extraction mechanism are presented in the following.

2 EXTRACTION METHOD

The extraction methods used in currently operating electron stretchers (which work at energies below 4 GeV) have been checked for their applicability to ELFE@DESY. The two mainly used methods are:

- The stable horizontal phase space area near a betatron resonance is shrinked by ramping the tune towards the resonance in such a way that a constant rate of particles becomes unstable and is extracted.
- A constant rate of particles is pushed out of the RF buckets, for example by RF phase ramps. The particles outside the buckets subsequently loose energy, and with the chromaticity of the ring this energy drift is converted into a tune drift onto a betatron resonance.

In both cases the horizontally unstable particles move along separatrix branches towards an extraction septum. Mostly a sextupole-driven third-order resonance is used where the stable phase space has the shape of a triangle (Fig. 2).[1] During the movement on the separatrix branch the stepwidth increases rapidly, providing a stepwidth sufficiently high to cross the septum with few losses of only 1-2%.

Calculations and simulations show that the energy loss per turn in HERA is too large to enable the use of the second method. The longitudinally unstable particles loose energy too fast, so that they cross the resonant tune with only a small chance of getting extracted in a controlled way. So the extraction method of choice is the tune ramp method.

The disadvantage of the tune ramp method is the dependence of the optics on the ramp. The most obvious effect is the drift of the separatrix branches, which is proportional to the tune shift and results in a drift of the x' coordinates of the extracted particles. This can easily be counteracted by an appropriately ramped dipole near the septum.

Other effects are an alteration of the stepwidth of the particles at the septum, and a change of the chromaticity. These two parameters affect the emittance of the beam during extraction, but in ELFE@HERA the influence is less than 5%.

[1] Sometimes a combination of a second and fourth order resonance is used, but there is no apparent advantage.

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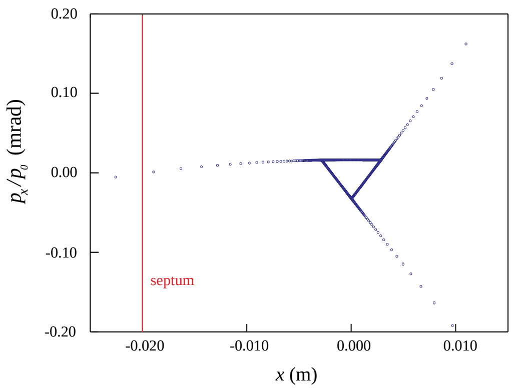

Figure 2: Separatrix triangle (with ELFE@DESY parameters)

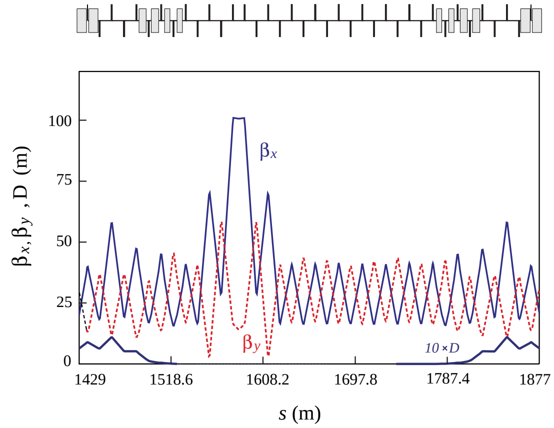

Figure 3: Straight section optics

3 TRANSVERSE OPTICS

To control shape and size of the separatrix area dedicated sextupoles are needed. The effect of a sextupole on the resonance strength scales with $\beta^{3/2}$, so these sextupoles should be placed within regions of high β functions. Likewise, to minimize the influence of the sextupoles needed for chromaticity correction on the resonance the phase advance per cell in the arcs should be near $60°$.

For an untilted triangle the phase advance between sextupoles and septum has to be $30°$ (modulo $120°$), and the α function at the septum should be zero. To achieve a small emittance of the extracted beam it is also desired to have vanishing ring chromaticity and a dispersion free beam optics at the septum, e.g. $\xi_x = 0$ and $D(s_{sep}) = D'(s_{sep}) = 0$.

Fortunately in the case of HERA the optics of the straight sections can be tuned nearly arbitrarily. So a beam optics has been designed to fulfil the criteria mentioned above. The betatron tunes, the extraction sextupole strengthes, the optical functions at the sextupoles and the septum, and the horizontal septum position have been chosen to get a stepwidth at the septum of 4 mm. This value is a good compromise between small emittance and small particle losses on the septum. Figure 3 shows the proposed optics of one straight section.

4 SIMULATION RESULTS

To get an estimation for the achievable performance of the machine in terms of duty factor, emittance and energy spread of the extracted beam a series of tracking simulations has been performed with MAD[6] and BETA. The tracking module of MAD fully includes the influence of synchrotron radiation, which in our case is important.

A small selection of the results is shown in Table 1. In the achromatic case the emittance is very small, but the energy spread is slightly larger than projected in[2]. By tuning the chromaticity the energy spread can be reduced, but then the emittance increases intolerably.

It has been demonstrated that by using an adaptive tune ramp shape control the machine can be emptied nearly completely, and an intensity distribution dependend duty factor of at least 90% can be reached. Taking into account the cycle timing and the filling structure of the ring the overall duty factor is reduced to nearly 80%.

5 ANALYTIC CALCULATIONS

The results of the tracking simulations have been counterchecked with analytic calculations. The emittance of the extracted beam as a function of energy, chromaticity and dispersion at the septum has been succesfully reproduced, as well as the reduction of energy spread by chromaticity change. Details can be found in[7].

The calculations are based on the analytic treatment of sextupole driven third order resonances. Without perturbations unstable particles move along the separatrix branches, in fact they are effectively pushed towards them. By approximating the resulting compression of the outgoing trajectories with exponential functions one is able to compute the effects of perturbing influences which push the particles away from the separatrix branches.

In the case of ELFE@DESY the main perturbation is the stochastic structure of the synchrotron radiation, which creates a random walk of the particles, and synchrotron oscillations in combination with non-zero chromaticity. In the latter case the separatrix branches are displaced periodically, and by the compression effect the particles follow these displacements, but with phase shifts and with smaller amplitudes.

6 SEPTA AND EXTRACTION CHANNEL

The first septum has to be as thin as possible to minimize particle losses. This suggests an electrostatic wire septum. The drawback of an electric septum is that the electrons can only be deflected weakly. Nonetheless with the help of additional magnetic septa it is possible to guide the electrons out of the machine.

Figure 4 shows a solution for the extraction channel with one electrostatic and three magnetic septa. The upper graph

energy [GeV]	horiz. chromaticity	ϵ_x/π (90% of beam) [mm·μrad]	$(\Delta p/p)_{FWHM}$ $[10^{-3}]$
15	zero	3.75 ± 0.16	1.19 ± 0.05
20	zero	6.76 ± 0.26	1.64 ± 0.06
25	zero	10.06 ± 0.37	2.01 ± 0.07
15	± 10	88.15 ± 3.11	0.92 ± 0.03
15	± 20	117.25 ± 5.23	0.69 ± 0.03
15	± 30	124.45 ± 7.09	0.48 ± 0.03

Table 1: Basic tracking results

shows the trajectory of a particle kicked by the electrostatic septum, whereas the lower graph includes the magnetic septa.

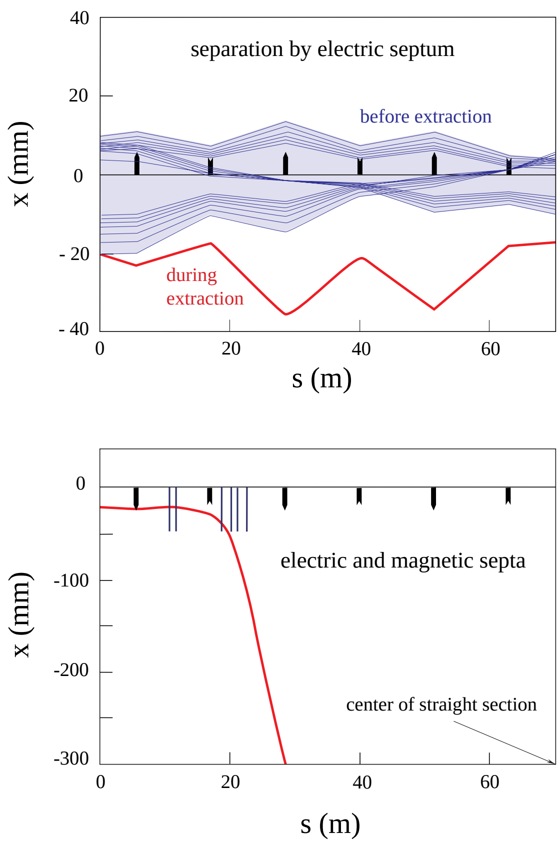

Figure 4: Extraction channel

The extracted beam leaves the ring vacuum chamber 20 m downstream the electrostatic septum. So, there is left a 40 m drift space to the center of the straight section, which should be enough for optical matching to the experimental target.

7 SUMMARY

It appears to be feasible to convert the electron ring of HERA into a stretcher for the pulses of a linear collider linac in the energy range of 15 to 25 GeV. The slow extraction from the ring makes use of a sextupole driven third order betatron resonance controlled by tune ramping. The extraction process has been extensively studied with tracking simulations and analytic models, to get estimations for the duty factor, the emittance and the energy spread of the extracted beam, and to find the optimal operation parameters of the ring.

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