On a Continuous Electron Beam Option at the TESLA and S-Band Linear Colliders

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1. Introduction

At DESY two approaches towards a next generation e+e- Linear Collider of 500 GeV centre-of-mass energy are presently under study, in international collaboration with many institutes and laboratories [1,2]. The TESLA approach uses superconducting cavities at a frequency of 1.3 Ghz and an accelerating gradient of 25 MV/m, whereas the S-Band approach is based on the well-known conventional 3 Ghz technology at a gradient of 17 MV/m. In both designs the linear accelerator would operate at a rather low duty cycle (0.4 % for TESLA, 0.01 % for S-Band). It has been suggested [3] to investigate the possibility of using the accelerator (or part of it) between the pulses for e+e- operation for other applications, in particular for driving an FEL in the Å-regime and for generating a continuous electron beam of 15-30 GeV for nuclear physics experiments. The latter application is discussed in this note. The emphasis will be on the TESLA approach, but some essential differences when using the S-Band design are also briefly described. In principle, a higher duty cycle, as required for this option, could be achieved by lowering the accelerating gradient and increasing the rf pulse length. This method is limited, though, since a fast change of the linac beam optics necessary to match the lower beam energy does not seem possible. In addition, the klystrons and modulators required to generate long low-peak power pulses would likely have to be different from the ones foreseen for the high energy collider. It is therefore suggested to use the linac in the low duty cycle mode and achieve the continuous beam by a pulse stretcher ring. If the Linear Collider is constructed at the DESY site, such an option could be realised at very low additional cost, since the existing HERA electron ring could be used as the pulse stretcher. In the following, the basic aspects of this approach to a continuous electron beam facility are discussed.

2. HERA-e as a Pulse Stretcher Ring

The HERA electron ring has a circumference of 6.336 km and is presently operated at an energy of 27.5 GeV in the e/p collider mode. The design beam current is 58 mA in 210 bunches (a recent report on the status of HERA is given in [4]). The most significant modifications necessary to convert HERA-e into a pulse stretcher concern the injection scheme, the rf-system and the resonance extraction required to provide a continuous external beam. We discuss here a parameter set comparable to the beam parameters foreseen for the first stage of the proposed ELFE project (i.e. a beam

energy of 15 GeV). At this energy, the required circumferential voltage in HERA could be reduced by about a factor of 10 compared to the present value of U_{rf}=125 MV. This would allow to drastically reduce the installed rf system and thus relax the problem of coupled bunch instabilities driven by rf cavity HOM's. It is assumed that a beam current of 150 mA can be stored, possibly even without the need for a multibunch feedback system if a cavity design with strong HOM damping is chosen (note that the B-factories under construction at SLAC and KEK have about an order of magnitude higher design intensities). In the case of TESLA, the ring would be refilled at a rate of 10 Hz, so that, if the entire beam is extracted between injections, an average current of about 30 μA results. The injection scheme has to take into account the rf-pulse length of the TESLA linac, which is foreseen to be 800 μs for e+e- operation. Assuming about the same pulse length for filling the stretcher ring implies that injection into HERA takes place over 40 revolutions in the ring. One way of accomplishing on-axis injection could be to devide the bunch train in the linac into 40 0.46 μs long "micro-pulses" spaced by the HERA revolution time (T_{rev} = 21.1 μs) plus a small gap (≈ 60 ns) for the injection kicker (see fig. 1). Wheras a kicker risetime of about 60ns seems feasible, the problem here is that this device has to provide 40 pulses at a rate of 47 kHz for one injection cycle. With a ring rf system operating at 650 Mhz every 2nd linac rf bucket is filled in the micro pulses. This scheme yields a fill in HERA with 40 batches of 300 bunches each and a bunch spacing of 1.54 ns (except for the 60 ns kicker gap between batches). Due to beamloading in the TESLA linac, the voltage drops over the length of one micro-pulse by about 0.6 % [5]. This can be compensated by an additional rf-system operating at a slightly different frequency (say, Δf=0.5 MHz) and a voltage of roughly 0.5% of the beam energy. The first 15 GeV of the TESLA e-linac, which would be used as the injector for the HERA ring, has to be operated at 15 Hz instead of 5 Hz for e+e- and stretcher ring operation in parallel. The required rf pulse power for the two additional pulses is only about one half of that required for the main pulse. Although some modifications in order to cope with the higher cryogenics load and the higher rep rate will be necessary, the technical components for this section of the linac are essentially the same as for the main part of the accelerator.

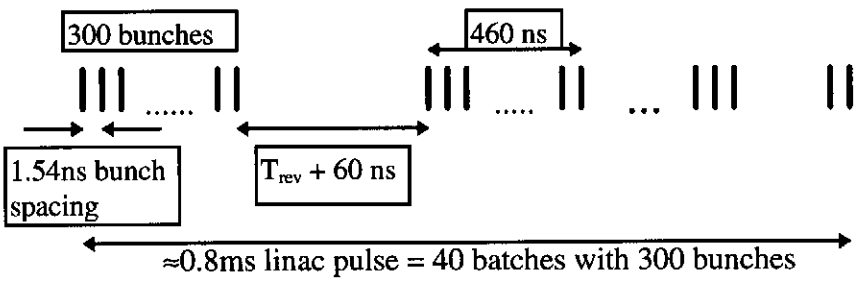

Fig. 1: TESLA linac pulse used to fill the stretcher ring

An overview over the parameters of the stored beam is given in table 1. It is expected that at the low bunch charge the horizontal emittance and the energy spread of the beam delivered by the linac are smaller than the equilibrium emittance in the

ring. Ideally, the injected emittances should be matched to the ring emittances. It is conceivable that this could be done by intentionally increasing the horizontal emittance (and the energy spread) using synchrotron radiation in the arc of the linac-to-ring transfer line.

E_{beam}	15 GeV
ΔE/revolution	7.7 MeV
P_{rad}	1.16 MW
U_{rf}	12 MV
I_{stored}	150 mA
n_b	12000
N_e/bunch	1.6×10^9
bunch spacing / ns	1.54 ns (+"kicker gaps")
$\varepsilon_{x,y}$	1.3×10^{-8} m / 0.6×10^{-9} m
norm. $\varepsilon_{x,y}$	3.8×10^{-4} m / 1.8×10^{-5} m
σ_E/E	0.052 %
filling rep. rate /Hz	10
av. extr. current / μA	30
duty cycle	>85 % (incl. gaps)

Table 1: basic parameters of HERA-e as a stretcher ring

The proposed scheme is sufficient to allow for experimentation with high density internal targets. However, an external beam is also highly desirable. This can be achieved with the well-known method of slow extraction by driving a 2nd or 3rd order resonance and using an electrostatic wire septum for extraction. A first test of this method has been done with a particle tracking simulation for the case of 3rd integer resonant extraction (see fig. 2). The strongly simplified model includes quantum excitation and radiation damping, a completely linear and uncoupled ring optics and a single sextupole to drive the resonance. With a 0.1 mm wire septum placed at a position with 100m beta function, an extraction efficiency of 98% was obtained. The calculated emittance of the extracted beam is $\varepsilon_x \approx 10^{-9}$ m under these idealised conditions.

3. Energy Variation and Upgrade to Higher Energy

A reduction of the stretcher ring operation energy should be straight forward. A potential problem could be the reduction of the coupled bunch instability threshold (if the ring can be operated at 15 GeV without feedback), so that the stored current may have to be reduced somewhat. Concerning the injector linac, a reduction of the energy

by up to about a factor of 1.5 should be feasible. An additional lower-energy extraction line from the linac may be used if a larger variation range is needed.

The assumptions made above for the stretcher ring are rather conservative concerning the required rf system. It is conceivable that with an upgraded rf system (the installed circumferential voltage has to be increased approximately with the 4th power of beam energy) an increase of the operation energy to about 25 GeV (or up to 30 GeV if the stored current is reduced) can be achieved. Besides higher investment and operating costs, the most critical accelerator physics issues in this case are coherent instabilities (due to the much larger installed cavity impedence) and the shorter radiation damping time in context with the resonance extraction scheme.

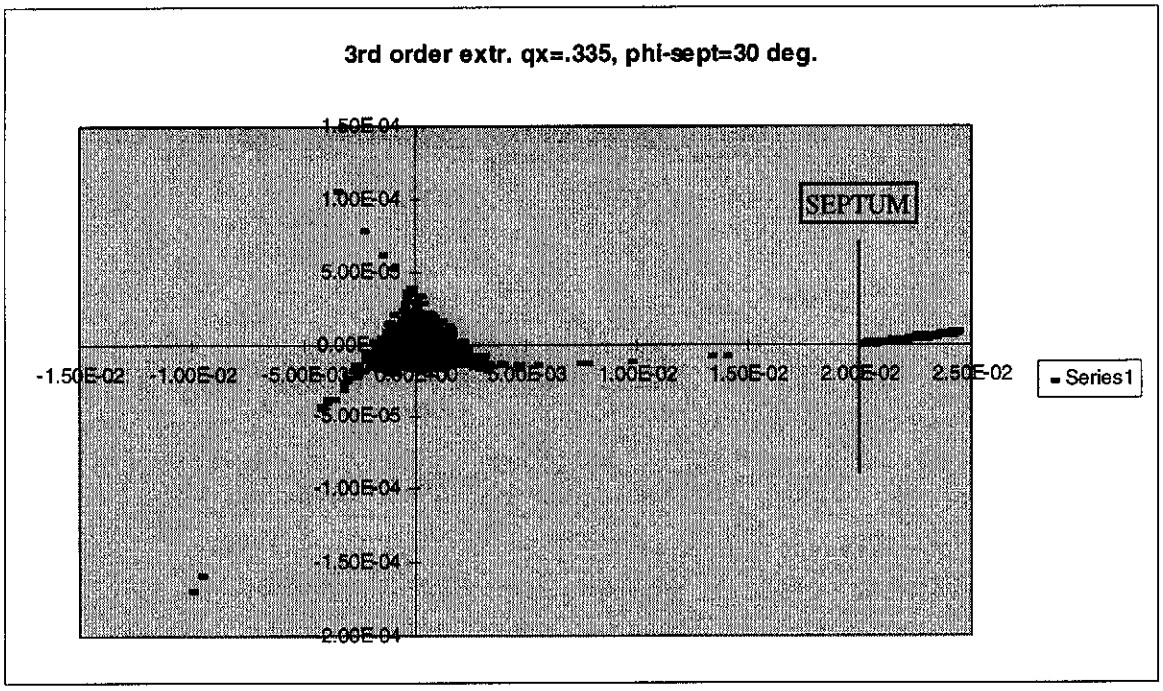

Fig. 2: Phase space at the extraction septum after tracking an ensemble of 2000 particles over 1000 revolutions. The hor. tune is 0.335, the beta-function at the sextupole and the septum (30 deg. downstream from the sextupole) 100m. Synchrotron radiation is taken into account, the ring is represented by a linear transfer matrix.

4. Comments on the S-Band Option

When considering the stretcher ring option with the S-Band Linear Collider approach, the shorter rf-pulse length (2 μs) must be taken into account. It is thus impossible to fill the entire ring with a single linac pulse. In principle one could increase the pulse length or the repetition rate in the first 15 GeV section of the S-Band accelerator by a large factor, but that would have a large impact on the linac

technology. The preferable solution is to fill and extract from the ring in a continuous fashion [6]. The required average current of 30μA can be achieved with a 50 Hz rep. rate and a pulse current of 300 mA, equal to the e+e- operation mode (this means that the first 15 GeV of the S-Band linac must operate at 100 Hz, using every 2nd pulse for filling the stretcher ring and for e+e- collisions, respectively). Every 6th rf bucket in the 3 GHz linac could be filled in order to match a 500 MHz ring rf system. The filling structure in HERA would consist of 10 2μs long batches of 1000 bunches each ($N = 3.8\times10^9$ p. bunch), separated by kicker gaps. Each batch is refilled every 10th linac pulse, i.e. every 200ms. One problem with this option is that the bunches in different batches have different intensities: the "old" ones have lost intensity due to the extraction process (and/or internal targets) while the freshly injected one has its full intensity. In order to produce a smooth extraction current, the extraction rate would have to be different for each batch of bunches (and also vary with time) which seems difficult to arrange. Furthermore, the bunch-to-bunch energy spread in the S-Band linac is large and cannot be easily corrected to the desired level of $< 0.05\%$. Another complication arises from the strong transient beamloading in the ring when a batch of 1000 bunches with $N = 3.8\times10^9$ electrons per bunch is injected. On the other hand, the injection kicker here has to operate at a rate of 50 Hz continuously, which seems to be easier than the device required for the TESLA approach.

5. Conclusion

The basic layout of a continuous electron beam option at a next generation Linear Collider presented in this paper can only serve as a first approach. Although there do not seem to be serious "show stoppers" at this level of investigation, many technical and accelerator physics questions still have to be addressed before a definite conclusion on the feasibility of such a facility can be drawn. It should also be mentioned that in the TESLA Linear Collider design the possibility of using the HERA ring as a positron damping ring is also still under discussion, which would, of course, exclude using HERA as a pulse stretcher. There is an attractive alternative for the damping ring, though (the so-called "dogbone" design [7]). Which way to go has to be decided on more detailed studies, including a cost estimate for the two damping ring versions. For S-Band, HERA would definitely not be used as a damping ring. However, as discussed above, there are some specific problems involved in using the S-Band linac as an injector for the pulse stretcher which must be addressed.

Finally, the integration of the electron beam facility into the overall layout of the collider has to be investigated. One possible arrangement, sketched in fig. 3, has the electron linac tangential to the HERA ring such that injection could take place in the straight section west of HERA. How extraction from the linac and transfer to HERA could be managed in this scheme has not been studied yet in any detail.

6. References

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[7] K. Flöttmann and J. Roßbach, Proc. EPAC, London 1994, Vol. I, p. 509.

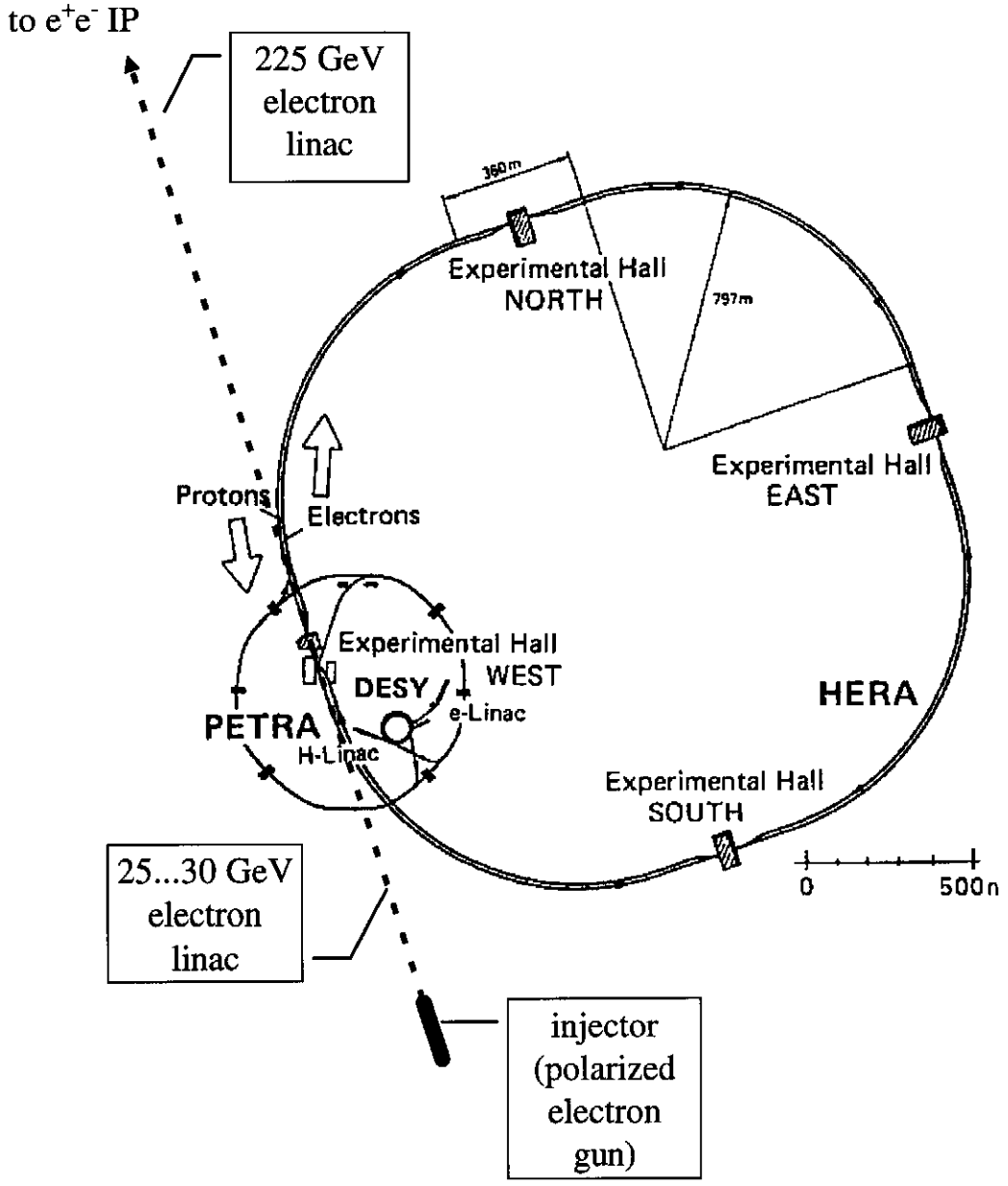

Fig. 3: Basic layout of HERA with the TESLA linac connected to the straight section west.