Improved Beam Stability with New Parameter Set for the S-band LinearCollider

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Abstract

With sufficient damping of long-range Higher Order Modes, the emittance dilution in the S-band Linear Collider is dominated by single bunch effects. We present an improved parameter set with reduced bunch charge which allows to relax the positioning tolerances in the main linac. The consequences for the other subsytems of the collider are also briefly discussed.

Introduction

The S-band approach towards a next generation Linear Collider of 500 GeV center-of-mass energy represents the most conservative one of several concepts presently under investigation [1]. The technology is well known for many years and the experience from the only existing Linear Collider, the SLC, can be used most directly. The relatively low frequency (3 GHz) is beneficial for keeping emittance dilution from wakefields small. In this context, a low bunch charge N_e is favorable since it reduces the short-range wakefields. This led us to a modification of the beam parameters, as will be described in the following.

New Parameter Set

The dilution of the beam emittance in the linac due to transverse short-range wakefields scales approximately as

$$\frac{\Delta\varepsilon}{\varepsilon} \propto \frac{N_e^2 \sigma_z < \beta >}{\varepsilon} \delta y_c^2 \qquad (1)$$

Here, σ_z denotes the bunchlength and δy_c the rms error of transverse structure alignment w.r.t. the beam orbit. The average focussing strength in the linac is expressed by $<\beta>$, we assume a scaling $\beta=\beta_0(E/E_0)^{1/2}$ with β_0=13m at E_0=3GeV. Stronger focussing seems advantageous with regard to transverse wakefield effects, but would lead to increased emittance dilution from chromatic aberrations.

The parameter optimization consists in a reduction of bunch charge by a factor of 0.4 and of bunch length by a factor of 0.6. The pulse current (and thus the average beam power) is kept unchanged by an appropriate reduction of bunch spacing and the interaction parameters are adjusted in order to keep the beamstrahlung constant. A complete overview of the S-Band Linear Collider (SBLC for short) parameters is given in table 1. According to eq. (1), we gain an order of magnitude reduction in transverse short-range wakefield effects. Part of this improvement is used to lower the vertical beam emittance (yielding a higher luminosity), the other part to relax the structure alignment tolerances. With the modified beam parameters, a complete simulation of beam dynamics also including other important effects such as long-range wakefields and chromatic aberrations has been performed.

	NEW	OLD	
total length	34	34	km
t_{pulse}	2	2	µs
n_b/pulse	333	125	
Δt_b	6	16	ns
f_{rep}	50	50	Hz
N_e/bunch	1.1	2.8	10^{10}
$\varepsilon_x/\varepsilon_y$	5/0.25	10/.5	10^{-6} m
β_x^*/β_y^*	11/0.45	22/0.8	mm
σ_x^*/σ_y^*	335/15	670/29	nm
σ_z	0.3	0.5	mm
cross. angle θ_c	6	3	mrad
$<\Delta E/E>_{rad}$	3	3	%
P_b (2 beams)	14.5	14.5	MW
P_{AC} (2 linacs)	140	140	MW
$\eta_{AC\text{-to-beam}}$	10.3	10.3	%
luminosity L	5	3.4	10^{33}cm^{-2}s^{-1}

Table1: New parameters of the S-Band Linear Collider in comparison with the original parameter set

Computer Simulation of Beam Dynamics

The beam dynamics in the S-band linac have been investigated by using the L3 particle tracking code [2]. The following assumptions are made for this study:

- initial alignment tolerances of 0.1mm (rms) for the accelerating structures, the quadrupoles and the position monitors (BPM's)

- one-to-one orbit correction followed by the “wake-free” correction algoritm [3] to reduce dispersive effects (assumed BPM resolution 5μm)
- beam-based alignment (by measuring the signal from two HOM-couplers per 6m long structure) of accelerating structures w.r.t. the beam orbit with an accuracy of 50μm (rms)
- damping of HOM’s by using the “lossy iris” concept [4]

For the reduced bunch charge, the longitudinal wakefield [5] is sufficient to provide BNS damping so that an rf-phase of zero deg., i.e. on-crest acceleration, is chosen. The correlated energy spread in the bunch is 0.35% in this case, about a factor of two smaller than in the previous design. Thus the parameter change is also beneficial for reducing chromatic emittance dilution from spurious dispersion. At the injection energy of 3GeV, an additional uncorrelated energy spread of 1% is taken into account. The bunch-to-bunch energy spread can be kept smaller than the single bunch energy spread by suitable beam-loading compensation [6] and is neglected here.

The simulation is performed for different values of the HOM quality factors in the range Q=2,000...10,000 using 10 different random seeds for each value of Q. The results for the vertical emittance growth are shown in fig. 1. The “lossy iris” HOM damping concept yields Q-values of 2,000...3,000 and we obtain a relative increase of the emittance of $\Delta\varepsilon_y/\varepsilon_y$ =(20±10)%.

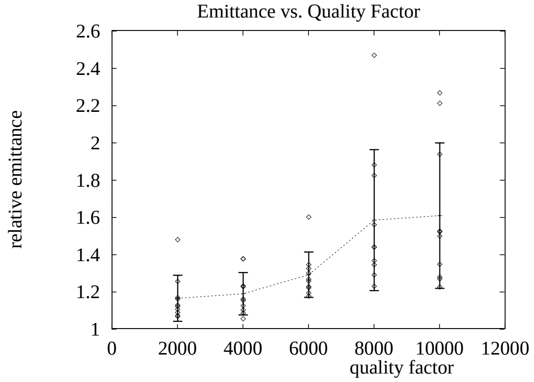

Fig.1: Simulation results for the vertical beam emittance (normalized by the design emittance) at the end of the S-band linac as a function of HOM quality factors.

Further computer simulations concerning the issue of long-term beam stability under the influence of ground motion were performed. We assume an uncorrelated diffusive ground motion according to the ATL-rule:

$$\Delta y^2 = A \cdot T \cdot L \qquad (2)$$

where L is the distance between two points along the linac and T the time. From measurements of orbit motion in HERA [7] we obtain A=10^{-17} m/s as a conservative upper limit. Starting with an ideal machine without alignment errors, the evolution of emittance dilution with time is determined. We find an emittance growth of 6% after 25 min. This means that after finding a “golden orbit” with the WF-method, an orbit correction which steers the beam back to this “golden orbit” has to be applied every 25min. in order to limit the additional emittance dilution to an average of 3%.

The effect of diffusive ground motion on the WF-correction method has also been studied. Since this method is based on measuring difference orbits after changing quadrupole strengths, which will require a certain amount of time, ground motion has the potential to spoil the measurement. We find that the time required for taking the difference orbits should not exceed 100s to avoid significant emittance dilution with the WF-method (see fig. 2).

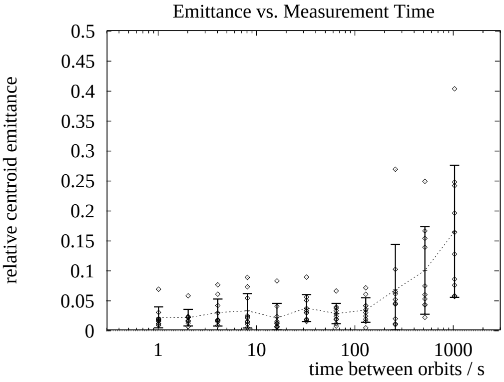

Fig. 2: Emittance growth caused by diffusive ground motion with A=10^{-17} m/s during the process of WF-correction as a function of time between orbit measurements.

The results of the beam dynamics study show that the reduced vertical emittance of the new parameer set can be obtained with reasonable alignment tolerances, which, in case of structure alignment, are more than a factor of two relaxed compared to the older version of the S-band parameters. In the studies presented here, empirical minimization of emittance dilution by using orbit bumps (common praxis at the SLC) is not yet included. This provides an additional safety margin in the S-band design.

Consequences for other Linear Collider Subsystems

The change of the beam parameters has a significant impact on the SBLC subsystems such as the damping ring and the final focus system.

The damping ring has to provide an emittance which is reduced by a factor of two in both planes. Fortunately, the original damping ring design [8] is capable of providing the required beam quality. With regard to single bunch instabilities the reduced bunch charge is an advantage. In case a multi-bunch feedback system is needed (this question is under study), the reduced bunch spacing can cause larger bandwidth requirements.

With the reduced bunchlength, stronger requirements for the bunch compressor result, but a single stage compressor device as described in [9] still seems feasible.

The final focus system must provide beta functions at the interaction point which are reduced by about a factor of two. This turns out to be straightforward without any problems concerning the momentum bandwidth. The vibration tolerances are somewhat tighter than for the older design, though. It is planned to use a fast orbit steering device at the interaction point to minimize luminosity loss from transverse beam separation [10].

The concept of dispersive crab-crossing [11] using the correlated energy spread in the bunch becomes more efficient, mainly due to the smaller bunchlength: For a given energy spread and dispersion, the maximum crossing angle which can be compensated scales like σ_z^{-1}. We make use of this advantage by increasing the crossing angle from 3mrad to 6mrad, thus creating more aperture for the outgoing beam, beamstrahlung and synchrotron radiation leaving the interaction region. The residual luminosity reduction due to the crossing angle amounts to about 5% in this case.

Conclusions

It has been shown that with the new parameter set for SBLC, a higher luminosity and at the same time relaxed tolerances can be obtained. The impact of the parameter modification on the overall design has been studied and found acceptable.

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