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Distribution of the RF System in a Very Large Lepton Collider

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Abstract

The consequences for the beam dynamics are discussed of concentrating the radio-frequency accelerating system of a very large circular e^+e^- collider VLLC in a few places around the circumference. As specific example, a VLLC with four long straight sections with RF systems and possibly interaction points and four arcs is used. At 184 GeV beam energy, each RF system accelerates the two beams by about 1 GeV, and causes energy variations between ± 0.27% around the circumference. By arranging the RF systems symmetrically around the interaction points, the centre-of-mass energies there are all equal to twice the beam energy. In a VLLC model without low-β insertions, the effects of this sawtooth energy variation on the mismatch of the horizontal orbit and dispersion, and the amplitude functions are all rather small.

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1 INTRODUCTION

This brief note contains a discussion of the consequences of concentrating the radio-frequency accelerating system in a few places around the circumference of a very large circular e^+e^- collider VLLC [1, 2]. The purpose of the RF system is compensating the synchrotron radiation losses that amount to about 4 GeV on a turn, or about 2.174% of the beam energy $E = 184$ GeV. I assume that the RF systems are installed in the long straight sections close to the interaction points, and that the dispersion vanishes there. There are several very good reasons for this choice. In the specific context of this note, it avoids exciting synchro-betatron resonances by the RF system. The long straight sections contain the same focusing arrangement as the arcs, i.e. FODO cells with length L_p, phase advance μ in units of 2π, and focal length f of the quadrupoles as shown in Tab. 1.

2 LAYOUT OF A SUPER-PERIOD

A super-period starts and finishes at an interaction point IP. Next to the IP are low-β insertions and associated matching sections, that match the low-β insertions to the FODO lattice in the rest of the VLLC. I have not studied these sections, and simply replaced them by three FODO cells for the purposes of this note. The RF systems are installed in the drift spaces between the quadrupoles of the following FODO cells. Each half cell of the lattice contains 40 RF cavities, that operate at about 400 MHz, are about 2 RF wavelengths long, and have about 6.7 MV peak voltage. The remainder of the long straight section is used for separating the two beams into two different magnetic channels [3]. Installing the RF system in the straight section common to the two rings halves the number of cavities, but does not change the RF power needed. Installing the RF system symmetrically around the interaction points has two beneficial effects: (i) it minimises the distance between bunches in the VLLC, and hence maximises their number, and (ii) it ensures that the centre-of-mass energies of the beam-beam collisions have the nominal value by symmetry [4]. Fig. 1 shows the layout of a FODO cell with the RF system. The arcs in a super-period are surrounded by dispersion suppressors. The far end of a super-period contains FODO cells for beam separation, an RF system, the matching and low-β insertions.

The number of super-periods must be at least two, resulting in a VLLC of racetrack shape. The RF systems in the two long straight sections must each accelerate the beams by about 2 GeV. The energy offsets at the entrances and exits of the arcs are then about ± 1 GeV, or about ± 0.54% of the beam energy.

3 RF SYSTEM DESIGN

The total peak RF voltage V_{RF} follows from the requirement that the quantum lifetime must at least be $\tau_q = 24$ h. The calculation [2] yields $V_{\mathrm{RF}} = 4.27326$ GV. If the

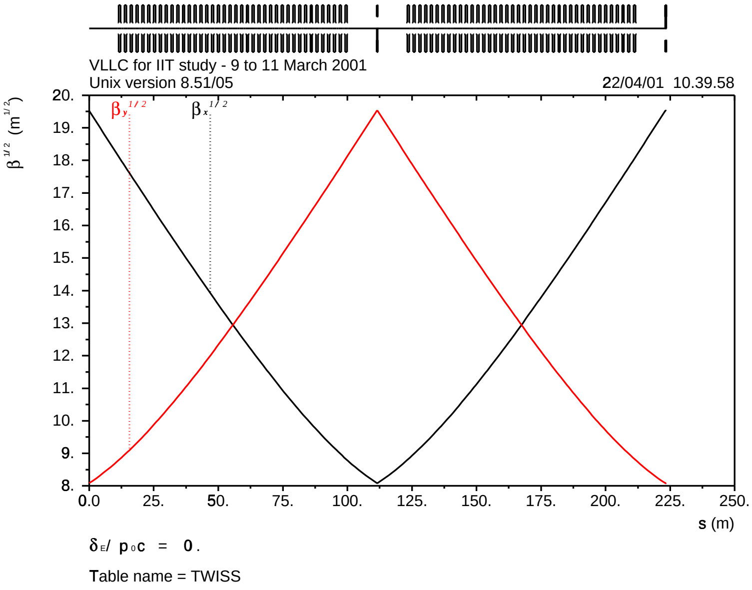

Figure 1: Schematic layout of a lattice cell with 40 RF cavities in each half cell, and orbit functions $\sqrt{\beta_x}$ and $\sqrt{\beta_y}$

whole RF system consisted of cavities similar to the super-conducting LEP cavities, each having about 10 MV peak accelerating voltage, at least about 432 cavities would be needed in total.

Table 1: VLLC Parameters

Collision energy E	184	GeV
FODO period length L_p	223.464	m
Phase advance $\mu/2\pi$	0.25	
Focal length of quadrupoles f	± 79.3774	m
Max. amplitude function β_x	383.268	m
Max. horizontal dispersion D_x	1.12054	m
Frequency of RF system f_{RF}	399.989	MHz
Number of RF cavities	640	
Peak RF voltage V_{RF}	4273.26	MV
Stable phase angle $\varphi_s/2\pi$	0.308234	
Relative bucket height	$5.98466 \cdot 10^{-3}$	

4 ORBITAL EFFECTS

In my calculations, I assume that the VLLC has four super-periods, and resembles a square with rounded corners. I install one lattice period with 80 RF cavities on either side of all four centres of long straight sections, whether they are interaction points or not. In this case, the total number of RF cavities is $8 \times 80 = 640$, and the peak accelerating voltage is 6.68 MV. Fig. 2 shows the relative momentum error δ, and demonstrates the variation of the beam energy along the orbit in sawtooth fashion. The relative momentum error δ vanishes near the interaction points at either end of the super-period. It rapidly increases in the RF system to the left of the graph, reaching about 0.5 GeV or about 0.27%, stays constant in the rest of the long straight section, and then drops through the arc. In the long straight section at the right edge of the graph, it stays constant again, and rises steeply in the second RF system. Fig. 3 shows the horizontal orbit offset along a super-period, if I do not take steps to adapt the strengths of the dipoles to the variation of the beam energy. The peak value of x is comparable to the RMS beam radius in a horizontally focusing quadrupole in the arcs $\sigma_x \approx 2$ mm. Note the little orbit wiggles in the long straight sections are either edge of the graph. One can argue that an orbit correction system will re-centre the horizontal orbit, by adding bending power at the entrance of the arcs where $\delta > 0$, and subtracting bending power at their exits where $\delta < 0$. If there are horizontal correctors next to every horizontally focusing quadrupole, then their strength must be about 0.0123 Tm for only correcting the energy sawtooth. This strength corresponds to a 0.5 m long corrector with the field of a standard arc dipole.

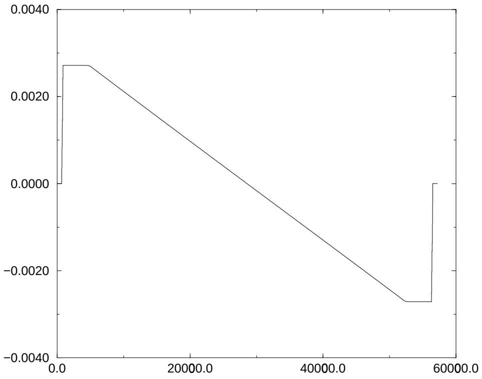

Figure 2: Relative momentum error δ along a super-period of VLLC

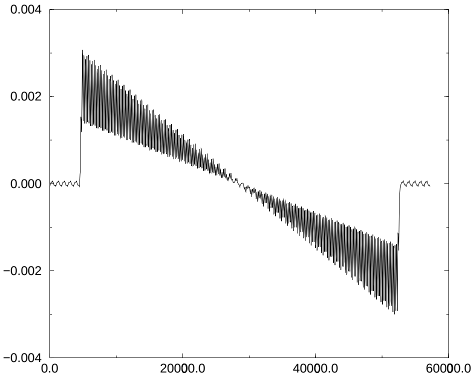

Figure 3: Horizontal orbit offset x in metres along a super-period of VLLC

Figs. 4, 5, 6, and 7 show closer views of the horizontal orbit offset x, the horizontal dispersion D_x, and the orbit functions $\sqrt{\beta_x}$ and $\sqrt{\beta_y}$ through 16 lattice periods in the long straight section between the RF system and the arc. All these functions repeat themselves since the phase advance through a lattice period is $\pi/2$, the former two four times, the latter two eight times. The horizontal offset x in the long straight sections is about 60 μm at most, only about 3% of the RMS beam radius. The dispersion $D_x$in the long straight sections is about 40 mm at most, less than 4% of the arc value. The beating of $\sqrt{\beta_x}$ and $\sqrt{\beta_y}$ is also surprisingly small, only a few percent. It is caused by the chromaticity correction.

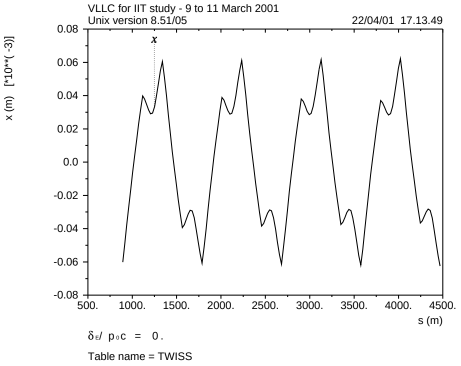

Figure 4: Horizontal orbit offset x in metres along 16 lattice periods in the long straight section of VLLC

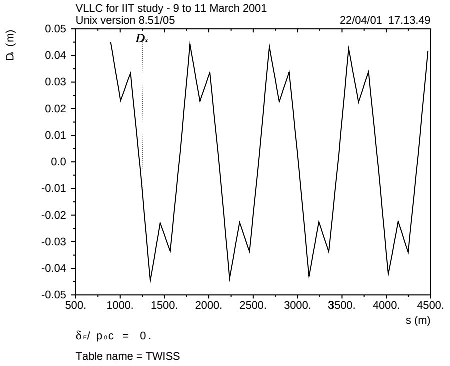

Figure 5: Horizontal dispersion D_x in metres along 16 lattice periods in the long straight section of VLLC

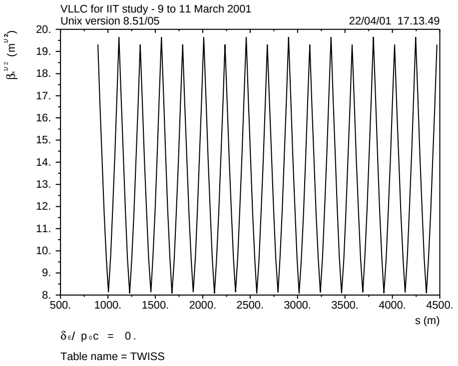

Figure 6: Horizontal orbit function $\sqrt{\beta_x}$ along 16 lattice periods in the long straight section of VLLC

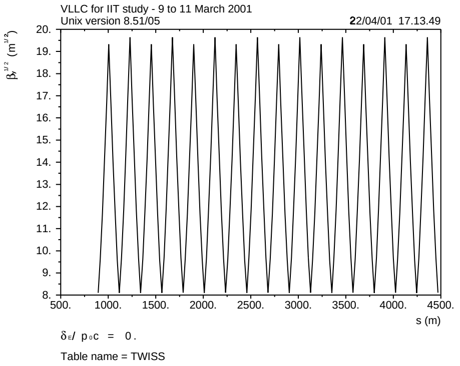

Figure 7: Vertical orbit function $\sqrt{\beta_y}$ along 16 lattice periods in the long straight section of VLLC

5 CONCLUSIONS

The consequences for the beam dynamics are discussed of concentrating the radio-frequency accelerating system of a very large circular e^+e^- collider VLLC in a few places around the circumference. As specific example, a VLLC with four long straight sections with RF systems and possibly interaction points and four arcs is used. At 184 GeV beam energy, each RF system accelerates the two beams by about 1 GeV, or 0.54% of the beam energy, and causes energy variations between ± 0.27% around the circumference. By arranging the RF systems symmetrically around the interaction points, the centre-of-mass energies there are all equal to twice the beam energy. In a VLLC model that does not contain low-β insertions, the effects of this sawtooth energy variation on the mismatch of the horizontal orbit, the horizontal dispersion, and the amplitude functions are all rather small. In a VLLC with only two long straight sections and two half-circular arcs they would be twice as large.

The VLLC parameters are computed in my *Mathematica* notebook [2]. It writes a short file with data for MAD [5]. In turn, MAD does the matching for elements of finite length, computes the orbit parameters, and prepares the graphs. This scheme allows an easy adaptation to changes in the VLLC parameters.

References

[1] T. Sen and J. Norem, *A Very Large Lepton Collider in the VLHC Tunnel*, to be published.

[2] E. Keil, *A Very Large Lepton Collider*, `http://wwwslap.cern.ch/~keil/Math/vllc.nb` (2001).

[3] E. Keil, *Beam Separation in a Very Large Lepton Collider*, CERN-SL-Note-2001-017 (AP) (2001)

[4] J.M. Jowett, *Consequences of less symmetrical locations of the polarization wigglers*, LEP Note 616 (1988)

[5] H. Grote and F.C. Iselin, *The MAD Program, Version 8.16, User's Reference Manual*, CERN SL/90-13 (AP) Rev.4 (1995).