Lattice Studies for a large Dog-bone Damping Ring for TESLA

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Abstract

A dog-bone shaped damping ring lattice is presented that meets all requirements of TESLA with respect to damping time, emittance, momentum compaction, bunch spacing and dynamic aperture. Due to its modular concept it exhibits large flexibility for future parameter modifications.

1. INTRODUCTION

A leading argument in the discussion of superconducting vs. normal conducting linear colliders is the efficiency of rf power conversion into beam power. With a highly efficient superconducting linear collider it is possible to obtain the desired luminosity at relaxed emittance tolerances or, alternatively, at moderate wall plug power consumption. Due to the long filling time of the rf sections, a very long bunch train will be characteristic for superconducting linear colliders (800 bunches, bunch spacing $\tau_b = 1\mu s$ for TESLA; see ref.1). The production and damping of a huge number of particles leads, however, to some increased requirements for both the particle sources and the damping ring.

As far as damping rings are concerned there are three complications with such large intensities and long bunch trains:

1. The TESLA design foresees a bunch train of $800 * 10^{-6} s * c = 240 km$ length. Obviously this bunch train can only be stored in a damping ring with a compressed bunch spacing and thus it must be expanded when extracted out of it. To this end very fast kickers will be required. Assuming a damping ring with circumference C and

$$\frac{240km}{C} = n \qquad (1)$$

we find the bunch spacing in the ring to be

$$\tau_{ring} = \frac{1}{n} * \tau_b = \frac{1}{n} * 1\mu s \qquad (2)$$

The ejection kicker has to operate with a rise time $\tau_r < \tau_{ring}$ at $\frac{1}{\tau_b} = 1MHz$ repetition rate.

2. Even if $\tau_r = 20ns$, $\tau_{ring} = 25ns$ is assumed, Eqs. 1,2 yield $n = 40$, $C = 6km$. Thus very large damping rings seem to be inevitable for TESLA.
3. Due to the bunch train compression, the mean current in the damping ring will be

$$I_{ring} = n * I_{linac} = n * 8mA$$

With n of the order of 40, a broad band multi-bunch feedback system of $n/2$ MHz band width is required to store that large current.

2. THE DOG-BONE DAMPING STRUCTURE

In order to make the circumference of the damping ring very large and to reduce the tunnel cost, we have suggested a dog-bone design [2], with long straight sections within the tunnel of the main linac and two small rings connecting the straight sections at both ends (Fig. 1). The major part of emittance damping takes place in two 190m long wiggler sections [3,4].

The dog-bone shape offers a large flexibility concerning the circumference of the ring and the resulting requirements for the feedback system and the kickers but also with respect to emittance, damping time, energy and bunch length. In this paper we investigate the principle design features of a dog-bone structure.

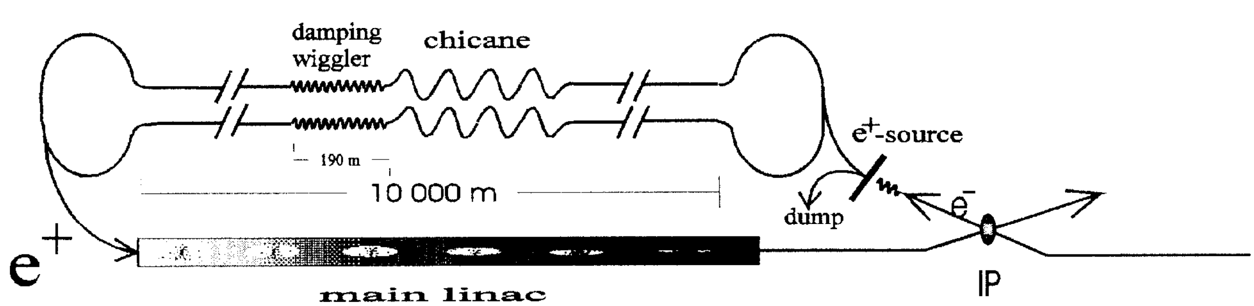

Fig.1 TESLA dog-bone damping ring scheme with circumference $C=20km$. The major part of emittance damping takes place in two 190m long wiggler sections. The chicanes provide momentum compaction without contributing too much of emittance growth.

For the arcs we use a modified lattice of R. Brinkmann's low emittance damping ring [5].

To find the optimum damping energy conflicting requirements have to be taken into consideration [2]:

* maximum energy is desired to reduce the length of the damping wiggler
* a higher energy increases instability limits
* minimum energy is favourable with respect to emittance generation in the chicane and bending sections, respectively.
* a lower energy simplifies the subsequent bunch compression.

We assume a circumference of the ring of $C=20km$ and an energy of $E=4GeV$ and get:

$$n = 12$$

$$\tau_{ring} = 83ns$$

$$I_{ring} = 96mA$$

band width of feedback system = $6MHz$

The straight sections of the ring consist of individual modules which can easily be combined to give maximum design flexibility. In addition we consider a twofold symmetry of the ring to increase the spacing of intrinsic resonances.

3. THE DAMPING WIGGLER MODULE

With the repetition frequency of the linac $\nu_{rep} = 10Hz$ a bunch can perform 1500 revolutions in the ring between successive rf pulses. Starting with a normalized beam emittance of $\varepsilon_x^N = 0.01\,\pi m$, as expected for the positron source [6], we need about 5 vertical damping times τ_D to reach the required vertical equilibrium emittance. In case of a low emittance electron source less damping times (i.e. a shorter damping wiggler) are sufficient.

With $\tau_D = 300 * T_0$ (T_0 = revolution time) and using:

$$\tau_D = 2\frac{E * T_0}{U_C} \qquad (3)$$

we obtain the energy loss per turn U_C to be:

$$U_C \geq \frac{E}{150} \qquad (4)$$

The energy loss per meter in a wiggler is given by:

$$\frac{\langle P_\gamma \rangle}{c}[GeV/m] = 3.3*10^{-13}\gamma^2 B[T]^2 \qquad (5)$$

Eqs. 4,5 can be combined into

$$B^2 L \geq \frac{1.03*10^7}{\gamma} T^2 m \qquad (6)$$

where L denotes the length of the wiggler section.

The condition for the emittance growth in the wiggler to be tolerable is [7,8]

$$\Delta\varepsilon_x(\text{per wiggler passage}) = \frac{1.05*10^{-15}}{m^3 T^5}\beta\lambda^2 B^5 L$$

$$< \frac{2T_0}{\tau_D}\frac{2*10^{-5}m}{\gamma} \qquad (7)$$

β = mean beta function in the wiggler section

λ = period of the wiggler

Note that the wiggler is traversed τ_D/T_0 times per damping time.

Using Eqs. 3 and 5 we get in addition to Eq. 6 the condition [9]

$$\beta\lambda^2 B^3 < 12 m^3 T^5 \qquad (8)$$

which is, remarkably, independent of energy.

Eqs. 8 shows that there is a large flexibility in choosing the wiggler parameter i.e. λ and B.

We have selected a high B version (yielding a minimum wiggler length) with $B=1.5T$, $\lambda=0.4m$ because this might be the optimum with respect to cost and chromaticity contribution.

Fig. 2 shows the optical functions in one wiggler module of 15m length.

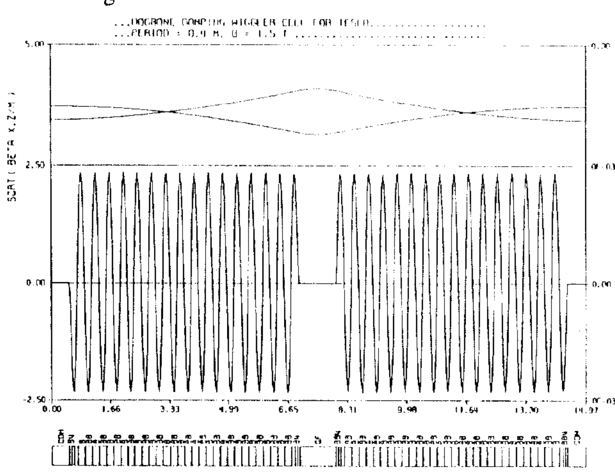

Fig. 2 Optical functions in the wiggler module.

4. THE CHICANE MODULE

In a dog-bone structure a momentum compaction factor α of -10^{-6} can be achieved. Thus a bunch length as small as 1mm would be possible. However, a larger bunch length (i.e. a larger α) will be required in the damping ring due to the microwave instability. A chicane can introduce a large, negative momentum compaction factor.

The longitudinal dynamic of a ring with negative momentum compaction factor has not been investigated in detail. According to experience with 'conventional' rings we assume that a momentum compaction of $\alpha = -2*10^{-4}$ is a reasonable number.

Neglecting the contributions of the arcs and the damping wiggler, α can be estimated at:

$$\alpha = -\frac{L}{2C}\left(\frac{ec}{2\pi E}\lambda B\right)^2 \qquad (9)$$

Combing Eq. 9 and Eq. 7 we get

$$\beta * B^3 < 0.29 mT^3 \qquad (10)$$

and with $\beta \approx 400m$

$$B < 0.09T$$

We select a field of $0.062T$ and set $L = \lambda * N$, where N denotes the number of periods, and get:

$$\lambda[m] = \left[14.6 * 10^6 / N\right]^{1/3} \qquad (11)$$

We want to keep the geometric deviations from a straight line small enough to accommodate the chicane inside the standard size linac tunnel. Also we want to avoid excessively large dispersion values D_x to relax error tolerances which could affect emittance coupling. Therefore we choose N=8 and get:

$$\lambda = 122m$$

$$D_x < 2m$$

Fig. 3 shows the optical functions in one chicane module.

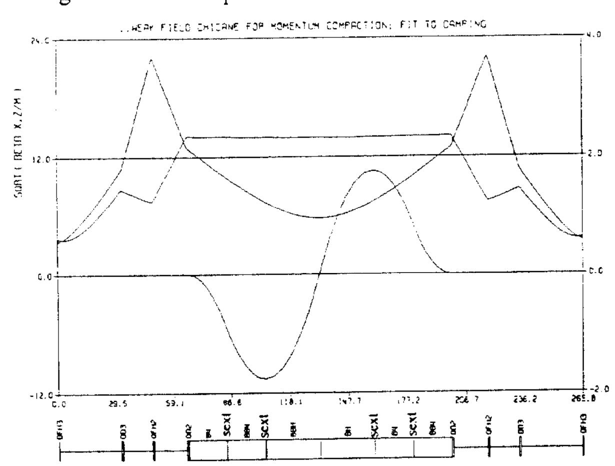

Fig.3 Optical functions in the chicane module.

5. COMPLETE DOG-BONE RING PARAMETER

The major part of the ring consists of long FODO cells which ensures a small chromaticity contribution of this long dispersion-free straight section and reduces costs.

As seen from Tab.1 the overall parameters meet the TESLA requirements.

Qx, Qy	106.30, 68.26
ξ_x, ξ_y	-159.0, -127.0
ε_x^N	$1.70*10^{-5}$ m
τ_D	18.9 ms
U_C	27 MV
σ_s at U_0=50 MV	7.0 mm
$\sigma P / P_0$	$1.2*10^{-3}$
α	$-2*10^{-4}$

Tab. 1 Parameters of the dog-bone ring.

The chromaticity of the long straight sections is compensated both by sextupoles in the chicane modules and in the arcs. It should be noted that the chromaticity of a ring with negative momentum compaction factor should also be negative in order to stabilize the first mode of the head-tail instability.

Four-dimensional tracking calculations including orbit errors have shown that the dynamic aperture exceeds the value required at injection within ± 1% energy width.

6. REFERENCES

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