STRAIGHTLINE COOLING SYSTEM FOR OBTAINING BEAMS OF ELECTRONS AND POSITRONS WITH MINIMAL EMITTANCE

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ABSTRACTS

The method of obtaining beams of electrons and positrons with minimal emittance is detailed. The general idea of the method proposed is that the wigglers and the accelerating structures are displayed along straight line one by one. At the energy of the beam about 15 Gev this system with the length about 1 km gives decrease of the transverse emittances, equivalent of few damping times. This system also excluded dependence of repetition rate.

INTRODUCTION

One of the first proposal to use the Damping ring as injector for Linear collider is represented in [1]. Since that time there was made a lot of consideration of such damping rings for obtain bunches with minimal emittances. It was found, that there are two main processes, which defined the equilibrium horizontal emittance (without consideration of the beam interaction with RF cavities and residual ions):excitation emittance by quantum fluctuations and intrabeam scattering. Equations for emittances

$$\frac{d\varepsilon_x}{dt} = \langle H_x \left(\frac{d}{dt}(\Delta E/E)^2_{IBS}\right\rangle + \langle H_x \left(\frac{d}{dt}(\Delta E/E)^2_{QE}\right\rangle - \frac{2}{\tau_x}(\varepsilon_x)_{eq}$$

$$\frac{d\varepsilon_z}{dt} = \langle \frac{\beta_z}{\gamma^2}\left(\frac{d}{dt}(\Delta E/E)^2_{IBS}\right\rangle + \varkappa^2 \frac{d\varepsilon_x}{dt} + \langle\frac{\beta_z}{\gamma^2}\left(\frac{d}{dt}(\Delta E/E)^2_{QE}\right\rangle - \frac{2}{\tau_z}(\varepsilon_z)_{eq} ,$$

where $\beta_{x,z}$ envelope functions and H_x

$$H_x = \frac{1}{\beta_x}\left(\eta_x^2 + (\beta_x\eta'_x - \frac{1}{2}\beta'_x\eta_x)^2\right) ,$$

$\varkappa^2$-coupling coefficient, subindex QE and IBS marks input from Quantum Excitation and IntraBeam Scattering respectively,η_x-dispersion function

$$\frac{d}{dt}(\Delta E/E)^2_{IBS} = \frac{N r_0^2 c(\varepsilon_x\beta_x)^{1/2} Ln_{Col}}{\gamma^3\varepsilon_x(\varepsilon_z\beta_z)^{1/2}\sigma_l\sigma_{sx}} ,$$

where $\sigma_{sx} = (\varepsilon_x\beta_x + \eta_x^2\ (\Delta E/E)^2)^{1/2}$,

$$\frac{d}{dt}(\Delta E/E)^2_Q = \frac{55\ \Lambda_0 r_0 c\ \gamma^5}{48\ (3)^{1/2}}(1/|\rho|^3),$$

$\Lambda_0 = r_0/\alpha = 137\ (e^2/mc^2)$, $\gamma=E/m_0c^2$

So, the efforts was concentrated to find the Magnetic Structure, which minimized H_x. As one can see, for minimization it is necessary to have minimum of η_x - function in places where particle radiates.This immediately yields low syncrotron frequency and problems, connected with stability of the beam in damping ring. For damping it is necessary to re-radiate of full energy of particle few times, so for satisfy the requirements of repetition rate of any Linear collider the RF system must have sufficient mean power in intermediate wavelength.

IBS and QE are physical restrictions which is not possible to overcome. As far as interaction with external systems (RF cavity and inhomogeneties of vacuum chamber) and residual ions, from our point of wiev, namely here there will be the real problem which prevents obtaining the beams with low emittance.

To overcome this problems in [2] there was proposed Linear Damping System (LDS,Fig.1), which contains wigglers and accelerating structures diplaced along straight line and which provides absolutely minimized value of the function H_x. For an accelerating structure problem, seems, is more clear and it must be solved in any case.

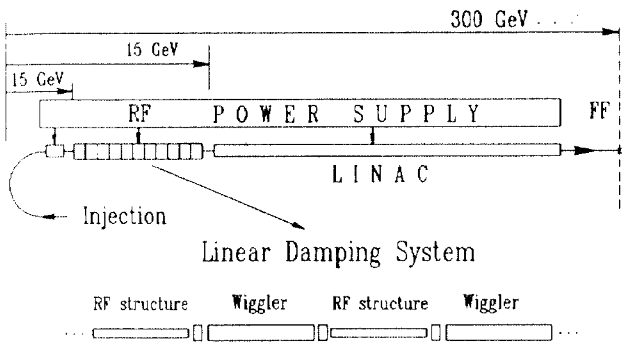

Fig.1. Linear Damping System (LDS). FF is the Final Focusing system.

Other advantage of LDS is that the RF power can be inputted to the beam by the same supply as Linac.

The problem for this System is sufficient length, cause particle must re-radiate its full energy E a few times. For such re-radiation it is necessary to achieve condition, when particle radiates on some way the same energy, that it gains from RF structures on the other way and do it a lot of times.

Typical gain of energy which is planned now for any Linear Collider is about 1 MeV/cm, so it is necessary to obtain the losses of energy in the wiggler about this value.

Number of re-radiations of full energy n shows us what is the damping rate of emittance $\varepsilon \cong \varepsilon_1 \exp(-n)$.

Let us describe it more carefully.

Losses of Energy

The amount of energy, radiated by the charged particle in some time, can be expressed by well formula

$$\frac{d\varepsilon}{dt} = -\frac{2e^2}{3c^3} w_\perp^2 \gamma^4,$$

where $w_\perp$- is transverse to velocity acceleration, e- charge of the particle. For energy losses this gives

$$\frac{d\gamma}{ds} = \frac{1}{m_0 c^3}\frac{d\varepsilon}{dt} = -\frac{F}{3} r_0 \gamma^2 \frac{P_\perp^2}{\bar{\lambda}^2} = K_w \gamma^2$$

where $P_\perp = eH\lambda/m_0c^2 = .934\ H[T]\ \lambda[cm]$, F -factor of order 1÷2 which describs the longitudinal distribution of the field (F=1 - for Sine like, F =2 for rectangular distribution or for helical wiggler), $\bar{\lambda}$ is the period of the wiggler λ divided by 2π. For accelerating structure with accelerating gradient 100 MeV/m

$$\frac{d\gamma}{ds} = \frac{1}{m c^3}\frac{d\varepsilon}{dt} = K_a = 2\ [1/\text{cm}]$$

Let L_a will be the total length of accelerating structures of LDS. Possible gain of energy which can be achieved is $\Delta\gamma = K_a L_a$. So, damping rate of emittance will be

$$\varepsilon_f/\varepsilon_1 \simeq \exp(-K_a L_a/\gamma),$$

and it is desirable to have the ratio $K_a L_a/\gamma$ as high as possible for *fixed length* of LDS which let be $L \simeq \simeq L_a + L_w$ where L_w is the total length of the wigglers. As energy does not changes after LDS, this yields $K_a L_a \simeq K_w \gamma^2 L_w$ and $L_a = L/(1+\gamma_0^2/\gamma^2)$, where γ_0 corresponds to the operation energy, when $L_w = L_a$. Substitute here for example $K_a = 2[\frac{1}{cm}]$, $F \simeq 2$ and for the field strength H = 15 T, we obtain $\gamma_0 \simeq (\frac{6}{F}/r_0)^{1/2}(\bar{\lambda}/P_\perp) \simeq 3.4\ 10^4$, or energy $\simeq$ 17 GeV. For number of re-radiations we obtain

$$n \simeq (K_a L/\gamma_0)(\gamma/\gamma_0)/(1+(\gamma/\gamma_0)^2),$$

which yields for the rate 1 MV/cm and $L \cong 1$ km, $(K_a L/\gamma_0) \simeq 6$. If $\gamma = \gamma_0$ then $n \simeq 3$, which corresponds to damping rate of emittance about 1/20.

So, particle with other energy or for other field strength will have damping rate according to formula for n. That may yield that the ratio $L_w/L_a \neq 1$ (for $\gamma \simeq \gamma_0$ $L_w/L_a = 1$).

Now we investigate the limitations of the level of damping due to particle dynamics.

Transverse Dynamics

For function H_x we can estimate $H_x \simeq \beta_x \eta_x'^2$ and for $\eta' \simeq P_\perp/\gamma$, which gives for emittances

$$\gamma\varepsilon_x \simeq 0.5\ \Lambda_0\ \bar{\beta}_x\ p_\perp^2 \gamma/\rho_w = 0.5\Lambda_0 \bar{\beta}_x p_\perp^3/\bar{\lambda}$$

$$\gamma\varepsilon_z \simeq 0.25\ \Lambda_0\ \bar{\beta}_z\gamma/\rho_w = 0.25\ \Lambda_0\bar{\beta}_z p_\perp/\bar{\lambda}$$

where $\rho_w = \lambda\gamma/p_\perp$ is the bending radius in the magnetic field of the wiggler, $\bar{\beta}_{x,z}$-is averaged values of envelope functions in the wiggler. Here we take into account only QE, cause IBS at energy about 17 GeV is negligible. For the plane wiggler vertical emittance mostly defined by coupling $\varkappa$ between vertical and horizontal oscillations. For compensation $\varkappa$ additional skew quads can be used like in usual Damping Ring. So, represented value for $\gamma\varepsilon z$ is minimal possible one for vertical emittance. For_ equilibrium values, when supposed $\beta_{x,y} \simeq 1$ m, $\bar{\lambda} \simeq 3$ cm, we obtain $\gamma\varepsilon_x \simeq 5\ 10^{-5}$m rad and $\gamma\varepsilon_z \simeq$ $\simeq 5\ 10^{-10}$m rad.

For estimation of $\varkappa$ due to rotation of the focusing quads we can write supposing random distribution of the angles with rms θ_0, Kl=Gl/BR

$$\varkappa^2 = \varepsilon_z\ /\ \varepsilon_x \simeq (Kl\theta_0)^2\beta_x\beta_z\ \mathrm{NP},$$

where NP is the number of quads on the length, corresponding n=1.

This restriction is the same as for main Linac structures.

For estimation of sextupole component of the field we can followed [3] and output that this restrictions are not serious.

Wiggler Design

Also there were made preliminary design of the wiggler. It has period $\lambda \simeq 15$ cm and $p_\perp \simeq 200$.

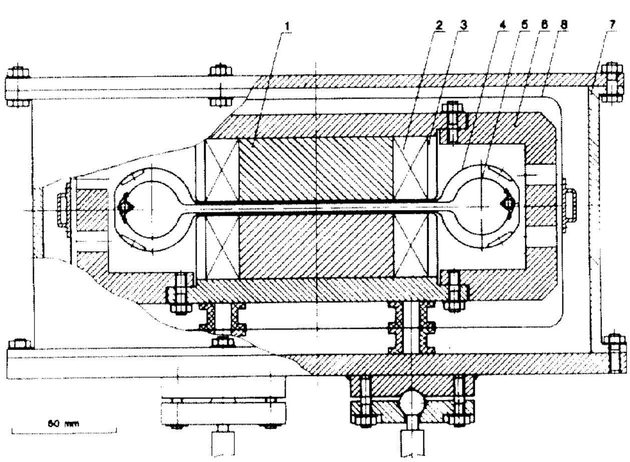

Fig.2. Wiggler design.

On Fig.2 there is represented the general layout of the Wiggler. Here 1-magnetic core, 2-sectioned coil, 3- volume for helium, 4,8-screen with liquid nitrogen, 5-inner chamber, cooled with water, 6-support (St.st.), 7- cabinet. Vacuum is the same in all inner volume of the cabinet, and inner chamber works as radiation shield. Magnetic core 1 placed on the support made with stainless steel with necessary accuracy. Pumping are going by pumps and by cryogenic absorption. Inner part of the coil is working with lower current. Vertical gap between poles is about 8 millimeters and the distance between plates of inner chamber 5 is about 5 mm. This size is limited by resistive wall instability.

For the losses of energy about 1 Mev/cm radiated power corresponds to the level

$$P = 1.6\ 10^{-11}\ Nf\ \text{[Watt/Meter]}$$

where N -number of the particles in the bunch, f -repetition rate. For $N = 10^{11}$, f = 1 kHz, P= 1.6 kW/M or about 800 W/M per each side.

Coils winded with multifilament composite cable made from pure Nb enclosed into the tin bronze matrix which is able to produce magnetic field with H $\simeq$ 16T at 1.6°K.

Calculations made for this geometry shows that maximal field is only 6 % higher than in median plane of the wiggler.

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