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LEDA-F STORAGE RING DEDICATED TO THE FREE ELECTRON LASER OPERATION. PRELIMINARY DESIGN

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ABSTRACT

The preliminary design of an electron storage ring dedicated to the free electron laser operation, is presented. The main feature of the proposed laser is the complete tunability in the wavelength range 0.3 μm < λ < 20 μm with an output average power of the order of 1 kW and an efficiency, electron beam-laser beam, of ~ 2%.

1. INTRODUCTION

In this paper is presented the preliminary design of the electron storage ring LEDA-F dedicated to the free electron laser (FEL) operation [1].

The electron beam (e.b.) and laser beam (l.b.) dynamics in a storage ring (SR) FEL has been worked out in Refs [2-7]. The main l.b. parameters are (for the notations see Table 1).

(a) Wavelength

$$\lambda = (\lambda_q/2)\ (1 + K^2)\ (m_0 c^2/E)^2, \quad (K = eB_W\ \lambda_q/(\sqrt{2}\cdot 2\pi\ m_0 c^2)) \qquad (1)$$

(b) Output power/bunch

$$P = (\Delta\omega/\omega)_0\ \chi(\xi)\ P_S\ (\gamma_M/\gamma_T), \qquad (2)$$

where we have defined (Σ_L = l.b. cross section)

$$\xi = \frac{8\pi^2}{\gamma_T}\ (r_0/ec)\ \sqrt{2\lambda/\lambda_q}\ (\Delta\omega/\omega)_0^{-3}\ (\lambda L_W/\Sigma_L)\ \frac{K^2}{(1+K^2)^{\frac{3}{2}}}\ \frac{I\nu_S}{\alpha_c} \qquad (3)$$

$P_S = U \cdot I/e$ = synchrotron emitted power/bunch, (4).

The function χ is plotted in Fig. 1. The physical meaning of ξ is straightforward, namely it is proportional to the ratio between the small signal gain (for the unperturbed e.b.) and the optical cavity loss γ_T.

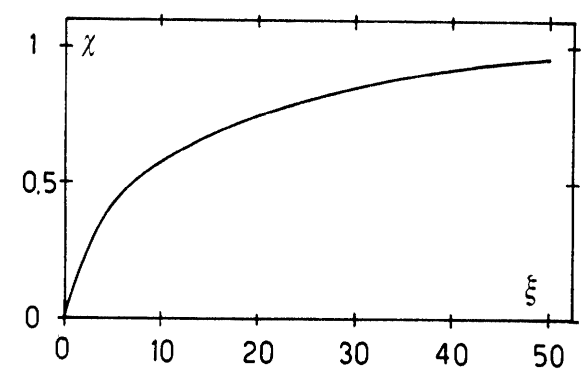

Fig. 1 - χ versus ξ

(c) Bandwidth and photon bunch length

The "natural" laser bandwidth is given by (as order of magnitude)

$$\frac{\Delta\nu}{\nu} \sim ((\lambda/(2\sigma_z))\ (\Delta\omega/\omega)_0)^{\frac{1}{2}} \qquad (5)$$

The corresponding photon bunch length reads,

$$\sigma_L \cong \sigma_z\ ((\lambda/(2\sigma_z))\ (\Delta\omega/\omega)_0^{-1})^{\frac{1}{2}} \qquad (6)$$

It is possible to reduce $\Delta\nu/\nu$ with an intracavity etalon. The minimum bandwidth is related to the maximum l.b. length, which cannot be greater than the e.b. one, i.e.

$$\sigma_L(\max) \sim \sigma_z \Rightarrow (\Delta\nu/\nu)(\min) \sim \lambda/(2\sigma_z) \qquad (7)$$

A further narrowing of the bandwidth strongly reduces the output power.

2. DESIGN CRITERIA

The SR and FEL parameters have been optimized [7] to achieve the maximum output power in the wavelength region $\lambda \sim 10\div20$ μm, at the bunch average current $I \sim 200$ mA. The optimization has been worked out under the following constraints: $L_W(\max) \sim 10$ m, $B_W(\max) \sim 5$ kG, $\nu_S/\alpha_c\ (\max) \sim 1$.

We have optimized the laser performances at 200 mA per bunch in order to have a good laser operation also at relatively low current. However we plan to store a larger current, namely $I \sim 1$A. Therefore the laser performances are evaluated (in the following) for such a current.

For fixed SR and FEL parameters, we can obtain a further increasing of the laser output by utilizing special high magnetic field insertions, enhancing the emitted synchrotron radiation power P_S (see Eq. (2)).

3. MACHINE LAYOUT

Magnetic lattice. The basic SR layout (LEDA-F1) is shown in Fig. 2. The machine has a twofold symmetry. Each quarter consists of three standard cells (D/2 -O -F -O - D/2) and one half insertion with two bending magnets and four independent quadrupoles (q-poles). The off-energy function η is non vanishing only in the region between the bending magnets, where are located the sextupoles (S) for chromaticity correction. The half laser straight section is 5.5 m long and the total free space in the whole machine is 54.4 m.

In a second time (LEDA-F2) a special high magnetic field system could be inserted in each quarter of machine, in place of two standard cells (see Fig. 2). This special insertion

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TABLE I

e, m_0, r_0 = electron charge, rest mass and classical radius

c = light velocity
$x, y, z,$ = radial, vertical and longitudinal coordinates

★ = FEL REGION, M = MAX VALUE	LEDA-F1	LEDA-F2
e- Beam		
- E = energy (MeV)	750	750
- I = current/bunch (A)	1	1
- number of bunches	6	6
- U = synchrotron radiation energy/turn (keV)	15.5	72.6
- r.m.s. dimensions (full coupling) (mm)		
$\sigma_x^{\star}$, $\sigma_y^{\star}$	2.3, 2.5	1.1, 1.5
σ_x^M, σ_y^M (laser off)	2.3, 2.5	1.6, 1.9
σ_x^M (laser on)	$\sim$ 24	$\sim$ 24
σ_z (laser off, laser on)	8.9,$\sim$217	15.9,$\sim$217
σ_ε (laser off, laser on) (%)	.04,$\sim$1	.08,$\sim$1
Magnetic structure		
- L = orbit length (m)	130.828	130.841
- $\omega_0/2\pi$ = c/L (MHz)	2.2915	2.2913
- FEL straight section (m)	2x11	2x11
- number of standard cells	12	4
- ρ = bending radius (m)	2	2
- bending field index	0	0
- Max bending field (kG)	12.5	12.5
- Q-pole length (m)	50x.45	38x.45+24x.85
- Max field gradient (kG/cm)	.4	.6
- Sextupole length (m)	8x.5	8x.5
Focusing parameters		
- $\nu_x = \nu_y$ = betatron tunes	4.875	7.125
- α_c = momentum compaction	9.56×10^{-3}	9.17×10^{-3}
- C_x, C_y (= $(E/\nu)(\Delta\nu/\Delta E)$)	-1.3,-1.5	-2.3,-2.4
- τ_z, τ_x, τ_y = damping times (ms)	21,46,42	4.5,9.2,9
- $A_x = A_y$ = emittance (mm x mrad)	2.2	0.4
r.f.		
- $\omega_{RF}/2\pi$ =R.F. frequency (MHz)	68.745	68.738
- h = ω_{RF}/ω_0	30	30
- peak voltage (MV)	1.50	1.44
- $\omega_s/2\pi$ = synchrotron frequency (kHz)	21.9	21.0
- $\nu_s = \omega_s/\omega_0$	9.56×10^{-3}	9.17×10^{-3}
- max power to the e.b. (kW)	93	435
- ε_M = relative energy acceptance (%)	7.3	7.3
FEL		
- λ_q, L_W = wiggler wavelength and length (m)	.42 , 10.08	
- $(\Delta\omega/\omega)_0 = \lambda_q/(2L_W)$	1/48	
- Cavity length = L/6 (m)	21.8	
- distance between photon bunches (ns)	72.7	
- γ_M = mirror transmission $\sim \gamma_T$ = cavity losses (%)	1.5	
- ξ^M (λ = 10÷20 μm, I $\sim$ 1A)	40	

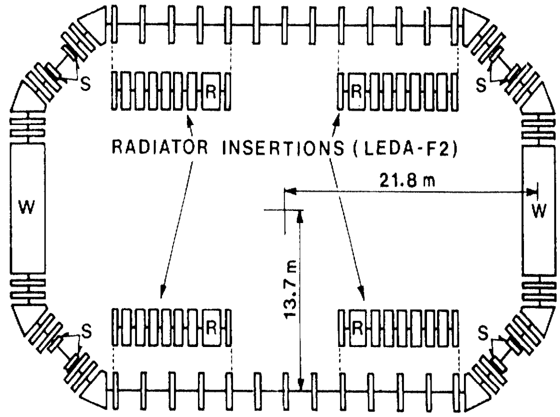

Fig. 2 - Basic layout (LEDA-F1) and radiator insertions (LEDA-F2)
W = wiggler laser
R = Radiator
S = sextupoles

consists of a 1.6 m long superconducting high field ($\sim$ 50 kG) wiggler (radiator) and six special q-poles, whose function is to keep $\nu_{x,y}$ constant during the raising up of the radiator magnetic field. In this configuration the total available free space is $\sim$ 22.4 m. In this preliminary stage of the project we have not worked out in detail the design of the R.F., vacuum and injection systems. The main requests to be fulfilled are the following:

R.F. $\nu_s/\alpha_c \sim 1$ (see Sect. 2) with an energy acceptance $\varepsilon_M \gtrsim 6\sigma_\varepsilon$ (laser on), in order to have a quantum life-time $\gtrsim$ many hours.

Vacuum. The high synchrotron radiation power ($\sim$ 70 kW/A, radiators on), requires a good cooling and shielding of the vacuum chamber.

Injection. Linear accelerator operating at the energy $\sim$ 250 MeV, peak current $\sim$ 100 mA, pulse duration $\sim$ 2 μs, repetition rate $\sim$ 1 Hz, energy spread $\sim$ 1%, emittance $\lesssim$ 5 mm x mrad (injection time $\sim$ 200 s/A).

In Table I are reported the LEDA-F and FEL parameters. In Fig. 3 are plotted the optical functions β and η.

4. LASER PERFORMANCES

In Table I are reported the laser main parameters. The cavity mirrors are chosen so as to have the minimum average l.b. cross-section in the wiggler region. The average laser power output (for six bunches) and the bandwidth are plotted in Fig. 4 for λ = 0.3÷÷20 μm. It is also reported (curve (d)), the minimum bandwidth we can obtain with an intracavity etalon (Eq. (7)). The frequency tuning is obtained by changing the wiggler magnetic field (Eq. (1)) and operating the SR at the maximum energy (750 MeV).

The maximum efficiency l.b. → e.b. defined as the ratio between the power radiated into the laser mode and the total synchrotron power is roughly given by (see eq. (2) and Fig.1): e.b. → l.b. efficiency $\sim (\Delta\omega/\omega)_0 \sim 2\%$.

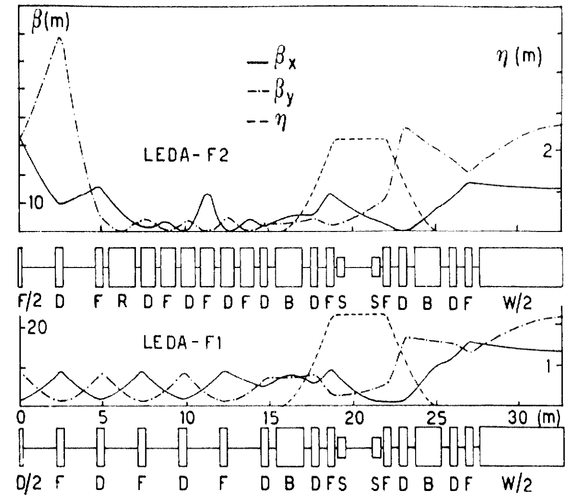

Fig. 3 - Optical functions and magnetic structure F,D = focusing and defocusing (radial) q-pole, B = bending magnet

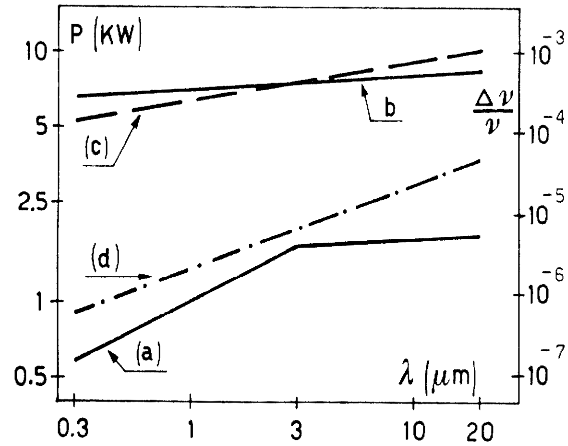

Fig. 4 - P vs λ: (a) LEDA-F1, (b) LEDA-F2
$\Delta\nu/\nu$ vs λ: (c) without etalon, (d) with etalon

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