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A.L.A. - A 1.2 GeV HIGH LUMINOSITY ELECTRON-POSITRON STORAGE RING. DESIGN STUDY

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Abstract

High electron-positron collision luminosity in the energy range between .5 and 1.2 GeV seems desirable in view of the results from recent experiments on existing e^+e^- storage rings. The optical structure of a ring, 70 m long with a 2.5 m bending radius is presented: low-β insertions and variable optics give a peak luminosity of $1.4\times10^{31}\,cm^{-2}s^{-1}$ at top energy for ξ_M=.06; luminosity is designed to stay higher than 1.5×10^{30} over the whole energy range. Design criteria, optical structure, apertures, injection, RF system, magnets and vacuum are described.

Introduction

Recent papers on e^+e^- physics[1,2,3] show that a high luminosity storage ring in the energy range from .5 to 1.2 Gev per beam could be an extremely interesting tool.

In a previous paper[4] we proposed the design of a 70 m long variable optics storage ring, featuring a luminosity versus energy dependence less steep than the E^4 natural law.

A second solution, in which control of beam size is achieved by means of variable "kinks" in the orbit, is also being considered: a final choice between the two possibilities has not been made yet, since a large part of the project does not depend critically on the optical structure. Most of the material in this paper refers however to the (more advanced) variable optics structure.

Design luminosity is presented for ξ_M (the "interaction parameter) equal to .06: this value of ξ_M is the maximum one expects to obtain, extrapolating from the Adone results. Experience with other operating machines tells us however that the value of ξ_M cannot be predicted to better than a factor ~ 2. The luminosity curve, assuming ξ_M=.03 is therefore also shown (see fig. 1).

Variable optics structure

The variable optics structure (see fig. 2) has a two-fold periodicity: further, each period is symmetric about its midpoint. Each quadrant has 6 indipendent quadrupoles and 2 bending magnets with field index n = .5. Given the smallness of the ring, it is not convenient to try and match low-β insertions to a periodic structure, since this decreases the number of available degrees of freedom; each ring quadrant is therefore considered to be an insertion , matched to the next one by symmetry only: in this way 4 of the six degrees of freedom (strengths of quadrupoles) are used to control the betatron wave numbers Q_x and Q_z and the betatron functions at the crossing point β_x^* and β_z^* ; the fifth one (namely the strength of the quadrupole in between the two bending magnets) to control the emittance of the beam, and the sixth to optimize the behaviour of the optical functions along the ring. Fig. 3 shows the behaviour of β_x , β_z , and the dispersion η for the two extreme configurations (low energy and high energy).

The single beam cross-section is proportional to the optical parameter M^* given by:

$$M^* = [\eta^2/2\beta_x]^* + \int_{\mathrm{MAGNETS}} [\gamma\eta^2 + 2\alpha\eta\eta' + \beta\eta'^2]\,\delta s$$

where α , β , and γ are the conventional Twiss functions and an asterisc indicates that the corresponding function is computed at the crossing point. When the beams interact, the exact proportionality factor between M^* and the beam cross-section is not well known: beams blow up by different amounts depending on energy, and in a way that is essentially different for every machine in operation. We assume however that M^* is still the scaling factor.

By changing M^* we gain a factor of the order of 4 (at the low energy end of the operating range) with respect to the E^4

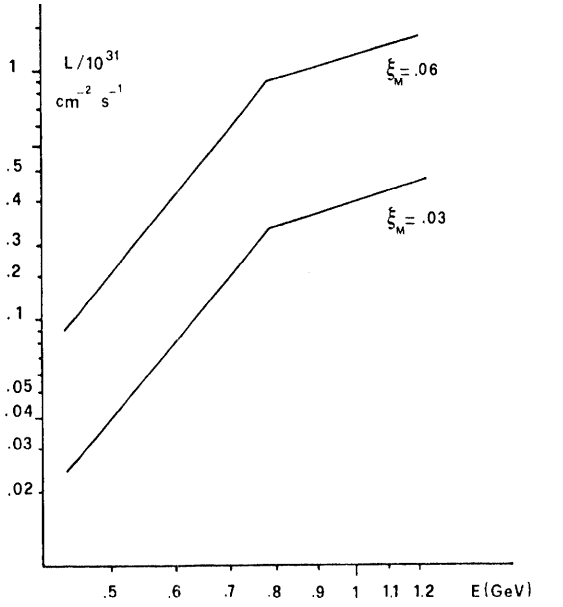

FIG.1 - Luminosity versus energy for ξ_M=.06 and ξ_M=.03

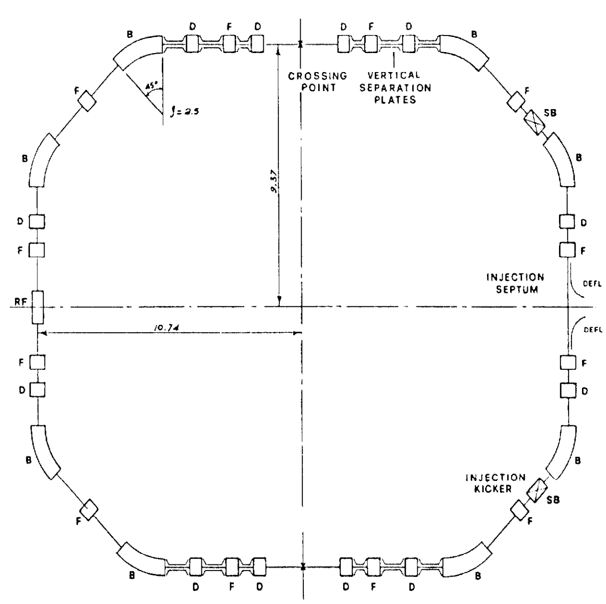

FIG.2 - Schematic layout of the ring

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optical law. The average luminosity power law is $\propto E^{2.6}$; if the optical model holds, luminosity is expected to behave as shown in Fig. 1.

The maximum luminosity at top energy is determined by the value of M^*, by the maximum permissible linear tune shift ξ_M and by the maximum storable current. We have assumed for ξ_M the value of .06, consistent with the best results obtained with Adone at around 1 GeV, scaled to 1 bunch/beam operation. We also assume we can store 2×10^{11} ($\rightarrow$150 mA) particles in a single bunch. At the low energy end of the operating range, the negative influence on luminosity of a smaller ξ_M could be compensated for by further increasing M^*, and therefore the current, as long as the aperture is sufficient to ensure the required lifetime. For ξ_M=.06 and M^*= .85 m the computed luminosity at top energy will be about 1.4×10^{31} $cm^{-2} s^{-1}$.

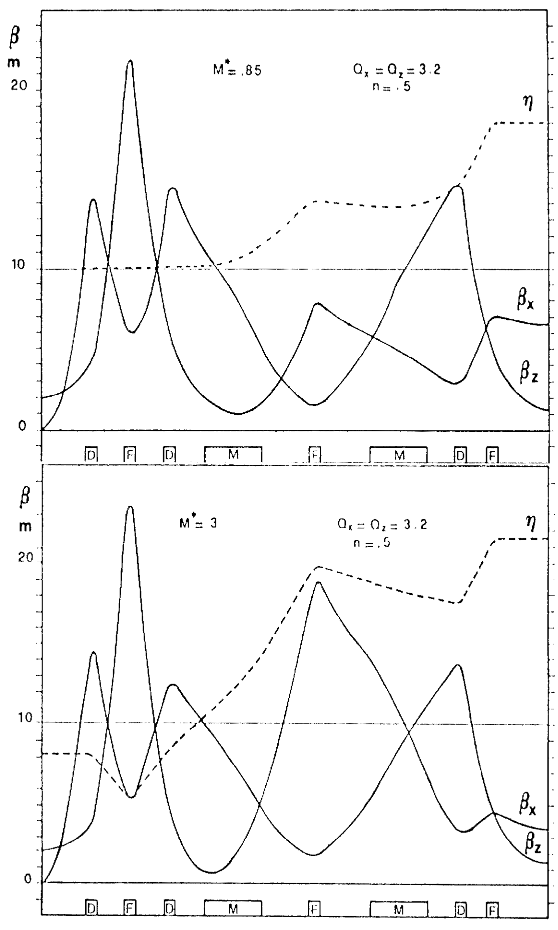

FIG.3 - Optical functions β_x, β_z and η for a ring quadrant, in the two extreme cases of high energy (1.2 GeV) and low energy (.5 GeV).

Kinks

For large storage rings, where the bending field is rather low, beam dimensions can be easily controlled by means of wiggler magnets (e.g. PEP includes 11 m of wiggler) occupying a small fraction of the total length of the ring. On the contrary for a small ring such as A.L.A. the required wiggler length would be a sizeable fraction of the circumference. It seems more economic to divide each bending magnet into 3 sections that can be separately powered, so as to achieve a bending radius variable with energy (solutions based on kinks in the orbit have been proposed in[5,6]).

At high energy all sections are powered, and the resulting bending radius is 2.5 m. At low energy (.5 GeV) the two end sections of each magnet are switched off, and the center one bends the particles in a 1 m radius. A factor 2.5 on the product M^*/ϱ, and therefore on the beam cross-section is obtained. Fig. 4 shows the schematic layout of one quadrant.

Four quadrupoles are needed to control Q_x, Q_z, β_x^* and β_z^*. Four magnets per quadrant ensure a better focusing distribution. The focusing effect of each kink changes with energy: this can be taken care of by properly choosing the angle of the magnet end faces with respect to the central orbit.

The best damping partition is obtained with zero field index rectangular magnets: in this case, however, since only vertical focusing is obtained, it is difficult to obtain interconnected high energy and low energy solutions. A compromise has been found with a field index n=0, and an end face angle of 5° for the center magnet. According to the existing theory, the luminosity obtained with this solution does not differ very much from the behaviour shown in Fig. 1. It is hoped, however, that the increased damping will favourably affect the maximum tolerable value of ξ_M. The larger energy spread intrinsic in this method may of course be listed as a disadvantage.

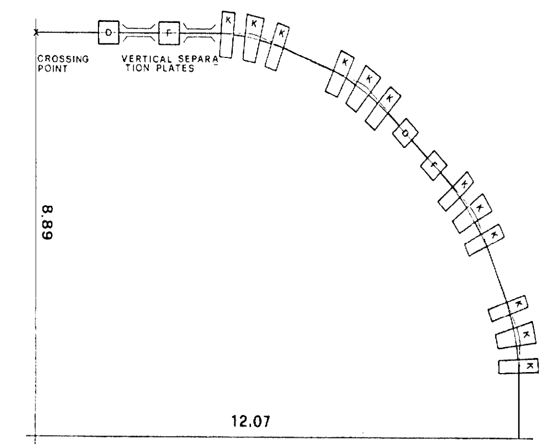

FIG.4 - One quarter of the ring. "Kinks" version.

Injection

Electron injection can be made directly from our Linac in less than a minute. Direct positron injection would require some important modifications to the Linac. Else, a booster has to be used as an interface between the two machines. Present Linac parameters are shown in Tab.I: in order to keep injection time within acceptable limits, it is necessary to improve the positron beam characteristics:

a) by increasing the positron peak current: this can be obtained by replacing the present gun with one capable of delivering an electron current ~10 times larger in a much shorter pulse (~10 ns, which can be accepted by the A.L.A. RF system);

b) by the addition of an energy compressor to decrease the energy spread of the positron beam to ± 2‰.

An injection time of the order of 10 minutes is expected assuming 100% efficient one turn injection: the minimum required ring horizontal aperture is in this case ~140 mm.

Adone could be used as a booster: its low RF frequency, the possibility of injecting 3 bunches at the same time and its large aperture allow for an injection time of the order of 5 minutes with the Linac as it is now. The major drawback is interference with other Adone experiments. We also considered the construction of a small (350 MeV) dedicated booster, capable of being filled at a 25 Hz repetition rate, with single turn injection: the injection time with the present Linac drops to 1÷2 minutes. Moreover, if Adone or the dedicated booster are used for positron injection, the required horizontal ring aperture is determined only by colliding beam operation and can be reduced to ~ 120 mm.

TABLE I

	Peak current (mA)	Energy (MeV)	Energy spread	Emittance (m.rad)
Present Linac	.3	350	$\pm 1 \times 10^{-2}$	$8\pi \times 10^{-6}$
Improved Linac	4.0	350	$\pm 2 \times 10^{-3}$	$8\pi \times 10^{-6}$
Adone (2 σ)		350	$\pm 3 \times 10^{-4}$	$7\pi \times 10^{-8}$
Dedicated booster		350	$\pm 5 \times 10^{-4}$	$3\pi \times 10^{-7}$

Aperture. For colliding beam operation we require a free aperture of $\pm 10\sigma$, plus a 10 mm closed orbit allowance. This corresponds to 120 mm in the horizontal plane and 55 mm in vertical. If a booster is used for injection, no extra aperture is needed. The quadrupole diameter is therefore 120 mm and the magnet gap is 70 mm.

Sextupoles. The sextupole strengths for correcting the ring chromaticity are small (35 T/m^2 max). The effects of nonlinearities have been invesigated using the tracking program TRALA: particles are tracked over a number of turns corresponding to one damping time, but the effect of damping is not included. For a relative energy spread 6 times larger than the natural one, the diameter of the stable region in the x,z plane is much larger than the vacuum chamber free aperture.

RF system. A 51 MHz, 250 KVolt, aluminium RF cavity under vacuum has been designed for A.L.A. Taking into account the power loss for synchrotron radiation and the cavity losses (shunt impedance = 1 MΩ), the total power required from the transmitter is ~60 KW. Fig. 5 shows the prototype 51 MHz RF cavity.

Magnet system. The 24 quadrupoles and 8 magnets are laminated (glued laminations). The bending magnet core is C-shaped for ease of assembly and accessibility to the vacuum chamber. The current density has been cost-optimized and is 5 A/mm .

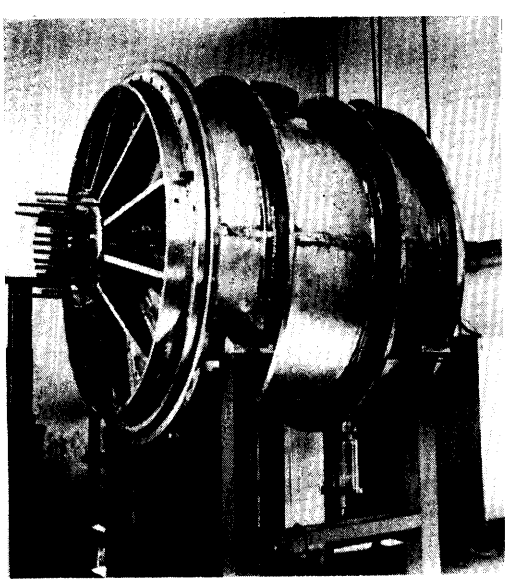

FIG.5 - Prototype 51 MHz RF cavity.

Vacuum system. Distributed pumping inside the bending magnets, turbomolecular and titanium localized pumps are provided to ensure an average pressure of ~ 10^{-9} Torr with beam: the pressure in the experimental straight section can be made a factor 10 better.

PARAMETER LIST (Variable optics)

Energy (GeV)	.5	.8	1.2
Luminosity x 10^{31} (cm^{-2}s^{-1})(ξ_M=.06)	.15	.9	1.4
Stored current (mA)	40	150	150
r.m.s. width at crossing (mm):			
horizontal (zero coupling)	.93	1.49	1.20
vertical (full coupling)	.20	.32	.27
longitudinal	49	95	117
Lifetime (hours)	16	12	10
Center of mass energy resolution (FWHM, MeV)	.45	1.10	2.59
Circumference (m)			70
Experimental straight section length (m)			3.1
Horizontal betatron wavenumber			3.2
Vertical betatron wavenumber			3.2
Horizontal betatron function at crossing (m)			2.0
Vertical betatron function at crossing (m)			0.2
Dispersion at crossing (m)			0 ÷ -1
Momentum compaction			.1 ÷ .23
Invariant M* (m)			.85 ÷ 3
Natural horizontal chromaticity			-6.2 ÷ -7.8
Natural vertical chromaticity			-6.5 ÷ -4.9
RF frequency (MHz)			51.4
Maximum RF voltage (KVolt)			250
Total power from the transmitter (KW)			60
Shunt impedance (MΩ)			1
Bending radius (m)			2.5
Maximum bending field (T)			1.6
Maximum quadrupole gradient (T/m)			8
Maximum sextupole gradient (T/m^2)			35
Magnet gap (mm)			70
Quadrupole free diameter (mm)			120

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