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The ADONE Group presented by S. Tazzari:

DESIGN STUDY FOR THE TRIESTE SYNCHROTRON LIGHT SOURCE

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DESIGN STUDY FOR THE TRIESTE SYNCHROTRON LIGHT SOURCE

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1. - DESCRIPTION OF THE FACILITY

1.1. - General information

The first synchrotron radiation users, back in the sixties, parasitically utilized the radiation from the bending magnets of HEP colliding beam facilities. These were the first generation synchrotron light sources.

With the rapid expansion of the field, dedicated storage rings started being built and novel radiation sources such as wiggler magnets and undulators being developed. These were the second generation.

Third generation machines covering different ranges of photon energies aim at improving the brilliance by several orders of magnitude by optimizing the storage ring magnetic lattices for low emittance and high circulating currents, and through the extensive use of insertion devices. Various third generation machines, covering a wide range of energies, are at present under design.

The approved Trieste Synchrotron Light Source facility belongs to the third generation. It consists of an electron storage ring, optimized at 1.5 GeV but capable of reaching 2 GeV that can accomodate up to fourteen beam lines from insertion devices and up to sixteen beam lines from bending magnets, and of a full energy positron injector.

The main ring has a large number of straight sections capable of accomodating a variety of insertion devices.

The storage ring emittance, in the range of 5 10^{-9} π·m·rad at 1.5 GeV and the design current value of up to 0.4 A in the multibunch mode, allow radiation beams with the highest brilliance, in the range of $10^{18}\div10^{19}$ ph/s/mm^2/.1%/mrad^2, to be produced.

The radiation beam time structure consists of gaussian pulses with a standard deviation in the order of 100 ps (fwhm).

Since several experimental stations can be derived from a single bending magnet or wiggler beam line, more than 30 stations could eventually be made available. An initial complement of 6 beam lines, corresponding to 11 experimental stations, is included in the proposed construction budget.

The injector complex consists of a preinjector linear accelerator followed by a booster synchrotron operating at ten Hertz.

1.2. - Performance specifications by the users

1.2.1. - The main specification concerns the minimum wavelength to be obtained, in the first harmonic, from an undulator magnet. This was indicated by the users to be in the range from 10 to 20 Å corresponding to an energy of $\approx 0.5\div1$ KeV, an energy region lower than and complementary to that for which the third generation high energy, hard X-ray machines under construction (in Europe the ESRF) are optimized.

From the specification of the first harmonic undulator wavelength and of its tunability range, and from the state of the art in storage ring design and in the fabrication of undulator magnets follows the main ring design energy, namely 1.5 to 2 GeV.

1.2.2. - The highest brilliance can only be obtained if the size of the electron beam circulating in the main ring, or better the electron beam emittance (the area occupied by the beam in phase space), are of the same order of magnitude as the minimum x-ray beam size, or emittance, determined by diffraction. For the energy range one is concerned with, the emittance should be in the range of 10^{-8} m·rad, or slightly lower. This requires a special magnetic lattice with very strong focalization.

1.2.3. - The lattice should include a large number of long straight sections to accomodate a variety of insertion devices. Not less than ten long straights should be made available for the purpose, and at least 5 m of free space in each of them should be provided. The betatron functions in the straights should be adjustable to maximize the performance of the insertion devices and minimize harmful effects possibly deriving from their installation.

1.2.4. - A long electron beam lifetime in the order of many hours, and therefore a very high vacuum inside the beam enclosure, has also to be achieved. Furthermore, scattering on the residual gas and intrabeam scattering have to be carefully considered in the energy range one is dealing with.

1.2.5. - A time structure consisting of very short intense pulses, and with variable time interval in between pulses is also desired. In particular it is important to foresee a mode of operation where a single intense bunch is present in the machine.

1.2.6. - The radiation beam spot size at the location of the experiment, tens of meters away from the source point, can be of the order of of a few tens of micrometers. A large number of beams each of which has to be reproducibly positioned to that accuracy, and kept stable over weeks and months of operation has to be provided. This requires special care in the selection of the site, the control of ground vibrations, and the design of the lattice, of the beam monitoring and control equipment, of the magnet supports and of the ancillary equipment.

1.3. - Design options

1.3.1 - Energy

A maximum energy of 2 GeV has been chosen for the present design study; the lattice is however optimized to give the design emittance at 1.5 GeV. The resulting[1] brilliance and tunability of the radiation beams originating from typical undulators are shown in Fig. 1, taken from Ref. [1].

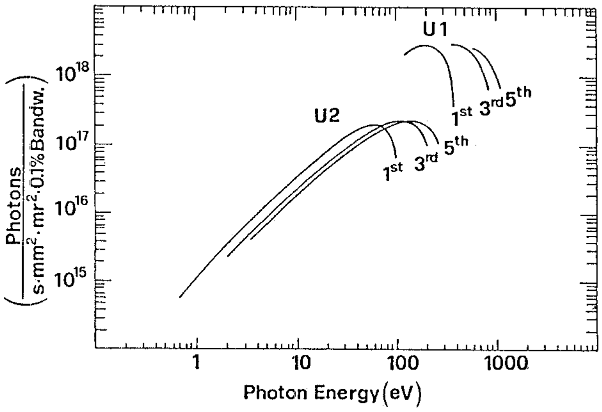

FIG. 1 - Average spectral brilliance as a function of photon energy for two typtical undulators.

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1.3.2. - Choice of the lattice

In the design of low emittance lattices one has to deal with a number of problems connected with the strong focussing leading to strong geometric and chromatic aberrations and extreme sensitivity to magnetic and alignment imperfections, and with current and lifetime requirements.

Systematic work on this subject, by various groups in Europe and in the USA [2,3], has started only in the past three to four years. Since one is dealing with complicated nonlinear dynamics problems, the main tools to study a lattice performance are numerical codes. One is forced to simulate the behaviour of many particles circulating in the machine, following them over a large number of turns. The work is very time consuming and a large number of parameters is involved so that no simple rule exists for optimizing the overall source performance.

It is therefore also of paramount importance that the lattice be flexible enough to allow for improvements, modifications and unforeseen modes of operation to come up during the machine commissioning and operation.

In the present design study it was felt important not to duplicate efforts being pursued elsewhere [2,3], but to explore the feasibility of new or not fully studied solutions. While providing a sound basis for a cost and feasibility estimate, the lattice would thus also provide a further valuable term of comparison with other proposed solutions before the design is finalized. A few promising configurations [4] have been considered in addition to the lattice presented here and further work is needed before a final decision on the lattice can be reached.

One of the main options available to the designer is the choice of the lattice periodicity. This determines the machine circumference and the maximum number of long straight sections but also affects many other relevant parameters. It influences both performance and cost and may be influenced by the choice of the site.

The solution presented here, of a sixteen period main ring with twelve to fourteen long straights available for the experiments, was arrived at on the basis of several arguments. The number of straights is fulfilling the specification with some margin. A higher periodicity than usual for rings of similar size is beneficial in that it allows for the design emittance to be reached with a relatively 'relaxed' lattice, to the advantage of reliabilty and flexibility and therefore of overall performance. In comparison with similar projects it fully exploits the unique features of the proposed site - size and ground quality - at an extra cost that is minor on the scale of the whole project. Furthermore, a larger than minimum circumference is expected to pay off in terms of future unforeseen developments.

2. - LATTICE DESCRIPTION

Several types of low emittance lattices have been proposed for synchrotron radiation dedicated storage rings. They are mainly constrained by the condition of vanishing dispersion in the straight sections where the insertion devices are to be installed. The insertion straights must therefore be connected to each other through curved sections having vanishing dispersion and vanishing first derivative of the dispersion at both ends. Such curved sections are called "achromats", and the lattice has one achromat per period.

Various solutions have been studied, to different levels of optimization, as possible candidates for the Trieste machine, and have shown comparable performance in terms of non linear behaviour and lattice sensitivity to magnetic and alignment imperfections.

An ECG strucure that has been studied in the most detail is used in the present design study for several reasons: it provides a sound basis for a cost estimate, it has an overall performance in some respect superior to that of other solutions (with a somewhat more complicated sextupole arrangement) and finally it provides, at design study level, a much needed comparison with other lattices notably the LBL (Berkeley) synchrotron radiation source.

The "Expanded Chasman-Green" (ECG) achromat is an attempt at combining the best features of the Chasman-Green (CG) and the FODO schemes. It consists of two bending magnets separated by an arbitrary odd number of quadrupoles of alternating polarity in a typical FODO arrangement.It is characterized by rather small values of the ß functions within the achromat which is a good feature. However, the horizontal and vertical ß functions are in general not too well separated and the dispersion function is small ewerywhere in the lattice so that the sextupole strengths required to correct the chromaticity are in general larger than those required for a CG.

In the absence of site restrictions we were led to explore the advantages to be obtained from a rather large machine circumference and a larger than usual number of achromats. We therefore chose a periodicity of sixteen that provides, for a limited cost increase, at the same time a larger complement of experimental beam lines and a more flexible, reliable machine.

A second lattice has also been studied in some detail that exhibits a performance comparable to that of the proposed ECG with a smaller number of magnetic elements and shorter (233 m instead of 300 m) but with the same number and length of insertion straights[4]. It is not being proposed as a first choice in the present study because it has not been fully analyzed yet. It is however the object of further work and we believe it could turn out to be a further important candidate for an optimized facility.

A list of parameters of the linear ECG lattice is given in Table I. Fig. 2 shows the behaviour of the optical functions over one period. The one standard deviation maximum sizes of the gaussian beam are shown in Fig. 3., the horizontal beam sizes correspond to no coupling while the vertical ones correspond to full coupling.

TABLE I - Parameters of the linear lattice

Energy (Gev)	1.5		2.0
Natural emittance (m.rad)	$4.7\text{x}10^{-9}$		$8.4\text{x}10^{-9}$
Natural energy spread	$5.7\text{x}10^{-4}$		$7.6\text{x}10^{-4}$
Momentum compaction		$6.8\text{x}10^{-4}$	
Horizontal betatron tune		19.830	
Vertical betatron tune		11.643	
Natural horizontal chromaticity		-32.43	
Natural vertical chromaticity		-22.92	
Circumference (m)		300.22	
Horizontal betatron damping time (ms)		33.8	14.2
Vertical betatron damping time (ms)		33.5	14.1
Number of periods		16	
Number of bending magnets		32	
Bending radius (m)		5.0	
Field index		0	
Shape		Rectangular	
Bending field (T)	1.0	1.333	
Number of quadrupoles		176	
Number of independent quadrupole families		6	
Maximum gradient (T/m)	12.8		17.0

A detailed description of the lattice including apertures, effects of systematic and random filed errors, sensitivity to alignment and closed orbit correction, is given in Refs. [4,5].

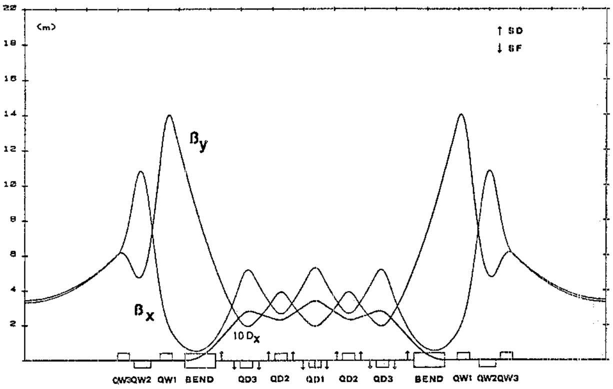

FIG. 2. - β functions and dispersion in one period of the ECG structure.

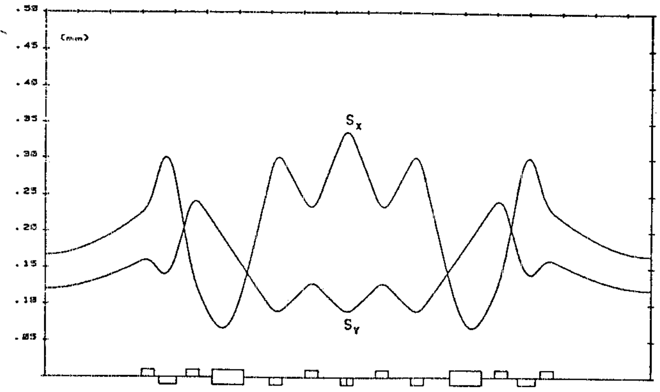

FIG. 3 - R.m.s. beam size in one period of the machine at maximum energy (2 Gev). The horizontal beam size is calculated without coupling, while the vertical is in full coupling.

3. - THE INJECTOR

The basic design choices for the injector complex concern the type of stored particle (electrons or positrons) to be stored, the injection energy and the repetition rate.

The question of electrons versus positrons has considerable implications concerning the size and cost of the preinjector. The reason for considering positrons is that an electron beam can, under certain circumstances, trap ions created in the residual gas. The trapped ions, besides possibly altering the local residual gas pressure, produce strongly nonlinear fields that can drive resonances, instabilities and coupling of the vertical to the horizontal motion, thereby blowing the emittance up, lowering the lifetime and in general leading to less stable beams.

For very low emittance lattices one would predict ion trapping to be impossible or easily avoidable under most operating conditions. However the theory is in qualitative agreement only with the scarce experimental results available on existing storage rings. Furthermore, very few data are available on rings with the kind of performance one is considering for third generation machines. Given also that the achievement of the design brilliance is the main justification for the construction of the source, the additional safety margin provided by a positron injector is considered well justified.

The injector is designed to easily reach the main ring maximum design energy of 2 GeV. Several reasons can be given. First, the desired beam orbit position stability and reproducibility, requiring a significant improvement over the present state of the art, do not seem to be achievable if the ring magnets have to be ramped from injection energy to full energy at every injection cycle.

Second, the very good vacuum necessary for the source to reach its design lifetime will only be achieved after a conditioning corresponding to about 150 A·h of circulating full energy beam. The conditioning time has to minimized when, as is the case for SR sources, frequent openings of the vacuum vessel to air are foreseen. With a full energy injector it can be kept in the order of a few days of continuous operation. An inadequate injection energy, entailing too low an effective injection rate , could stretch this time to a point where the machine performance would be seriously jeopardized.

In order to further enhance the overall injection efficiency the booster has also been designed to provide a rather low emittance ($\approx 6\ 10^{-7}\ \pi$ m rad at 2 GeV).

Following the above considerations, an injector complex consisting of a positron preinjector Linac followed by a low emittance 2 GeV booster synchrotron is proposed. The Linac is designed for optimum cost effectiveness and uses an advanced RF-pulse compression scheme. The positron energy is 220 MeV, allowing for easy injection into the booster. The booster operates at 10 Hz, a value that guarantees high injection rates and ease of operation while still avoiding the special technical solutions that would be required for much higher repetition rates. The design positron injection rate is such that the main ring can be filled to its maximum design current of .4 A in less than 10 minutes.

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