ELSA, A STRETCHER AND POST ACCELERATOR FOR THE BONN 2.5-GEV ELECTRON SYNCHROTRON

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Abstract

ELSA (Electron Stretcher and Accelerator) operates in two different modes. Up to the maximum energy of the synchrotron it works at a constant magnetic field. The electrons from the synchrotron which runs at 50 Hz repetition rate are injected, stored, and ejected at a constant rate. In this operation mode the macroscopic duty cycle is 95 % at least. In the operation mode of post acceleration which is possible up to 3.5 GeV the duty cycle is reduced to 60 %. The intensity in this operation mode is 5 % of that in the stretcher mode. Higher intensities are available at lower duty cycle. ELSA mainly is dedicated to feed a tagged photon facility.

Introduction

The Bonn 2.5 GeV Electron Synchrotron which started operation in 1967 is working for about 6000 hours per year for elementary particle physics. A small part of the operation time is given to users of synchrotron radiation, too. The internal beam intensity has been increased to a record of 95 mA. Most of the high energy physics experiments, however, are working at reduced machine intensity because of accidental coincidence rate problems at the beam duty cycle of 5 %.

For a new generation of experiments with multiparticle final states - most of them are planned to be carried out with help of tagged photons - a crucial increase of the beam duty cycle is necessary[1].

A second demand of the elementary particle physicists is to get high energy beams up to 3.5 GeV to allow experiments on vector mesons at masses up to 1.8 GeV, for instance.

In 1979 we proposed to build a new particle physics laboratory including ELSA[1,2]. The high energy electrons had to be transferred through a 300 meter long beam line from the existing 2.5 GeV synchrotron to ELSA. But due to the bad financial situation this proposal had to be reduced to the machine itself and a tunnel for it's installation[3]. In this new concept particle physics has to be carried out in the existing experimental areas at the 2.5 GeV synchrotron and in the hall of the still operating 500 MeV synchrotron which from that reason will be closed down in 1984.

Compared to other present-day proposals of "Stretchers" and "CW-Microtrons" in the medium energy range ELSA is a low intensity machine mainly destinated to feed a tagged-photon facility[4,5,6].

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Beam Properties

ELSA has been specified to produce electron and bremsstrahlung beams at high duty cycle. Up to the maximum energy of the synchrotron ELSA works as a stretcher. At a maximum rate of 50 Hz, pulses of high energy electrons from the synchrotron are injected into ELSA. Short after injection the ejection of electrons from the circulating beam begins. The constant rate of ejected electrons empties the machine within 20 msec or more (see fig.1). The duty cycle of this stretcher mode only depends on the time needed to switch the machine from stable injection to resonant ejection operation. A gap of 1 msec in the external beam perhaps might appear, so that the duty cycle amounts to 95 %. The number of electrons circulating in ELSA differs from that in the synchrotron by the efficiencies of synchrotron ejection and ELSA-injection. For very low intensities the injection rate might be reduced to 2 Hz. Storage and ejection time then becomes 500 msec.

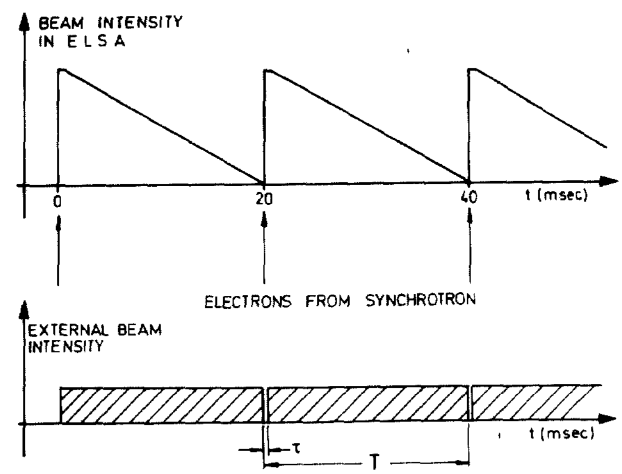

Fig.1

In the case of post acceleration, time for ramping up and down the magnetic field is necessary. The electrons from the synchrotron are transferred to ELSA at an energy of 1.75 GeV. Therefore the maximum field change is a factor of two. To save electrical power the times for ramping up and down are fixed to 150 msec either. To obtain a high duty cycle one has to eject the electrons during a flat top as long as possible. For ELSA a maximum length of the high energy flat top of 500 msec is foreseen. Together with a 20 msec injection flat top the duty cycle then is about 60 %. In the case that two pulses of electrons from the synchrotron are transferred to ELSA the intensity of the external beam is roughly 5 % of that in the pure stretcher mode. Intensities up to 30 % may be obtained at a reduced duty cycle (see fig. 2).

The beam from ELSA has a bunch structure corresponding to the 500 MHz RF-acceleration. The microscopic duty factor of the bunch structure is not included in the above given numbers for the duty cycle.

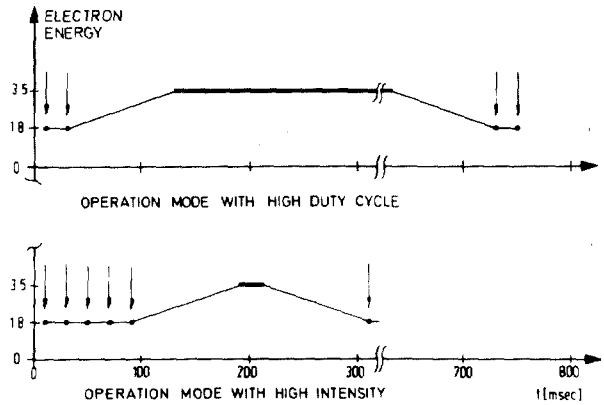

Fig.2

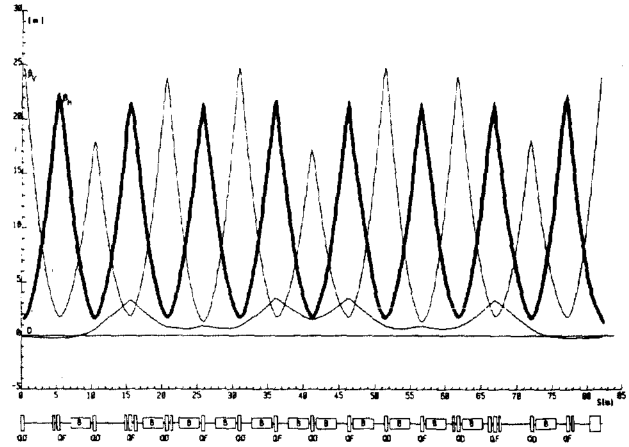

Fig.3

Lattice and Optics

As in the case of a synchrotron the most important aspect for the lattice and optics design of a stretcher is that of beam extraction. In addition to that aspect other criteria might to be considered and to be combined with the first one. In the case of ELSA we had to enable a beam storage time in the order of one second to obtain a high duty cycle in the operation mode of post acceleration. Therefore the ELSA-lattice is of the separated function type which ensures radiation damping of the horizontal betatron oscillation together with a wide range tunability of the betatron working point for resonant extraction purposes. Another feature of the ELSA-lattice is the insertion of long straight and dispersion free sections. They are foreseen for installation of long RF-cavities, the injection system, one of the two extraction systems and perhaps for other equipment later on.

According to the above given design criteria the ELSA-ring is composed of 16 FODO-cells, each about 10 meters in length. Only 24 of the 32 half cells of the ring contain one bending magnet each. The bending magnet is inserted asymmetrically between the F- and the D-quadrupole to make available a hanging together straight section as long as possible.

To obtain long straight sections with vanishing dispersion we use the "missing magnet" concept[7]. This leads to a ring configuration as shown in figure 4.

From beam extraction point of view it is advantageous to have a smooth behaviour of the horizontal beam envelope (in case of horizontal extraction), i.e. a small or even no modulation of the radial β-function maxima along the orbit. To achieve this behaviour one has to arrange a very regular lattice with almost equal horizontal focusing power per cell. Therefore we use rectangular type bending magnets with small radial focusing effect. As the quadrupole strength variation for matching to the dispersion free straight sections is small only (below 7 % within one quadrupole family) the demand for a smooth horizontal beam enveloppe is satisfied. Figure 3 shows the β-functions and the dispersion function for half the ELSA-ring at a tune $Q_x = Q_z = 5.4$.

Operating ELSA in the pure stretcher mode the ring is tuned to the horizontal betatron resonance for extraction by the main quadrupoles. Only during the short time of injection the ring is tuned to stable condition with help of a few auxiliary quadrupoles which are pulsed.

In the post acceleration mode of operation the main quadrupoles have to be tracked proportionally to the electron energy. To tune the ring from stable condition during injection and acceleration time to resonant condition at upper flat top quadrupole tracking is not exactly proportional to the electron energy. A fine tune at flat top may be done by auxiliary quadrupoles.

Due to our calculations concerning beam extraction we plan to operate ELSA at a horizontal betatron tune around five. Table 1 gives the main lattice and optics data of the ELSA-ring.

Table 1: Lattice and Optics Data

bending radius	10.84	m
circumference	164.4	m
number of FODO-cells	16	
length of FODO-cells	10.28	m
number of dipoles	24	
number of quads	32	
length of dipole core	2.84	m
length of quad core	0.45	m
at 3.5 GeV and $Q_x = Q_z = 5.4$:		
magnetic field strength	1.08	T
strength of F-quad	0.78	m^{-2}
strength of D-quad	0.75	m^{-2}
momentum compaction factor	4.6	%
damping times: horizontal	3.1	msec
vertical	3.1	msec
energy	1.6	msec
maximum horizontal β-fct.	22.2	m
minimum horizontal β-fct.	1.54	m
max. vertical β-fct.	24.6	m
min. vertical β-fct.	1.26	m
max. dispersion fct.	3.42	m
natural energy width	0.09	%
natural horiz. emittance	0.76	mm x mrad
natural chromaticity		
horiz.	-9.1	
vert.	-8.4	

Magnets and Power Supplies

The ELSA-ring contains 24 main dipoles and 32 main quadrupoles. Besides them there are correction dipoles, auxiliary quadrupoles, higher multipoles, kicker and septum magnets. Until now only the main magnets are designed.

Dipoles

The C-type yoke is stacked in parallel from steel laminations of 1 mm thickness. To reduce the aperture requirement for sagitta effects the laminations are stacked with small transversal displacements from one to the other so that the final stack is curved. The lamination stack is held together by special steel slabs which are welded to the stack. The choice of the steel is determined by the high field characteristics and in connection with field ramping by it's electrical conductivity. So we have

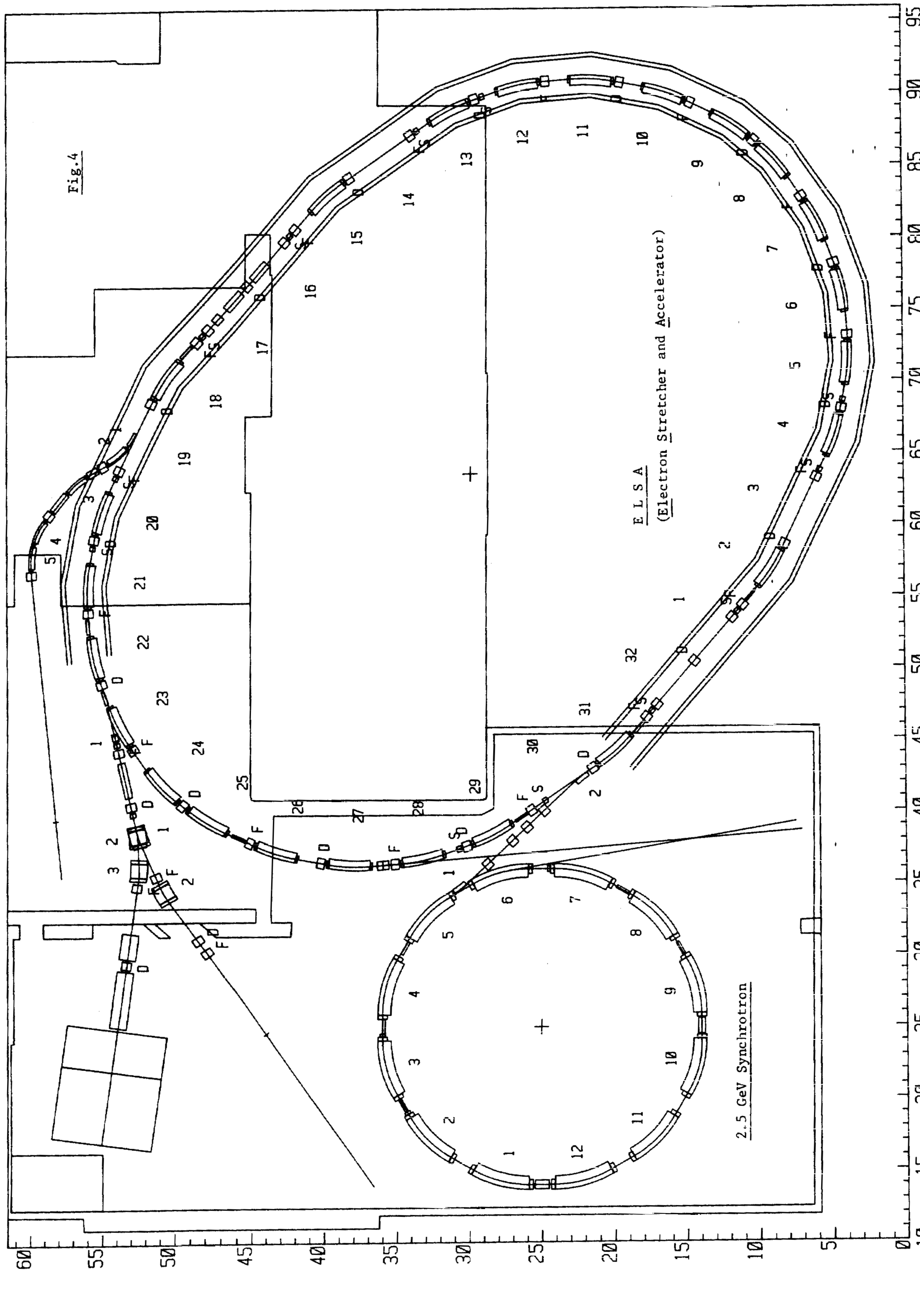
E L S A
(Electron Stretcher and Accelerator)
2.5 GeV Synchrotron

Fig.4

chosen a mild steel with a Carbon content below 0.005 % but a Silicium content of 1.5 %.

The air gap magnetic flux density at 3.5 GeV is 1.08 T only. This value has been chosen as a compromise between the demands for a small outline of ELSA and low operation costs.

For field excitation the yoke bears two copper coils with 7 windings each. The low number of windings keeps down the inductance and thereby the maximum voltage and power of the dipoles while ramping up and down. The disadvantage of the low number of windings is the high current of 3090 A at 3.5 GeV. The copper cross section of one winding is 638 mm^2 resulting in a maximum current density of 4.85 A/mm^2 which still is moderate for a water cooled copper conductor. To reduce local eddy current effects each winding is composed of 6 conductors in parallel. To reduce also "equalizing currents" between the 6 conductors of one winding the connection from one coil to the other of one magnet is arranged in a special manner.

The maximum speed of current change while ramping up or down the magnet field is 10.3 KA/sec.

Table 2: Dipole Data

core length	2.84	m
gap height	5	cm
gap width	16	cm
"good field" region of gap	8	cm
cross section of lamination (width x height)	52 x 51.5	cm^2
maximum magnet flux density in air gap	1.08	T
number of coils	2	
number of windings	14	
cross section of winding	638	mm^2
resistance at 35°C	2.8	m Ω
current at 1.08 T	3090	A
power at 1.08 T	26.7	kW
inductance	2.6	mH
max. speed of current change	10.3	KA/sec
induced voltage per dipole at 10.3 KA/sec	26.8	V

Quadrupoles

The quadrupole design is derived from that of the PETRA standard quadrupoles[8]. The modifications are: The steel lamination thickness is reduced from 5 to 1 mm with respect to eddy current effects. The steel itself is the same as we use for the dipoles. The core length is 45 cm only. The coils are wound from copper conductor in our case. The number of windings per pole is 11, but each winding is composed of 4 single copper profiles again. As in the case of the dipoles the single conductors of the quadrupole coils are connected in a certain manner that "equalizing currents" are deminished.

Table 3: Quadrupole Data

length	45	cm
aperture	10	cm
lamination thickness	1	mm
number of windings per pole	11	
cross section of winding	286	mm^2
resistance at 35°C	4.38	m Ω
inductance	2	mH
max. field gradient	10	T/m
max. current	910	A
max. power	3.44	kW
max. speed of current change	3.03	KA/sec
induced voltage per quad at 3.03 KA/sec	6	V

Power Supplies

The 24 main dipoles of ELSA are connected in series, the same with the two families of quadrupoles (F-quads, D-quads). Each of the three circuits is powered by it's own stabilized current supply. The main problem of these power supplies is that of very different voltage and power requirements during ramping intervals on one hand and during flat top intervals on the other hand. In the case of the dipoles - which is the worst case - a maximum peak voltage of 850 V and a maximum peak power of 2.63 MVA is needed while ramping up to 3.5 GeV. During the 3.5 GeV flat top, however, only 208 V and 0.64 MVA is necessary. Supplying the power by a normal thyristor controlled generator causes a high reactive power consumption during flat top. Therefore a special supply has been developped. It consists of two different generators, one for ramping purposes and a second for flat top operation. In the case of the quadrupole supplies the problem is less important because of the lower power. Therefore here it is convenient to use normal supplies.

For operating ELSA with post acceleration the quadrupole fields have to be tracked in a well defined way. This will be guaranteed with help of microprocessors in each of the three main power supplies which are controlled again by the central ELSA-computer.

The small differences in the field strength of the quads of one family for matching purposes are provided by transistor shunts to the quads.

RF-System

The early proposed stretchers for low energies were designed for operation without an RF-acceleration system[9,10,11]. At our energy level it is nearly impossible to abandon the RF-acceleration. In the case of ELSA where we want to do post acceleration a RF-system is absolutely necessary.

The RF-frequency is 500 MHz like in the case of the 2.5 GeV synchrotron. The energy loss of the electrons per turn changes from 0.5 KeV at 500 MeV to 1.2 MeV at 3.5 GeV. For a beam quantum lifetime of 10 seconds a peak voltage of 2.5 KV at 500 MeV and 3.05 MV at 3.5 GeV have to be supplied. For an efficient voltage supply concerning power consumption from the network, two separate RF-systems are foreseen. The first one consists of a 40 KW transmitter and one DORIS-cavity[12]. This system is sufficient for the pure stretcher mode of operation up to 2 GeV at an intensity of 5 x 10^{10} electrons circulating in ELSA. The second system (which will be installed somewhat later) uses a 250 KW transmitter together with 2 PETRA-cavities[13].

Table 4: Data of the RF-systems

revolution frequency	1.82	MHz
RF-frequency	499.67	MHz
harmonic number	274	
energy loss per turn at 500 MeV	0.5	KeV
at 3.5 GeV	1.22	MeV
peak voltage for 10 sec qu. lifetime at 500 MeV	2.5	kV
at 3.5 GeV	3.05	MV
radiated power of 5 x 10^{10} electrons at 500 MeV	7.5	W
at 3.5 GeV	18	kW
System I		
number of cavities	1	
shunt impedance	3	MΩ
transmitter RF-power	40	kW
System II		
number of cavities	2	
shunt impedance (total)	36	MΩ
transmitter RF-power	250	kW

Vacuum-System

Both Bonn Synchrotrons operate well with vacuum chambers made from ceramics since years. Therefore we invented the possibility to use a Al_2O_3-chamber for ELSA, too. But it turned out that a chamber of this kind is at least three times as expensive as a corrugated stainless steel chamber. This type of chamber is approved in some synchrotrons and is available from industry. Our chamber for inside the main dipoles and quadrupoles is produced from 0.3 mm thick stainless steel and has an elliptical cross section with a clearance of 100 mm in the horizontal and 40 mm in the vertical direction. The chamber for outside the magnets is made from aluminium pipe.

The design pressure value is 10^{-8} Torr which is kept by ion sputter pumps. These pumps have a nominal pumping speed of 270 l/sec and there is one pump per half cell. Additional pumps will be applied to components inserted into the straight sections.

For pumping down from atmospheric pressure to the UHV-region turbomolecular pumps are used.

Injection

The circumference of the ELSA-ring is larger by a factor of 2.35 than that of the 2.5 GeV synchrotron. To obtain a 100 % filling of the ELSA-ring with one electron pulse from the synchrotron it is necessary to extract the electrons from the synchrotron during several turns. It is foreseen to do extraction by a shaving method[14,15]. The efficiency of this method, however, drops down with the number of turns for extraction. So we will try to get a homogenous filling of ELSA with a three turn extraction. Another possibility for a high efficient short time extraction might be the fast resonant method[16]. It still is under study.

As the horizontal damping time for ELSA at 1.75 GeV is near to 20 msec it is possible to inject more than one pulse from the synchrotron into ELSA. This scheme allows to operate ELSA at higher intensities in the post acceleration mode. The injection scheme itself is the conventional storage ring injection. The demands to kickers and the septum magnet are not out of the today's possibilities.

More attention has to be paid to the extraction hardware of the synchrotron because of the small electron revolution time of 230 nsec in that machine.

Extraction

To get a high duty cycle beam a slow resonant extraction has to be used. To get a constant rate of extracted electrons for intervals up to 500 msec it is necessary to have a good control of the betatron tune and the higher multipole magnetic field. Another point is the choice of an optimal betatron tune (third or half integer?). Our considerations and calculations guided us to use a third integer resonance. In our case it is not crucial to empty the machine down to 1 % of the primary beam intensity. But we need a soft resonance to obtain a spill time of up to 500 msec. For this aim we also study the stochastic extraction with a wiggler control[17].

Status

The construction of ELSA has begun in 1982 already. We spent a 3 MDM for machine components. Tunnel construction will begin this early summer and be finished in spring of next year. ELSA will be ready to operate in the stretcher mode at the end of 1985. Operation of post acceleration mode will be possible one year later.

References

1) Vorschlag für den Bau eines Stretcherringes am 2,5 GeV-Elektronensynchrotron der Universität Bonn, Internal Report BONN-IR-79-31 (Oct. 1979)
2) K.H. Althoff et al., Proc. 11th Int. Acc. Conf., CERN 1980, p.196
3) Vorschlag für den Bau eines Stretcherringes am 2,5 GeV-Elektronensynchrotron der Universität Bonn (revidierte Fassung Mai 1982), Internal Report BONN-IR-82-17 (May 1982)
4) Proposal for a National Electron Accelerator Laboratory 1982 (NEAL), Southeastern Universities Research Association, October 1982
5) H. Herminghaus et al.: The Design of a Cascaded 800 MeV Normal Conducting C.W. Race Track Microtron, Nucl. Instr. a. Meth. 138 (1976), 1-12
6) GEM, a National CW GeV Electron Microtron Laboratory, Argonne National Laboratory, ANL-82-83
7) E. Keil: Single-Particle Dynamics - Linear Machine Lattices, Proc. First Course of Int. School of Part. Acc., Erice 1976, p. 22
8) PETRA, Updated Version of the Petra Proposal, DESY, Hamburg Febr. 1976
9) R.A. Beck et al.: ALIS, avant project d'un Anneau lisseur de cycle de l'accelerateur lineaire de Saclay ALS 300; Department du Synchrotron Saturne, DSS/SOCALIS 32, SE FSTD 70.65 (Oct. 1970)
10) R. Servranchx: EROS, The Electron Ring of Saskatoon; Proc. of the Int. Conf. on Photonnuclear Reactions and Applications, Asilomar Conf. Grounds, March 1973, p. 1039
11) G. Loew: Properties of a Linac-Storage Ring Stretcher System; SLAC-PUB-2262, Febr. 1979
12) Vorschlag zum Bau eines 3 GeV-Elektron-Positron-Doppelspeicherringes für DESY, DESY, Hamburg Sept. 1967
13) H. Gerke, H.P. Scholz, M. Sommerfeld, A. Zolfaghari: Das PETRA-Cavity; Interner Bericht DESY PET-77/08 (Aug. 1977)
14) L.N. Blumberg et al.: Fast Extraction of Debunched AGS Beam, Proc. US Nat. Part. Acc. Conf. 1971, IEEE Trans. Nucl. Sci. NS-18, No. 3, 1009 (1971)
L.N. Blumberg et al.: BNL Fast Shaving Extraction System, Proc. IXth Int. Conf. on HE Acc., Stanford 1974, 462 (1974)
15) C. Bovet et al.: The Fast Shaving Ejection for Beam Transfer from the CPS to the CERN 300 GeV Machine, Proc. US Nat. Part. Acc. Conf. 1973, IEEE Trans. Nucl. Sci. NS-20, No.3, 438 (1973)
16) A. van Steenbergen a. M. Month: Three Turn Resonant Fast Extraction, Proc. VIIth Int. Conf. on HE Acc., Yerevan 1969, 578 (1969)