IEEE Transactions on Nuclear Science, Vol. NS-30, No. 4, August 1983

ALS II : THE SACLAY PROPOSAL FOR A 2-GeV, CW ELECTRON FACILITY

B. Aune, C. Grunberg, M. Jablonka, F. Koechlin, J. Magne, A. Mosnier, B. Phung and F. Netter

DPh-N/AL, CEN Saclay, 91191 Gif-sur-Yvette Cedex, France

Abstract

The transformation of the Saclay electron linac facility (ALS) into a 2 GeV, 100 μA CW electron facility is described. Polarized electrons will be available in the whole energy range. In order to reach the required performances, the linac is rebuilt with new klystrons and with the addition of a partial recirculation. The 100 % duty cycle is obtained with a stretcher ring.

Introduction

The development of electronuclear and photonuclear physics requires in all the concerned laboratories the use of 100 % duty cycle, high intensity electron beams, with a further step in energy in order to study higher momentum transfers and quarks in nuclei. Studies have been undertaken for several years at ALS Saclay[1] to define a physics program as well as a new facility, and now give rise to a complete project, ALS II. The accelerator part of this project is described here. The main characteristics of the project are given in table I.

Table I

ALS II project parameters

Energy range	0.5 to 2 GeV (at full intensity)
Average current	≃ 100 μA
Duty cycle	≃ 100 %
Energy spread	$< 10^{-3}$
Polarization	longitudinal or transverse at all energies

In order to use the greatest part of the existing facility (a 600 MeV, 180 m., 1 % duty cycle linac), it has been decided to add a stretcher ring to the linac, and to modify the latter in several steps, reaching finally the parameters indicated in table I. Priority has been given to obtaining a 100 % duty cycle electron beam, first at the presently available energy, then at 1.3 GeV max, 100 μA, by installing new klystrons, and finally at 2.0 GeV, 100 μA (and 3 GeV, 20 μA) by using a single head-to-tail recirculation. This last step includes the construction of new experimental halls (Fig. 1), as experiments with electrons of energies up to 1.3 GeV only can be performed in the existing halls.

The linac transformation

A one-turn injection into the stretcher ring has been chosen, in order to optimize the transverse phase space in the ring and the extracted beam emittance ; it is then a good compromise to use 1 μsec beam pulses from the linac and a 300 meters circumference ring.

The new linac will be built at a reduced cost, as it will make use of the existing tunnel, of the existing accelerating structures and of a new high power klystron from Thomson-CSF (25 MW, 40 kW, efficiency 45 %). The characteristics of the new linac are given in table II.

Table II

New linac parameters

Number of sections	23
Peak RF power/section	25 MW
Average RF power	40 kW
No-load accelerating field	13 MeV/m
Maximum peak current	200 mA
RF pulse length	2 μsec
Beam pulse length	1 μsec
Max.repetition rate	500 Hz
No-load energy	1.75 GeV
Energy at $\bar{i}$ = 100 μA	1.3 GeV

Due to obvious limits in average RF power per section, the beam duty cycle is limited to 5×10^{-3}, resulting in a high peak current operation. Beam break-up and beam loading problems must then be examined carefully. Concerning beam break-up, since our linac has already accelerated a 40 mA, 10 μsec beam, with an electric field of 2 MeV/m, the acceleration of a 200 mA, 1 μsec beam with an electric field of ≃ 10 MeV/m should not pose any problem.

Transient beam loading is important, because the RF structure filling time is comparable to the beam pulse duration and the structure impedance is high. The compensation method, which consists in switching on successively different sets of klystrons, is well known.[2]

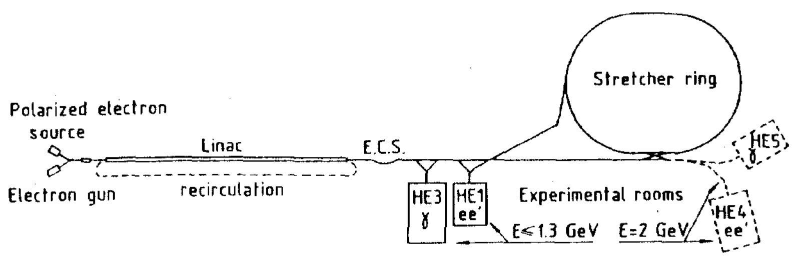

Fig. 1 - Layout of the new facility designed at ALS Saclay. 1st stage : 1.3 GeV, 100 % d.c. 2nd stage : 2 to 3 GeV (dashed lines).

Positron acceleration, presently performed at Saclay in order to produce monochromatic photon beams, is not planned for the future facility, as it is thought that photon tagging will be thoroughly implemented. Conversely, it is planned to supply polarized electrons with either longitudinal or transverse polarization in the two electron scattering experimental halls.

Computations and simulation measurements on the present linac have been carried out and are reported elswhere.[3] According to this work , it seems reasonable to expect an energy dispersion of the order of 1 % at the linac exit , even with recirculation. An energy compression system of a classical design[4] will be installed to reduce this energy dispersion down to about 10^{-3} before injecting into the ring.

0018-9499/83/0800-3296$01.00© 1983 IEEE

The new linac is shown in Fig. 3. Part of the existing linac (23 sections out of 27) will be rearranged (Fig. 2) in the existing tunnel to provide space for focusing, beam monitoring, and for installing the energy compression system. The maximum beam energy as a function of average current is shown in Fig. 4 (curve 1).

In order to reach an energy of 2 GeV with an average current of 100 μA, a straightforward solution is to add 13 new accelerating structures and klystrons to the 23 units described here. However, in order to save investment cost and electrical power, it is wiser to plan a single recirculation[5] (Fig. 3). Due to the large amount of beam loading in the proposed operation mode, a head-to-tail recirculation is necessary, as it should avoid any transient electric fields in the waveguides. Thus, the time associated to the linac length and the recirculation path must be equal to beam pulse duration t_B, i.e. 1 μs. For this reason, the beam is recirculated through the 20 last RF structures only. In this mode of operation, the repetition rate is 400 Hz only. The no-load energy is about 3.3 GeV, and the energy is 2.4 GeV at $\bar{i}$ = 80 μA ($\hat{i}$ = 200 mA). It is possible to obtain higher average currents, e.g. $\bar{i}$ = 100 μA at 2 GeV, by increasing the repetition rate. Then, above $\bar{i}$ = 80 μA, the maximum beam energy varies like $\bar{i}^{-1}$ (curve 2 in Fig. 4).

The injector

In order to insure a 100 % capture at injection into the ring, the beam has to be bunched at the RF frequency of the ring. This one must then be a subharmonic of the linac frequence F_0 (F_0 = 3000 MHz). The frequency of 600 MHz ($F_0/5$) has been chosen, because none of its harmonics is equal to 3/2 F_0 which falls within the passband of the BBU mode in our section. In the 600 MHz chopper and prebuncher cavities, as well as in the 3000 MHz buncher which follows, space charge will be five times larger than in a conventional injector. This effect is being studied with the PARMELA code.[6] An energy of 20 MeV is expected at the exit on the injector. The emittance should not be greater than 5π mm.mrad.

The stretcher ring

The purpose of the stretcher ring is to change a pulsed, low duty cycle beam from the linac into an almost cw electron beam ; the principle is well known since the ALIS project.[7]

For the present project, a 300 m. circumference ring with a single turn injection and about 2000 turns resonant extraction has been chosen. The ring configuration is classical - a FODO lattice with a betatron phase advance of 60° per cell - and its characteristics are summarized in table III. The design includes two long achromatic straight sections (24 m.) and two short ones (6 m.) (Fig. 5).

Due to the 2000 to 2500 turns extraction period, the synchrotron radiation losses must be compensated by an RF accelerating voltage. The choice of a 600 MHz frequency allows the use of a structure with a small number of cells (1 to 3), so as to avoid instabilities. This frequency is high enough in order that the beam microstructure be compatible with the response time δt of the detectors (no difference with a 1000 MHz RF as long as δt ≥ 1 ns). The RF structure will probably be of a type developed for the PETRA ring,[8] with a shunt impedance of 15 MΩ. It will be supplied with a 55 kW television klystron.

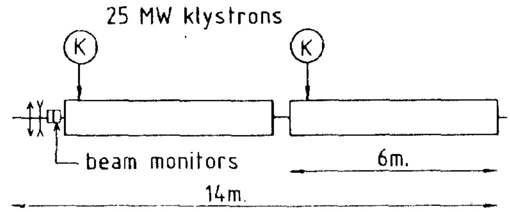

Fig. 2 - Linac elementary cell ; energy gain (i ≈ 0) 150 MeV, ($\bar{i}$ = 100 μA) 110 MeV. Klystron duty cycle ≥ 10⁻³ at 25 MW.

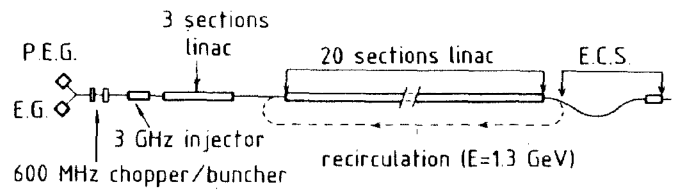

Fig. 3 - Layout of the new linac (100 μA, 1.3 GeV without recirculation, 2 GeV with recirculation). P.E.G. : polarized electron gun ; E.C.S. : energy compression system.

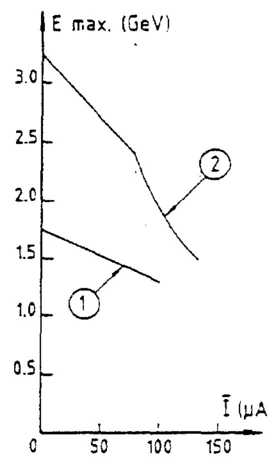

Fig. 4 - Characteristics of the modified linac ; (1) without recirculation ; (2) with recirculation.

The injection will be achieved in a single turn, in the horizontal plane and on the equilibrium orbit. As the storage times are much shorter than the damping time, this method insures that the stored beam emittance will be very close to that of the linac beam, i.e. ε ≤ 0.1 π mm.mrad in both planes. This injection scheme requires the use of a high duty cycle and short fall time kicker. Due to this fall time, the ring could be filled up to 90 % only.

The extraction makes use of a half-integer resonance near ν_x = 8.5. The choice of the half-integer resonant extraction has been dictated mainly by the need of a very high efficiency. Indeed, due to the large average current, losses greater than 1 % would cause radiation problems. An extraction efficiency of 99 % has been demonstrated at KEK proton synchrotron using half-integer resonant extraction.[9] Further, in order to minimize the losses of particules on the electrostatic septum, the pitch of the extracted beam must be sufficient (e.g. a pitch of 1 cm is necessary to insure losses less than 1 % for a septum thickness of 0.1 mm). It is then necessary

Table III

ALS II stretcher ring parameters

Nominal energy	2 GeV
Stored electron current	200 mA
Circumference	300 m.
Bending radius	15 m
Maximum bending field (at E = 3.3 GeV)	0.734 T.
Number of bending magnets	64
Number of cells	50
Number of normal quadrupoles	100
Quadrupole strength	0.35 m^{-1}
Magnet power dissipation (at 2 GeV)	400 kW
Horizontal tune ν_x	8.5
Vertical tune ν_z	8.4
Momentum compaction	0.02
Synchrotron radiation loss/turn	95 keV
Peak cavity RF voltage	500 kV
Harmonic number	600
RF frequency	600 MHz
Number of synchrotron oscillations/turn	0.02
β_x max/min	10 m/3.5 m
β_z max/min	10.5 m/3.5 m
η max/min (normal cell)	1.5 m/0.9 m
Number of extracted beams	⩾ 2

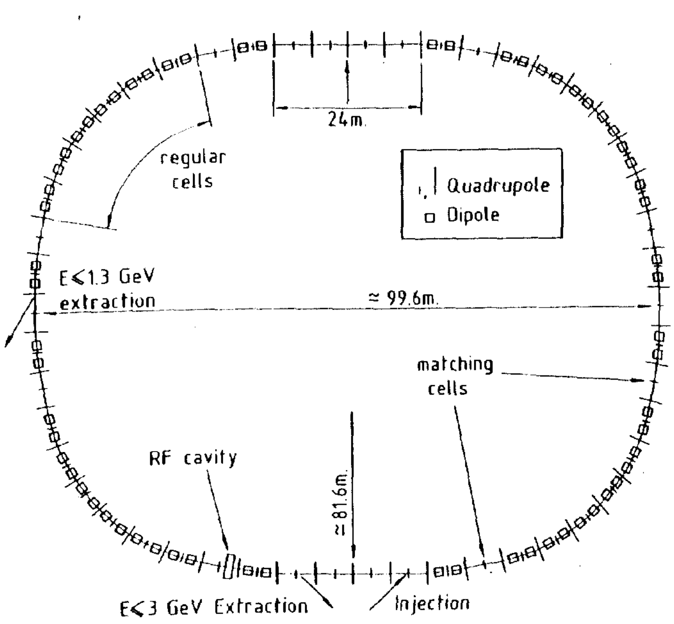

Fig. 5 - The stretcher ring (circumference : 300 m. ; magnetic radius ρ = 15 m.).

to control carefully the divergence of the beam and its evolution during the extraction in order to minimize the horizontal emittance of the extracted beam. Computer simulations have shown than one can expect an horizontal emittance ε_H of the order of 0.5 π mm.mrad. The vertical emittance should not be affected by the extraction and should be that of the injected beam i.e. $\varepsilon_V \lesssim 0.1$ π mm.mrad. The energy dispersion of the extracted beam will be the same as that of the circulating beam. Calculations have shown that the initial dispersion can be reduced by a factor of 3 by a special use of the RF cavity. Therefore one can reasonably expect an energy dispersion of 10^{-3} for the extracted beam.

Two extractions are planned for the new facility, one directed towards the existing experimental areas, the other devoted to new areas which will house higher momentum spectrometers. Several beams of the same energy but with possibly very different intensities will be available simultaneously, either by operating two extractions from the ring, or by splitting the higher energy beam into a low and a high intensity parts with a magnetic splitter.

Free space for further installation of a third extraction or of an internal target hall is available.

Polarized electrons will be accelerated and stored in the ring with a transverse polarization and wide energy range spin rotators will be installed to supply longitudinally polarized electrons in both electron scattering experimental halls.

Acknowledgement

Discussions with J.L. Laclare from Laboratoire National Saturne (Saclay) were of great help in the design of the ring.

References

1. B. Aune, in Symposium on perspectives in electro and photonuclear physics, Report DPh-N/HE 81-2, Saclay (1981).
2. R.B. Neal, ed., The Stanford two-mile accelerator, chapter 5, W.A., Benjamin, Inc. (1968).
3. B. Aune, J. Leroy and A. Mosnier, this conference.
4. H. Leboutet, Internal report CSF-DTW-5606, Paris (1964).
5. J. Flanz, Recirculator report, Bates laboratory (1980).
6. K.R. Crandall, private communication.
7. R. Beck et al., ALIS, Internal report DSS/SOC-ALIS-32, Saclay (1970).
8. H. Gerke and H. Musfeld, DESY Internal report 79/33 (1979).
9. K. Endo and C. Steinback, Internal report KEK-77-13 (1977).