TOWARDS A 12 GeV ELECTRON ACCELERATOR FOR NUCLEAR PHYSICS WITH A 100% DUTY CYCLE

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Abstract

For the future researches in nuclear physics it is widely believed that the electromagnetic probe is a very useful tool. Therefore in 1989 a preliminary study of a 4 GeV, 100% duty cycle accelerator was carried out. The accelerator consists essentially of a recirculating linac using the superconducting cavities being developed at Saclay. Two nuclear physics experimental rooms would be fed simultaneously at the 1.5 GHz RF frequency. Provisions could be made for a later upgrading of the accelerator up to 12 GeV, as recommanded by the French Academy of Sciences, although other approaches towards a 12 GeV electron accelerator are also under study.

Introduction

This 4 GeV project was made to obtain :

a 100 μA beam with a 100% duty cycle

an emittance (phase surface/π) = 10^{-8} m.rad for 95% of the electron beam

a relative energy spread = $3 * 10^{-4}$ FWHM

two beams being delivered at the same time on fixed targets, either at the same energy, or at different energies (one being chosen at random up to 4 GeV, the choice for the other one is restricted to a set of a few values corresponding to extraction at a previous turn)

The project is based on recirculating linacs. The general lay-out is shown on figure 1 and 2.

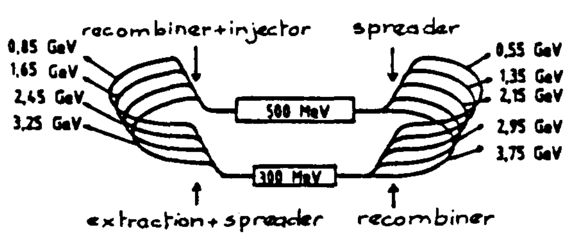

Fig 1.General layout of the 4 GeV recirculating accelerator.

Although it can be seen that this is a "CEBAF-like" design [1], with five turns in the linacs, the project differs from the CEBAF design on four main points :

1. The two beams delivered simultaneously on the experimental areas are energy separated instead of being time separated. The consequence is that each user sees bunches coming at 1.5 GHz (which is the RF frequency) instead of half of this frequency. This is obviously an advantage as far as the detectors electronics is able to catch events at the rate of 1.5 GHz.

2. Superconducting cavities are supposed to be operated at an effective accelerating field :

$$E_{acc} = 10 \text{ MV/m}$$

with an unloaded quality factor :

$$Q_o = 6 * 10^9 \text{ @ } 1.8 \text{ Kelvin}$$

3. The so-called HOM couplers, responsible for rejecting higher order modes in the cavities, are especially designed for recirculating linacs. It means that they are efficient primarily for the transverse modes. The concept results in a simpler coupler design [2].

4. The general design of the accelerator is a compact one. Of course the linacs are shorter since the accelerating field is large, but the radius of the arcs has been taken as small as possible taking into account the requirements stated above.

We will not give a general description of this project, since the concept of recirculating linacs is well known. We will rather focus on the points which are specific to this design. Detailed informations will be found in the so-called "blue book" proposal.

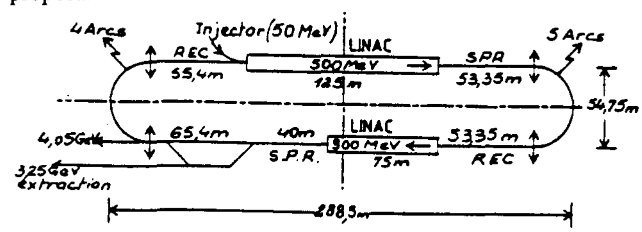

Fig 2.Main structures of the Linac.

Injection and extraction

A 50 MeV injection energy has been chosen for two reasons : first, the velocity of the electrons is close enough to c so that the phase shift in the first turn of the linac is acceptable ; second, focusing in the linac is not too difficult. This value guarantees that the threshold current for BBU should be much larger than the design value with the chosen cavities.

Actually, two beams are injected at the same time and the same place. Their energies differ by 4 MeV. This 4 MeV difference will be carried all the way to the final energy, and will be used to separate the two beams at the extraction level. Figure 3 shows schematically the injection system. It can be noted that provisions have been made for a polarized electron source.

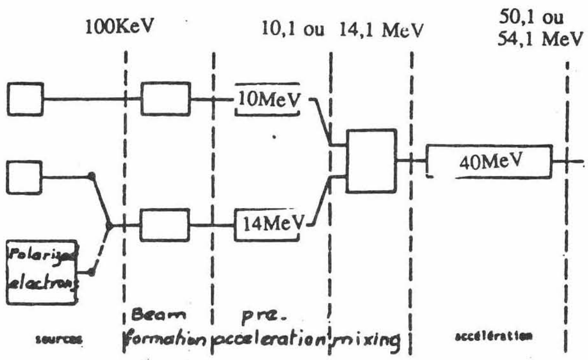

Fig 3.Injector design.

The two sets of bunches differing by 4 MeV are exactly superimposed in the linacs. They are slightly separated in the radial direction in the arcs. The choice of 4 MeV for the energy difference results from a compromise between an easy separation at extraction and a small enough radial spread in the first arc.

Superconducting cavities

A research and development program on superconducting cavities started at Saclay a few years ago. It includes basic research on RF superconductivity, studies on field emission, surface characterization, development of HOM couplers and statistics on industrially manufactured niobium cavities. This R/D program is beeing continued, but it already showed that a project can be based on cavities with an effective accelerating field of 10 MV/m and a quality factor of $6*10^9$ at 1.8 Kelvin.

Last year it was decided to build a test facility for superconducting electron linac, the so-called "MACSE" [3]. This is going to be a small CW linac with a current of a few hundreds of microamperes. Technological developments undertaken for this project have been applied to the design of the 4 GeV accelerator. One cryomule consists of 4 five-cell cavities. Its length is about 4 meters. There are 44 such cryomodules in the 4 GeV project. Each cavity is fed with a 5 kW klystron, which means 176 klystrons altogether. Only half of these 5 kW are needed for the beam. The other half is available for dynamic compensation of cavity detuning.

The cryogenic system power must be 2.5 kW at 1.8 Kelvin. The corresponding line power amounts to 5 MW.

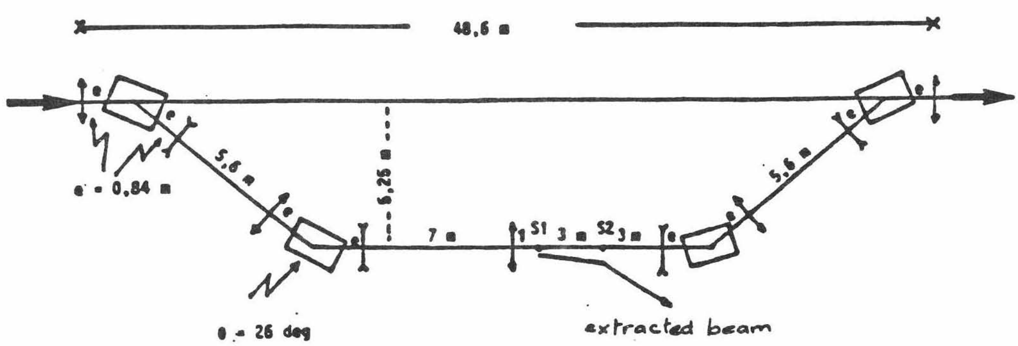

Fig 4.Design of the extraction system at 3.25 GeV and at 4 GeV.

Figures 4 and 5 show the extraction system and the bunch separation in the radial phase space.

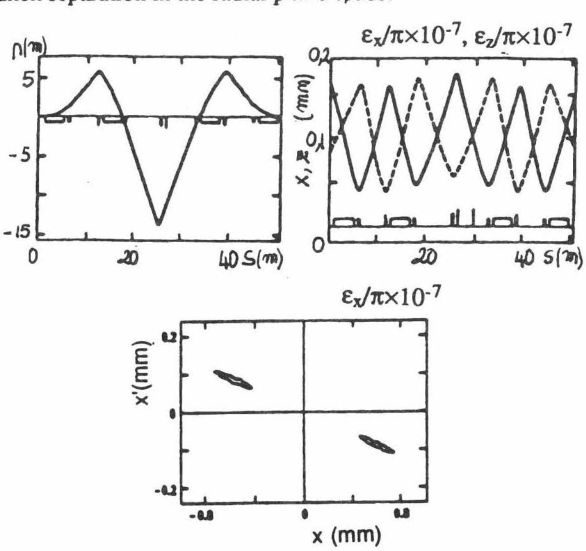

Fig 5.Optical characteristics of the extraction system at 3.25 GeV.

Focusing in the linacs

Focusing is chosen so that the beam is adapted for its first turn (with a $2\pi/3$ betatron phase advance). But it must still be good enough for the other turns. The 50 MeV beam entering the first linac reaches 850 MeV at its output. This large relative energy gain obliged to put a quadrupole every 5 meters, which means that there is always a quadrupole between two cryomodules. The β functions are displayed on figure 6 for the first and last turn.

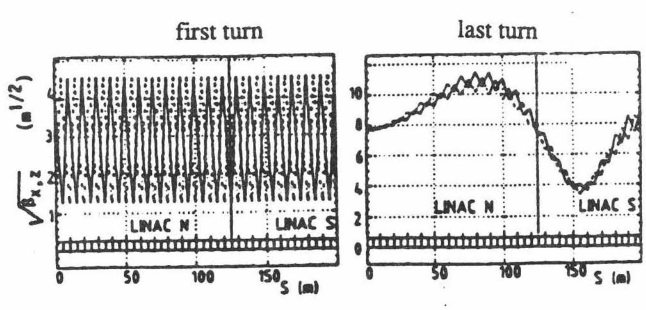

Fig 6. $\sqrt{\beta x,z}$ functions for the first and fifth turn.

The arcs

The arcs consist of 4 periods, each period consisting of 3 FODO cells and 4 magnets (missing magnets technique). The magnetic radius is 10 meters, while the physical radius of the arc is 27 meters. The arc is an achromat, and the structure provides isochronism from linac to linac.

With such arcs, it has been caculated that the $\langle \mathcal{H} \rangle$ function is equal to 0.45 meter, which is small enough to avoid large emittance growth in the arcs.

Figures 7 and 8 show respectively the β functions for one period and the dispersion coefficient for one arc.

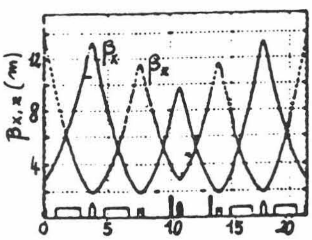

Fig 7.$\beta_{x,z}$ functions for one lattice.

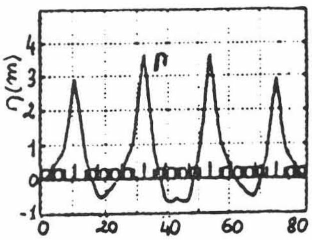

Fig 8.Dispersion function for one arc.

Spreaders and recombiners

They are still rather long, more than 50 meters. Obviously the principle of spreaders and recombiners must be modified in the case where one should wish to have a larger number of turns in the linacs (for instance use vertical and horizontal spread).

Upgrading up to 12 GeV

To follow recommandations issued by the French Academy of Sciences, a modified version of this project has been made. It consists in a two phase construction. As shown on figure 9, the two linacs (500 + 300 MeV) have been replaced by a single 800 MeV linac. During phase 1, the RF cavities are operated at 10 MV/m and the maximum energy is 4 GeV as before. Phase two consists in building additional arcs with a 100 m physical radius. In the meantime the development of RF superconducting cavities is expected to have reached the point where effective accelerating fields of 15 MV/m can be routinely obtained ; the existing 800 MeV linac would benefit of such improvement either by changing the cavities (worst case) or by a simple surface treatment of the cavities (best case) ; it would become a 1.2 GeV linac. Ten passes of the beam would deliver a 30 μa, 12 GeV beam, the total beam power being kept constant. The emittance would be 10^{-7} m.rad for 95% of the beam and the relative energy spread 10^{-3} FWHM.

Other approaches

At a time where the nuclear physics community is discussing on what is the most interesting research field in the long term, the specifications for the needed accelerator are not clearly stated. It seems that a first step at 4 GeV may be worthless, a higher energy being required at once ; a recirculating linac project would have to be optimized consequently. Moreover the desired maximum energy may be significantly higher than 12 GeV. In that case, a recirculating linac may not be the best choice. Discussions have started at a European level so as to be able to answer the needs when they are known.

References

1. C. Leeman, "CEBAF design overview and project status", CEBAF-PR-88-001.

2. A. Mosnier and al. "Damping of the HOM's in a multicell superconducting cavitiy", Procceedings of the European Particle Accelerator Conference, Rome 1988, p. 1287.

3. B. Aune and al. "MACSE : a superconducting test facility for superconducting electron linac", this conference.

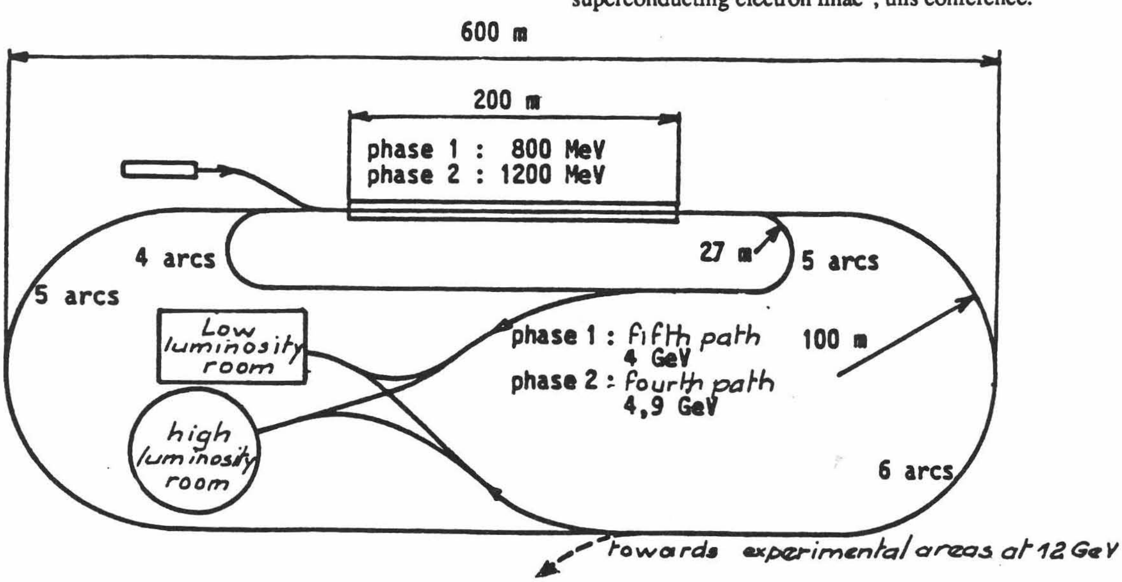

Fig 9.Layout of the 12 GeV recirculating Linac.