ELFE, an Electron Laboratory For Europe

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1 INTRODUCTION

An interest was identified in the European nuclear physics community several years ago for a 15 GeV electron accelerator [1]. Four countries participated in the studies for this accelerator : France, Germany, Italy and The Netherlands. A brief report has been given on the status of the studies at the last European Accelerator Conference [2]. A full report on the project has now been published [3]. We are going here to give an overview of this project, then the prices of the accelerator main subsystem will be given, and links will be established between these prices and the specifications. Finally suggestions will be made on which modifications should be made to the specifications in order to reduce significantly the cost of the accelerator.

2 THE SPECIFICATIONS

The accelerator was required to be a high duty factor one, and the project has been established on the basis of a 100% duty cycle, that is to say a continuous beam accelerator. The maximum accelerated beam is 50 μA, which means 750 kW on target at 15 GeV. The energy resolution is less than $3 * 10^{-4}$ FWHM at 15 GeV while the emittance ε/π is less than 10^{-8} at 15 GeV (m * rad at 95%). In addition, it was requested that the beam could be shared between 3 end stations, either time shared with time slots of tens of milliseconds, or bunch to bunch separated *à la* CEBAF, each end station receiving a continuous beam with bunches coming at a frequency a third of the RF. A last requirement was that the design of the accelerator would be such that a later upgrade could bring the energy up to 30 GeV with of course modifications of the accelerating system. Other accelerator sub-systems will be also modified to a less extent, but no major civil construction work will be needed.

3 THE GENERAL LAY OUT

Several possibilities have been contemplated for the general lay out of the accelerator. Studies have been made for a while on a solution based on a modified microtron scheme named a polytron. Finally a recirculating superconducting linear accelerator was chosen. Figure 1 shows a plane view of the laboratory. The result of the studies was that the optimum of cost will be reached with the following choices

. a 10 MeV/m gradient in the accelerating cavities. This gradient is considered as the state of the art, and there is no need for higher gradients in such a continuous beam linac (see below).
. a single sided linac, in order to lower as much as possible the energy of the last recirculating arc, which has a strong effect on the beam quality. A large arc radius is needed to meet energy spread and emittance requirements if the energy is too high.
. a 3 passes, 5 GeV linac. Taking into account a 0.5 GeV injector, this means an energy of 5.5 GeV for the first return path and 10.5 GeV for the second.

It turns out that due to relaxed quality of the beam needed at 30 GeV, the design of a 15 GeV accelerator is also suitable for a 30 GeV machine, as far as civil construction is concerned. So the first investment for a 15 GeV machine does correspond to an optimisation made for a 15 GeV accelerator (excepted the arc magnets, for which the iron is calculated for 30 GeV).

1 Injector building
2 Main building
3 Superconducting cavity building
4 Arc buildings
5 Engine room
6 Cryogenic building
7 Klystron buildings
8 End stations
9 Counting house and service building
10 Physics buildings
11 110 kV station, main station and water cooling station
12 Substations and water cooling stations

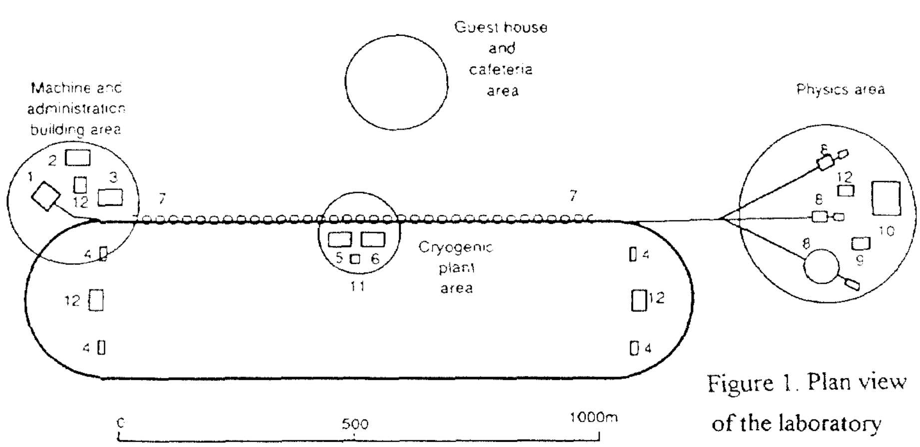


Figure 1. Plan view of the laboratory

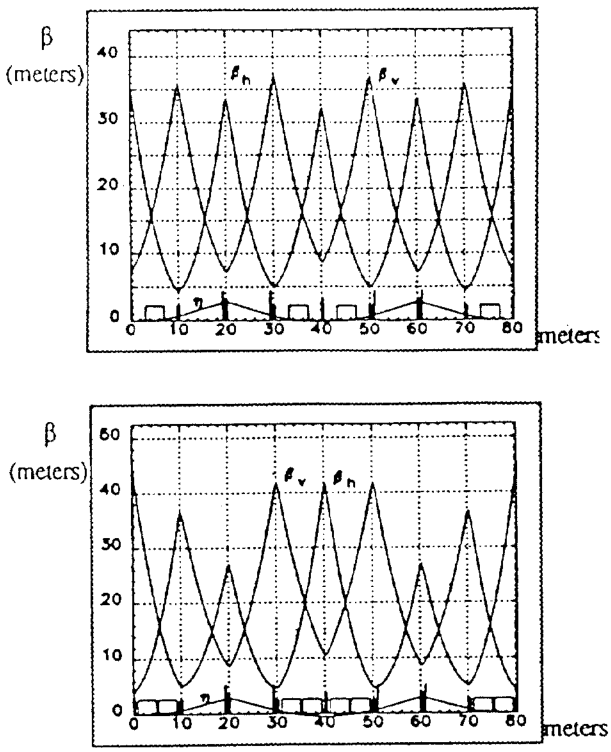


Figure 2. β and dispersion functions for the low and high energy arcs in the isochronous mode

4 THE DESIGN OF THE ARCS

Each arc has a periodic structure and consists of 6 identical and symmetrical periods composed of modified "missing magnets" FODO cells. There are 24 dipoles in each arc for the first return path (dipole bending radius = 30 m.), and 48 for the second return path (bending radius = 60 m.). The physical radius of the arcs is 153.5 m. It must be noted that while the magnets are designed for 30 GeV, the power supplies are limited to 15 GeV only. An interesting point is that the arcs may be operated either in the isochronous mode (the classical one for recirculating linacs), or in a non-isochronous mode (the microtron mode), which could bring some advantages when a minimum energy dispersion is looked for. Figure 2 shows the β and η functions for the low and high energy arcs in the isochronous mode.

5 CAVITIES

The cavities which have been chosen are 9-cell cavities working at 1.3 GHz, the TESLA frequency. Made of solid niobium, they will work at 2 K. The radio frequency system has been designed for a quality coefficient $Q = 4 * 10^9$. The coupling coefficient is chosen so that the apparent cavity bandwidth is 70 Hz. Eight cavities are grouped in a cryostat, and four cryostats are gathered in a cold module, with the advantage to stay cold for 50 meters. Figure 3 shows such a cold module. Each transition between liquid helium temperature and room temperature is expensive, so these transitions have been avoided as much as possible in this design. Moreover, long modules make it easier for liquid helium distribution. As a consequence, quadrupoles will be superconducting ones. Special beam diagnostic devices will be located in the 10 metres long sections between the cold modules. All together, the linac is 900 metres long (15 cold modules).

6 THE RF SYSTEM

In order to save on the capital cost of the RF system, a single klystron will feed 8 cavities (this has been tried successfully at Saclay with the 4 cavities of the MACSE demonstration linac). The principles are as follows :

. there is a slow mechanical tuning system for the frequency control of each cavity.

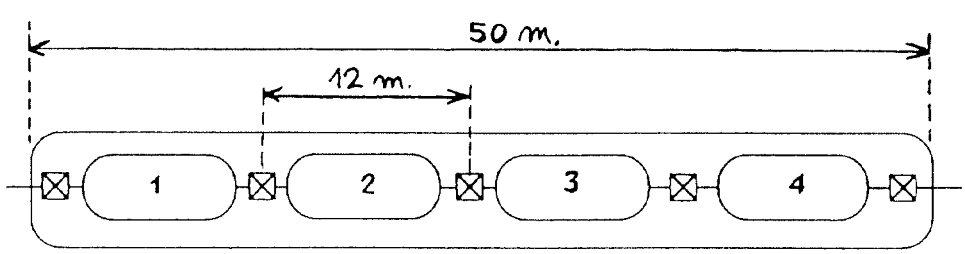
. the vectorial sum of the signals coming out of the eight cavities drives the fast control of the klystron output phase and voltage. Loops with gains of 80 dB in amplitude and 60 dB in phase guarantee a beam energy resolution of $2 * 10^{-4}$.

. two secondary loops stabilize the klystron output, thus a DC power supply with a 10^{-3} stabilization is enough.

7 LINAC BEAM DYNAMICS

Quadrupoles are 12 metres apart, thus the FODO cell length is 24 metres. A 120 degrees betatron phase advance per cell has been chosen for the beam first pass. It has been checked that the beam envelopes for the second and third pass are quite acceptable, thanks to the choice of 0.5 GeV as injection energy. The quadrupole aperture is 50 mm. in diameter, and their transverse alignment tolerances are 0.2 mm. RMS and 5 mrad. RMS.

Figure 3.
A cold module,
with its 4 cryostats
and 5 quadrupoles



As far as multiple pass beam break-up is concerned, the lowest threshold is found to be 0.7 mA, more than one order of magnitude larger than the design current of 0.05 mA. The mode responsible for this threshold is a trapped mode, TE121.

8 THE CRYOGENIC PLANT

The total heat load and installed power (in parentheses) have been estimated to be :

at 2 K :	13 kW (18.4 kW)
at 4.5 K :	1.2 kW (2.0 kW)
at 70 K :	6.3 kW (10 kW)

The total installed power for the cryogenic plant is of the order of 20 to 25 MW.

9 COST ESTIMATE

The prices are given here in millions of French Francs, without taxes, without contingencies, without spare parts, without staff man power, for the accelerator plus civil construction and conventional facilities. Experimental areas are not included. The accelerator is based on the "state of the art technology", which means that there is no need for an R/D program before construction. However, the prices below are "advanced prices" in that sense that they assume that technical efforts have been made before construction in the field of cryomodule conception, cryogenics, and to a less extent RF system. We are speaking here of engineering design applied in the scope of long cryomodules, huge cryogenic plants, big RF transmitters.

RF transmitters		137	
cavities and cryomodules	300 >		
laboratory equipment	20 >	460	
testing and mounting	140 >		
arcs + spreader + recombiner		224	
cryogenic plant		215	
0.5 GeV injector		70	
computer control		65	
miscellaneous		36	
Total			1207 MFF
Civil construction			228 MFF
Conventional facilities			106 MFF

10 A LESS EXPENSIVE PROJECT

The nature of the physics which will be addressed with this accelerator commands the choice of energy, energy dispersion and beam emittance. Beam current is not a particularly costly parameter (RF power is not proportional to beam power ; a part of it is reflected to get the wanted 70 Hz apparent bandwidth). But duty cycle is costly indeed. Going to higher gradients, as it is hoped for TESLA, would result in a better cavity efficiency and a cost reduction. However it is a nonsense with a 100% duty cycle, since it would increase the cost of the already large cryogenic plant. But, for the same average beam current, working with a smaller duty cycle would open the possibility to use gradients above 10 MeV/m. This means a shorter linac, and a price reduction. It can be estimated that with cavities working at 15 MeV/m, the same quality coefficient and the same cryogenic plant, the cost reduction would be 177 MFF for a 67% duty cycle. One could also imagine a further reduction of the duty cycle, with again 15 MeV/m, but a cheaper cryogenic plant. Clearly a detailed optimization analysis should be made to get the best of a reduced duty cycle.

An other important point to be mentioned is that many developments made for TESLA (500 GeV, 1% duty cycle, 4 times the cryogenic power needed for ELFE) can be very useful for ELFE [4]. Comparing development efforts :

. ELFE cavities can be identical to TESLA ones, but they can also be simpler because they are not detuned permanently by the pulsed RF.

. ELFE cryostats can be identical to TESLA ones, but can be simpler because their static losses are not dominant.

. ELFE RF components can be identical to TESLA ones, but they can be simpler because, although the mean power is the same, the peak power is 100 times lower.

. ELFE thermal power density running through the cryostat lines is much higher than it is for TESLA.

11 CONCLUSION

The ELFE project as it is now must be considered as a reference from which further efforts should be made :

. to adjust the duty cycle by taking into account economic considerations.

. in parallel with TESLA for the technological work to be made on cryomodules and cryogenics.

12 REFERENCES

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[3] "The ELFE project", edited by J. Arvieux and E. de Sanctis, Italian Physical Society, Conference Proceedings Vol. 44, page 589.

[4] M. Tigner, "Superconducting linear colliders", LC92, ECFA workshop on $e^+ e^-$ linear colliders, ECFA 93-154 page 229.