THE PHOTOCATHODE INJECTOR AND THE SUPERCONDUCTING LINAC FOR THE ELFA PROJECT

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ABSTRACT

The conceptual design of a 10 MeV, 400 A peak current, electron accelerator for the ELFA project is reported. The accelerator consists of 3.5 MeV photocathode injector and a superconducting LEP II module. A general description of the main accelerator components and the results of the beam dynamics are presented.

INTRODUCTION

ELFA is a free electron laser amplifier designed to operate in the high gain, single pass, Compton regime in the frequency range 30-300 GHz, with peak power in excess of 100 MW. A complete review of the project is given elsewhere at this conference [1]. The accelerator will provide 10 MeV electron bunches with 400 A peak current. The beam characteristics as required from the present FEL experiment are summarized in Table 1.

Table 1 - Beam Parameters

Energy	10 MeV
Peak Current	400 A
Normalized Emittance (90%)	10^{-3} $m\ rad$
Energy Spread	1%
Micropulse Length	200 $psec$
Charge per micropulse	80 nC
No. of micropulses	4
Repetition Rate	$\geq$50 Hz

The request of a pulse length of 200 ps leads to chose a low accelerator frequency, namely 352 MHz. The 400 A peak current condition determines the high charge per pulse of 80 nC; this charge value and the relatively low electric field, substainable at the chosen frequency, make the quality of the beam dominated by the space charge forces.

A further decrease of the beam qualities (emittance and energy spread) are given by the relatively long rf pulse (22 ° rf). A photocathode directly placed in a cavity is the best solution to optimize the beam quality. The accelerator has been therefore divided into two sections: a photocathode injector and a superconducting LEP II module. The accelerator design has been focused on the extraction and the acceleration of the beam in the injector where space charge forces and rf dynamic determines the final beam quality. The conceptual design of the photocathode injector has been performed at the Los Alamos National Laboratory in the framework of an official collaboration between DOE and the Italian National Institute for Nuclear Physics [2].

THE ACCELERATOR

General layout. The accelerator, schematically shown in fig 1, consists of two sections: a photocathode injector providing a 3.5 MeV beam and a superconducting LEP II module to increase the energy up to 10 MeV. The drift between the two sections allows the injection of the photocathode laser, the installation of the beam diagnostic and a focusing solenoid to transport the beam to the LEP module. Two quadrupole doublets, after the LEP cavities, provide the matching of the beam into the wiggler. Space is available for additional diagnostic and for the injection of the microwave signal to be amplified in the wiggler.

Photocathode. A photoemission electron gun, of the type recently developed in Los Alamos can provide very intense electron beam [3] and we plan to use a similar system in our injector. A photoemission surface is placed in the back wall of the first half cavity of the injector and is hit by a laser shot to extract the electron pulse. The beam shape and its current are completly determined by the laser performances and the surface quantum efficiency. The material for the surface consists of a mixture of Cesium, Antimony and Potassium and it has a quantum efficiency of several percents. The operating vacuum of the photocathode should be of the order of 10^{-10} torr.

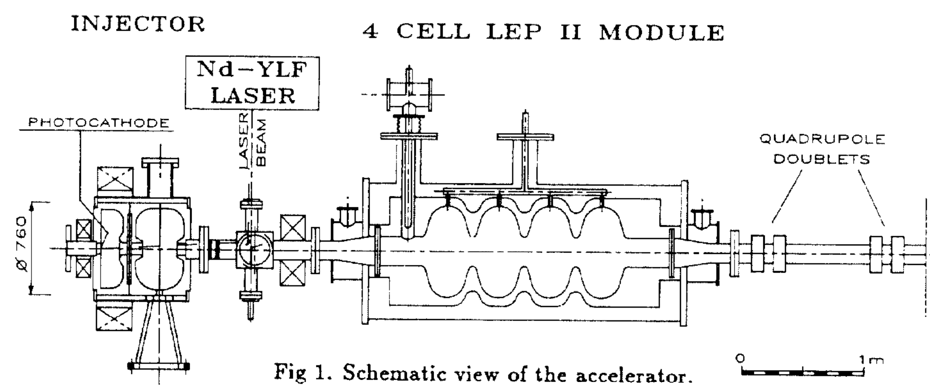

Fig 1. Schematic view of the accelerator.

Laser system. The photocathode driving laser system must provide bursts of 4 flat topped pulses of 200 ps separated by 2.8 ns (352 MHz) with energy of 20 μJ at a wavelength of 526 nm. The burst repetition rate is 50 Hz. The laser system, shown in fig 2, consists of a CW modelocked Nd:YLF laser oscillator followed by a pulse shaper, a pulse selector, two amplifiers, a second harmonic stage and a 4-time pulse multiplexer. The oscillator operates at 1053 nm and 88 MHz with output pulses of 50 ps which are accurately phased to the radiofrequency used to drive the accelerator. After some isolation optics, the output beam is sent to a pulse shaping system, which using dispersive as well as non-linear effects in optical fibres, reshapes the pulses to a flat topped temporal profile of 200 ps duration. At the repetition rate of 50 Hz only one generated square pulse is selected by the pulse selector and sent to two regenerative amplifiers which raise the pulse energy up to 250 μJ. After second harmonic generation the pulse energy is about 100 μJ. Finally the pulse at 526 nm is sent to the multiplexer, where using a series of splittings a sequence of four collinear pulses is generated with proper temporal spacing. This arrangement ensures that the pulses have a well defined phase relationship with one another.

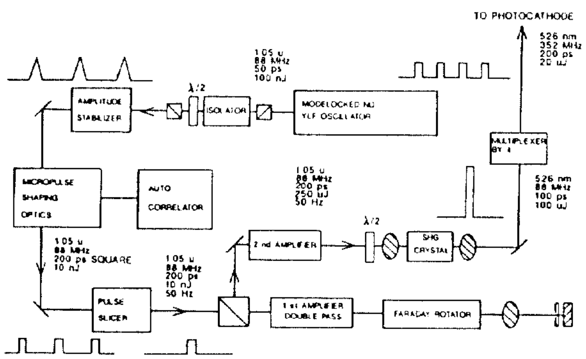

Fig 2. Scheme of the photocathode driving laser.

Injector cavities. The injector design is a scaled up version of the HIBAF injector [4] developed at Los Alamos at 1.3 GHz. However because of the different characteristics of our pulse some corrections have been made to the HIBAF reference design, as in the case of the cathode wall of the first cavity that is flat and not bent. The injector (fig 3) consists of one-half accelerating cell (with the photocathode in the back wall), one coupling cell and one full accelerating cell operating in the $\pi/2$ mode at 352 MHz. The relative amplitude of the rf in the two accelerating cells is fixed by the coupling constants between the coupling cell and the accelerating cells. With 1.1 MW of rf power availiable in the injector we can sustain in the first one-half cell a spatial average field of 9.6 MV/m whereas in the full cell the average field is 5.6 MV/m; this choice is determined by the necessity to reduce the space charge effects, increasing the particles energy, since these forces are proportional to $1/\gamma^2$. The phase difference between the two accelerating cells is fixed at 180°, furthermore this mode is much more stable than the π mode and satisfies the same conditions for the best energy gain [5]. The nose of the first cell has been shaped so that the radial component of the electric field is almost linear in the region occupied by the particles. A detailed thermal and structure analysis has been carried out using the code Cosmos/M, assuming an average dissipated power of 85 kW. The cavities are cooled longitudinally and radially (up to the nose). Frequency tuning (1 kHz) is obtained through temperature control of the cavity by mean of the cooling fluid. The two cavities are made of high conductivity copper and are enclosed by a stainless steel vacuum jacket; slots are drilled on the boundary of the cells to provide high pumping conductance.

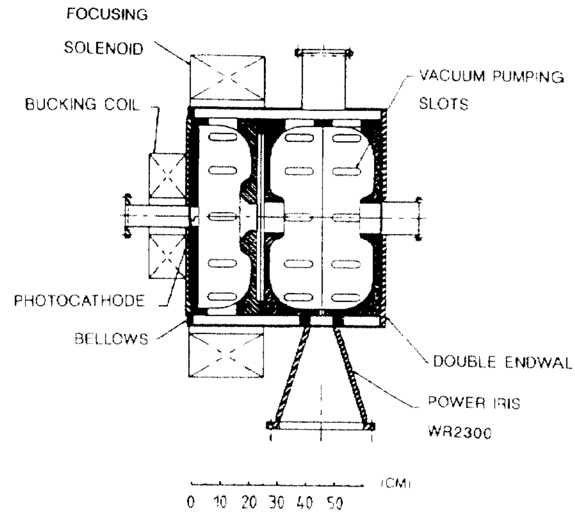

Fig 3. Scheme of the photocathode injector.

Focusing system. A radial focusing system is necessary to counteract the space charge forces, to keep a reasonable beam size and to minimize emittance growth, since already at the cathode the beam size is quite large (r=1.5 cm) and there is an rf defocusing at the end of the first cell. Therefore a solenoid will provide radial focusing in the first cell while a bucking coil, placed behind the cathode, will null the field to avoid beam degradation already at the cathode. The peak magnetic field, achieved at the end of the first cell, is around 550 Gauss.

LEP II cavities. The second accelerating section is a 4 cells superconducting LEP II module (bulk niobium) [6]. The cryostat is filled with 200 l of liquid helium at the temperature of 4.2 K; the static heat load is 25 W. The nominal accelerating field is 5 MV/m (active length 1.7 m) with an unloadeded Q= 3 10^9. There are indications that the HOM coupler used at CERN doesn't require modifications, for our specific case, to avoid the deleterius effects produced by the wake fields. A 50 kW tetrode will be used for the rf power. Some margin is therefore left for an increase of the energy also taking into account that accelerating fields of 7 MV/m have been measured with Q=2 10^9.

RF system. The rf system for the injector accelerator is based on the use of a modified Thompson TH2089 klystron. Although a 1.6 MW peak power would be sufficient to satisfy the beam requirements, as resulting from the beam dynamics study, at present we are considering the possibility of using a 2.5 MW peak power. The advantages of this choice on the beam properties have still to be investigated in detail.

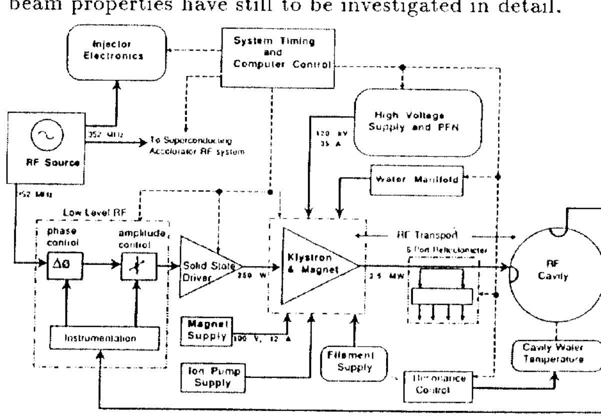

Fig 4. RF system for the injector.

The basic TH 2089 klystron will be modified for pulsed operation to 2.5 MW peak power, and 0.1 MW average power. The cathode modulator proposed is a PFN (pulse forming network) type. A block diagram of the rf system is shown in fig 4. The most important part of the system is the low level rf/feedback controls. A solution which is envisaged at the moment for this application is the feedback control system based on the design developed at Los Alamos for the GTA program. The system is based on standard PID (proportional-integral-differential) and has been studied to be generically applicable to most accelerator systems. The LEP II cavities control will be integrated in this system.

BEAM DYNAMICS

The beam dynamics has been studied with the program Parmela, which simulates the motion of the electrons in the cavity (and along the beam lines), taking in full account space charge effects, image charges and rf dynamics. Multibunch effects and wake fields are therefore not included in this study and will be investigated in the future.

For the given fields of the photocathode cells, as substained by the available rf power, the optimization of the beam parameters requires a careful balance between charge density, radial focusing strength and the starting rf phase. The beam at the cathode, for our case, can be assumed ideal i.e. with no transverse emittance and no energy spread. Pulse shaping of the laser beam has been assumed. The 80 nC beam pulse is generated at the cathode with a uniform longitudinal distribution within 180 ps, ignoring the rising time of 15-20 ps. In the radial space the distribution is gaussian with σ_r=1.2 cm and r_{max}=1.5 cm.

The beam characteristics are essentially determined in the first cell, although, for the correlation between transverse and longitudinal position, the evolution of the normalized emittance can be influenced by the position and the strength of the focusing lenses [7]. A flat cathode wall has been selected since there are no specific advantages, according to the simulation, in using a shaped wall. The starting phase for the central particle (52 rf°) has been chosen as a compromise between the maximum acceleration condition and the compensation for space charge longitudinal effect.

The transverse and longitudinal phase-space at the injector exit and at the end of the accelerator are represented in fig 5. The numerical values of the relevant paremeters of the beam are summarized in Table 2.

Table 2 - Beam dynamics results

	Injector		
	1st cell	2nd cell	LEP II
Energy MeV	1.745	3.594	9.876
90% Normalized Emittance $\pi mm\ mrad$	490	640	590
Energy Spread, rms, %	5.6	1.7	1.05
Beam Radius, rms, mm	12.1	11.6	6.7
Pulse Width, rms, $°rf$	6.7	6.8	7.1

The transverse beam quality can be further improved since the minimum emittance value, 310 π mm mrad, is obtained at the entrance of the Lep II cavities while at the exit this value has grown to 590 π mm mrad. However with the present configuration the beam characteristics satisfy the initial requirements.

Two other cases have been also investigated:

—a 60 nC beam, peak current 300 A, which gives 0.83% of rms energy spread and a final emittance of 332 π mm mrad

—an uniform cilindrical beam (radius 1.2 cm at the cathode) with 70% of increase of the rf field (requiring 3 MW rf power) which gives energy spread rms 0.8% and normalized emittance (90%) of 110 π mm mrad

The first case shows the major influence of the total charge value of the pulse on the final beam quality, while the second set a lower limit on the emittance and energy spread since it is assumed the ideal beam shape (uniform distribution) and maximum values of the rf fields. More investigations will be carried out in the future to optimize the beam quality through pulse shaping and/or an increase of the rf fields.

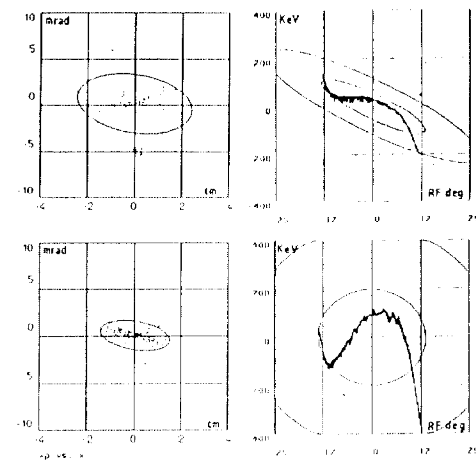

Fig 5. Parmela plot of the transverse and longitudinal phase space at the exit of the injector and of the LEP cavities.

CONCLUSIONS

The conceptual design of the electron accelerator for the ELFA project has shown that beam properties adeguate for the envisaged experiment are obtainable with present technologies, also at low frequency at 352 MHz. A realistic scheme of the accelerator has been presented in this paper.

The ELFA project has been funded by INFN; the final design of the accelerator structure should be completed by the end of the year.

REFERENCES

[1] R. Bonifacio, et al. contributions to these procedings

[2] DOE's Agreement No.DEFI04-89A158708

[3] R.Sheffield, "Photocathode RF Guns", Los Alamos National Laboratory, Report LA-UR-89-424 (1989)

[4] B.Carlsten, L.Young, M.Jones, B.Blind, E.Svaton, K.Chan, "Accelerator Design and Calculated Performance of the Los Alamos HIBAF facility", Los Alamos National Laboratory, Report LA-UR-89-3379 (1989)

[5] B.C.Knapp, E.A.Knapp, G.J.Lucas, J.M.Potter, IEEE Transactions on Nuclear Science, 12, 159(1965)

[6] P. Bernard et al., Proceedings in EPAC Conference, Rome, Italy, June 1988.

[7] B.E.Carlsten, "New Photoelectric Injector Design for the Los Alamos National Laboratory XUV FEL Accelerator", Nuclear Instruments, A285 (1989) 313-319.