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ALFA, FEASIBILITY STUDY OF AN ELECTRON PULSE STRETCHER TO INCREASE THE DUTY FACTOR OF THE FRASCATI LINAC

S. Guiducci, G. Martinelli, M.A. Preger

I.N.F.N., Frascati National Laboratories, C.P. 13 - 00044 Frascati (Italy)

Abstract

The present duty-factor of the 400 MeV Frascati National Laboratories Linac (8×10^{-4}) can be made to approach unity by using an electron storage ring as a pulse stretcher: resonant extraction near an m/3 resonance by means of sextupolar nonlinearities in the ring allows slow extraction of the stored current with small energy spread. The feasibility of a machine, capable of 100μA average current and 10^{-3} energy spread between 200 and 500 MeV is investigated. The optical structure of a ring, 120 m long with a 5 m bending radius, is presented. The necessary modifications to the Linac are indicated. Expected parameters of the extracted beam are presented.

Introduction

In July 1976 a pulse stretcher for the Linac of the Frascati National Laboratories (LNF) was first proposed (ALFA project). Two solutions were considered: a modification of the storage ring Adone and the construction of an entirely new machine: for the first solution we refer to Ref. 1.

In this report we present the preliminary design of a dedicated pulse stretcher.

Design criteria

The theory of resonant extraction by sextupolar magnetic fields has been extensively developed[1,2,3]: nonlinear perturbations of the optical structure allow slow extraction of a stored beam, sweeping its betatron frequency spectrum across an m/3 resonance (m integer): this can be achieved either by changing the tune of the ring, or by exploiting the natural chromaticity of the machine and the energy loss due to synchrotron radiation. In the first case (achromatic extraction) the energy distribution of the stored beam does not change during extraction, while with the second method (monochromatic extraction) the energy spread of the extracted beam depends mainly on the chromaticity of the ring; moreover, the emittance of the beam in the extraction phase plane can be significantly smaller than in the achromatic case: our design aim is, therefore, to obtain monochromatic extraction in the energy range 200 ÷ 500 MeV, with a duty factor near unity.

The duty factor D of the stretcher, defined as the extraction time of a stored pulse times the Linac repetition rate $1/T_L$ is given by:

$$D = \frac{\varrho L}{K E^3 T_L} \left[(\Delta E/E)_L + (\Delta E/E)_{EX}\right] \qquad (1)$$

where $K = 2.65\times10^4\ \mathrm{GeV^{-3} m^2 s^{-1}}$, ϱ is the bending radius, L the circumference of the ring, E the energy in GeV; $(\Delta E/E)_L$ is the energy spread of the injector Linac, and $(\Delta E/E)_{EX}$ is the energy spread of the extracted beam, which can be computed from the distribution of the injected beam in phase space.

Injector Linac. Optimum performance over the required energy range requires some important modifications to the present LNF Linac, namely:

a) Increase of the maximum energy range (at 100 mA peak current) to 500 MeV with the same duty-cycle.
b) Possibility of operating at various repetition rates and pulse widths.
c) Addition of an energy compressor[5] to control the energy spread of the Linac beam from the present $\pm5\times10^{-3}$ down to $\pm 10^{-3}$.

Points a) and b) require the installation of two accelerating sections and the replacement of all existing klystrons with higher efficiency ones (~65%). The klystron modulators would also have to be modified.

Assuming the present peak current (100 mA) can still be obtained at 500 MeV, the peak current increases linearly with decreasing energy up to 250 mA at ~400 MeV; below this energy peak current remains constant, due to Linac limitations. The maximum RF duty-cycle (1.1×10^{-3}) is limited by the klystron average power (~3 KW): if the Linac repetition rate is increased, the RF pulse width, and therefore the beam pulse width, must be accordingly reduced; the lower limit is given by the Linac section filling time (1.2 μs).

The pulse stretcher. The product ϱL of the ring circumference times the bending radius (see (1)) has been chosen in order to obtain monochromatic extraction with unit duty-cycle up to ~500 MeV ($\varrho L \sim 590\ \mathrm{m^2}$).

The average extracted current is given by the average Linac current times the overall efficiency ε (ε is the product of injection, extraction and transport efficiencies). Since up to now no machine has been operated with similar injection and extraction characteristics, no experimental data for a reliable estimate of ε are available. The average extracted current presented in this report (see Fig. 1) assumes $\varepsilon = 1$ to be comparable with other existing projects[6,7] ; it is reasonable to assume that the overall efficiency can be made $\gtrsim 50\%$.

Given the Linac repetition rate, there is an energy range, inside which the average Linac current can be extracted with unit duty-cycle, changing the Linac energy spread, by tuning the energy compressor: at lower energies all the stored current cannot be extracted, and fast extraction of the remaining particles may be necessary: the average extracted current decreases therefore as E^3. At higher energies, a limit on the duty-cycle is set by the maximum energy spread accepted by the injection system: D decreases therefore as E^{-3}. The limits of this energy range depend on the Linac repetition rate, as it can be seen from Fig. 1.

Given the ring chromaticity and the Linac beam emittance, the relative energy spread of the extracted beam is of the order of 10^{-3}.

Multiturn injection in both planes[8] is envisaged to minimize the emittance of the extracted beam; vertical emittance is determined only by injection conditions, and depends on the length of the Linac pulse and the chromaticity of the ring: horizontal emittance does not change much with different operating conditions, and has been estimated to be ~4 mm.mrad.

Fig. 1 shows the dipendence of duty-cycle, average extracted current for unit efficiency and vertical emittance for two

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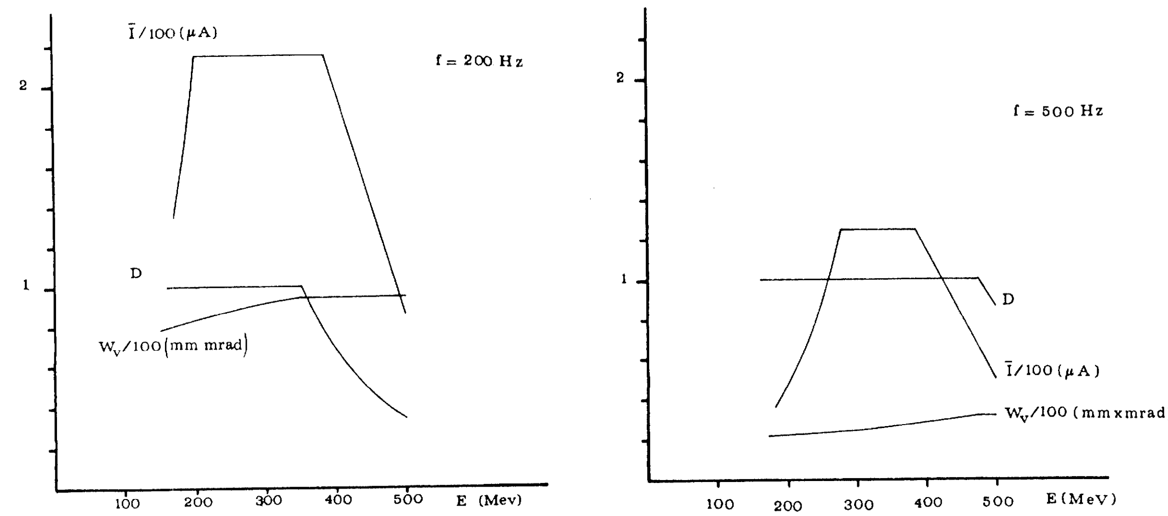

FIG.1 - Duty-cycle, average current for unit efficiency and vertical emittance of the extracted beam as a function of energy for two Linac repetition rates.

Linac repetition rates: it can be seen that a high repetition rate gives a good vertical emittance of the extracted beam up to almost the maximum energy, at the expense of a reduced average current: on the other hand, a low repetition rate allows for a higher extracted current, at the expense of a fairly large vertical emittance and a limited duty-cycle at high energy.

Optical structure

The optical structure has been designed to fulfill the following conditions:

a) The construction of injection and extraction bending elements becomes easier as injection and extraction straight sections are made longer: this led us to choose a straight section length cf 3 m.

b) It is convenient to have a vanishing dispersion function η at the injection and extraction points: in this case the horizontal emittance of the injected beam and, as a consequence, the energy spread of the extracted beam, are minimized; moreover, the requirement of a small aperture in the magnetic elements can be fulfilled by mantaining $\eta \leqslant 2$ m.

c) The ratio $R_\beta = \beta_x^{max} / \beta_x^{inj}$ (β_x^{max} being the maximum value of the horizontal betatron function and β_x^{inj} its value at injection point) must be made as small as possible, compatibly with the condition of having the maximum value of the vertical betatron function at the injection point: the maximum amplitude of the horizontal betatron oscillations and therefore the necessary aperture, increase with R_β.

The optical structure is built of two six-cell arcs, and two straight sections dedicated to injection and extraction. The layout of the ring is shown in Fig. 2.

The condition of a vanishing dispersion in the straight sections can be satisfied by the requirement that the horizontal transfer matrix T of a period of the bending section satisfy the condition $T^6 = I$.

The maximum value of η in the bending section is determined by the magnet radius and the horizontal betatron phase advance per period ($\eta_{max} \propto \varrho / \pi_x^2$). Following the choise of

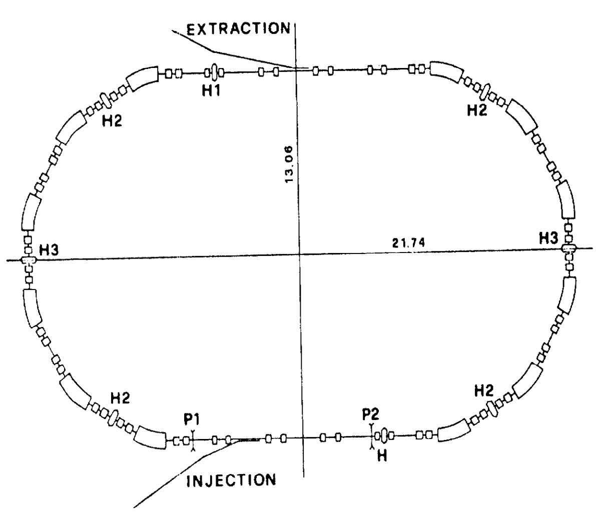

FIG.2 - Ring layout. The positions of injection and extraction septa, sextupoles (H) and injection orbit perturbators (P1 and P2) are shown.

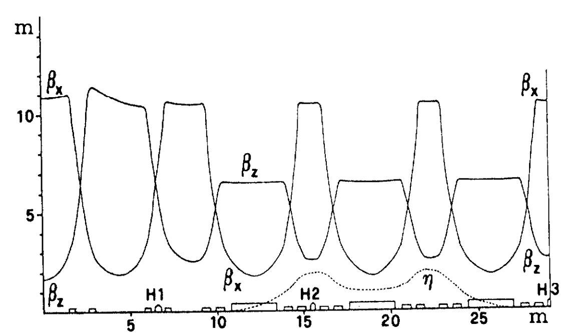

FIG.3 - Optical functions β_x, β_z, η over one fourth of the ring, starting from the extraction straight section. The position of sextupoles H_1, H_2, H_3 is also shown.

5 m bending radius, in order to decrease η_{max}, a total betatron phase advance in the bending sections $\Delta\mu_x = 4\,x(2\pi)$ has been chosen, corresponding to a $2\pi/3$ phase advance per period.

Fig. 3 shows the optical functions β_x, β_z and η over one fourth of the circumference.

TABLE I

Number of periods in the arcs	12
Number of magnets	12
Number of quadrupoles	64
Number of independent quadrupole power supplies	6
Number of sextupoles	10
Number of independent sextupole power supplies	3
Circumference	118 m
Bending radius	5 m
Horizontal betatron wavenumber	5.33
Vertical betatron wavenumber	4.125
Maximum β_x in the ring	10.77 m
Minimum β_x in the ring	1.77 m
Maximum β_z in the ring	11.44 m
Minimum β_z in the ring	1.66 m
Maximum η in the ring	1.99 m
Maximum η in bending magnets	1.13 m
Natural horizontal chromaticity	- 7.5
Natural vertical chromaticity	- 5.0
Maximum field in bending magnets	0.333 T
Maximum gradient in quadrupoles	2.2 T/m
Maximum sextupole intensity (B_p/a^2) (a = free radius, B_p = pole field)	5 T/m^2
Horizontal aperture	180 mm
Vertical aperture in the arcs	85 mm
Vertical aperture at injection	180 mm

The vertical aperture is determined by the injected beam emittance, closed orbit errors and localized closed orbit perturbation ("bump").

Horizontal aperture is determined by extraction conditions: it is given by the extraction septum position, plus the "jump" effected by the particles, when they cross the extraction septum.

The main parameters of the optical structure are listed in Table I.

The sextupole arrangement around the ring allows one to control the horizontal chromaticity, the extracted beam emittance and energy spread: from Fig.3 it can be seen that sextupoles H_2 are placed where the dispersion is not zero, and therefore can be used to change the chromaticity; sextupoles H_1 and H_3 can be used to control the emittance and energy spread of the extracted beam.

REFERENCES

1 - ALFA proposal , Report of the study group, LNF 77/46 August 1977.

2 - K.R. Symon, Extraction at a third integral resonance, Reports FN 130, FN 134, FN 140, FN 144, Fermilab (1968).

3 - G. Gendrau, J.L. Laclare, G. Leleux, Dynamics of chromatic particles in the resonant extraction, SOC/ALIS 22, Saclay, July 1969.

4 - F. Amman, R. Andreani, The electron and positron linear accelerator, LNF 63/46, July 1963.

5 - H. Herminghaus, K.H. Kaiser, Design, construction and performance of the energy compressing system of the Mainz 300 MeV electron Linac, Nuclear instruments and Methods, 113, p.189, April 1973.

6 - Proposal for the construction of an electron storage ring (EROS) to increase the duty factor of the Saskatchevan electron accelerator, University of Saskatchevan, Saskatoon, 1976.

7 - R.A. Beck et al., ALIS - Avant-project d'un anneau lisseur de cycle de l'accélérateur linéaire de Saclay, ALS 300, DSS/SOC-ALIS-32, SEFS-TD-70/65 (1970).

8 - S. Guiducci, G. Martinelli, M.A. Preger, ALFA, feasibility study of an electron pulse stretcher to increase the duty factor of the Frascati Linac, LNF 78/44(R), October 1978.