An Energy Spectrum Compressor System (ESC) for the Amsterdam Pulse Stretcher (AmPS)

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Summary

To obtain high duty (90%) electron beams, the present 2% d.f. 500 MeV linac (MEA) will be modified into a low d.f. (0.1%) injector for the pulse stretcher ring presently under construction[1]. The accelerator peak current has to be increased from 10 mA to 80 mA to obtain from the pulse stretcher an average current of 65 μA . The resulting increase of the energy spread from 0.3% to 1 - 2% requires the installation of an energy compression system (ESC) to match the 0.2% acceptance of the pulse stretcher. The ESC consists of four magnets followed by a short-filling time r.f. traveling wave accelerator structure. Considerations concerning required energy range, beam loading, phase errors, and current ripple which determine the longitudinal dispersion and the required r.f. power source are presented.

Introduction

The energy spread of electron beams emerging from a linear accelerator can be considerably reduced by means of an energy compression system[2]. Such a system contains two parts: a magnetic channel in which the energy spread of the beam -through path length differences- is translated into a longitudinal phase stretching of the electron bunch and an acceleration structure in which the energy compression of the enlarged phase spread of the bunches occurs. The layout of the ESC is given in Fig.1. The four-magnet system, designed to fit in the existing acceleration vault, is based on laminated magnets to enable fast degaussing. This allows fast switching between compressing and non compressing mode. The choice of four magnets allows installation of monitoring equipment (viewing screen and a SEM grid for energy spread detection) in the center of the system. Optical considerations request the application of large pole face rotations. To reduce occurance of second order aberrations due to pole face rotation, the magnets will be provided with field clamps. The energy spread acceptance of the system is restricted to 1.8% by a 1.8 cm diameter collimator, installed between the first and second magnet. In the following we will discuss in some detail the design considerations of the two elements of the ESC.

Choice of longitudinal dispersion value.

The accelerator will be provided with 10 MW klystrons of which the high voltage will be supplied by a line type modulator [3]. With this type of modulator a considerable contribution to the energy spread is due to the effects of high voltage ripple on the RF. The total accelerator energy spread,±δ, can be calculated from,

$$2\delta = f(\varphi_0, \varphi_k, \varphi_B, \varphi_c) \cdot \frac{E + E_l}{E} + \frac{E_l}{E} \cdot \frac{di}{i} \qquad (1)$$

E is the energy (MeV) including beam loading, E_l is the total beam loading (2.57 MeV/mA) and di/i is the relative beam current ripple. $f(\varphi_0, \varphi_k, \varphi_B, \varphi_c)$ represents the effect of the klystron high voltage ripple (φ_k), the effective bunch width (φ_B) and the position of the bunch center (φ_c)[4]. φ_0 is the angle where RF power variation due to klystron voltage ripple is just compensated by the corresponding phase change ($\varphi_0 \approx 7^\circ$ in our case). φ_c and φ_0 are related to the crest of the accelerating field. The growth of the bunch after traversing the magnets is,

$$\varphi_{BD} = 360 \frac{D}{\lambda} \delta \quad (^\circ) \qquad (2)$$

D is the longitudinal dispersion in cm/%, and λ is the free space wavelength (0.105 m in our case).
Fig.2 shows the relation between the compression factor and the dispersive bunch part φ_{BD}, with the non dispersive bunch part φ_B as parameter. Also four working lines are given for D=2 cm/%, E=600 MeV , i=80 mA and $\varphi_{kc} = \pm 1^\circ$. φ_{kc} is the phase ripple of the compressor RF power. These lines have been obtained by calculating working points using (1) and (2). These points have been corrected for φ_{kc}. The working lines extend from $(\varphi_B)_{min}$ to $(\varphi_B)_{max}$. With increasing working line number the energy spread increases due to contributions according Table 1. $d\varphi_c$ is the deviation from the optimum φ_c value. With $\varphi_k = \pm 1^\circ$ corresponds a klystron high voltage ripple of 0.3%.

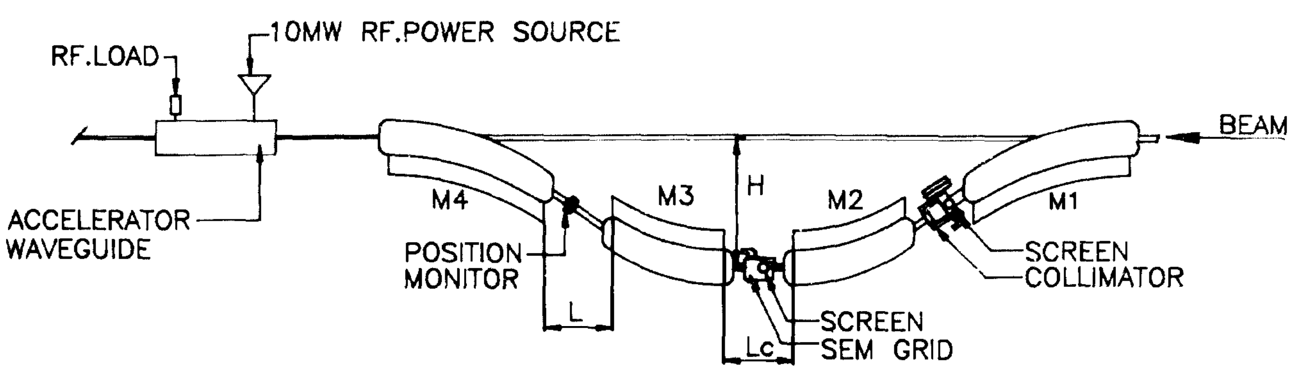

Fig.1, ESC layout.

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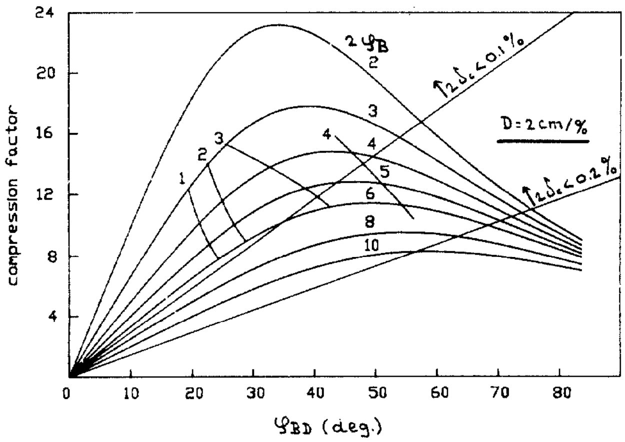

Fig.2, Compression factor as function of dispersive bunch part φ_{BD}. Four working lines (see Table 1) and 0.1% and 0.2% separatrices are also given (see text).

Table 1,Parameter values of working lines in Fig. 1.

line nr	$d\varphi_c$ (°)	φ_k (°)	di/i(%)
1	± 0	± 1	0
2	± 1	± 1	0
3	± 1	± 2	0
4	± 1	± 2	1

Fig.1 shows also 0.1% and 0.2% lines. Above these lines the compressed energy spread $2\delta_c$ is better than these values and below these lines it is worse. We prefer $2\delta_c$ not to be worse than 0.1%. Consequently the working points below the 0.1% line (largest φ_{BD} values) should be positioned close to the maximum of the compression curves. As can be concluded from Fig.1 D=2 cm/% does meet this criterion fairly well.

Compressor accelerator section and RF power source

The required maximum field (E_c) of the compressor accelerator is given by,

$$E_c = \frac{\varphi_c}{\sin\varphi_c} \cdot \frac{\lambda}{2\pi} \cdot \frac{E}{D} \qquad (3)$$

φ_e is the angle (rad) where the deviation from the central energy is just compensated by the compressor accelerator field. The required field is maximum when E is maximum (900 MeV, i ≈ 0) and φ_e has its corresponding maximum possible value. For $\varphi_B=\varphi_k=\varphi_{kc}=\pm 2^o$ and $d\varphi_c = \pm 1^o$, $(\varphi_c)_{max}=31.4^o$ [5]. Substituting these values in eq. (3) yields $E_c \approx 8$ MeV. The maximum energy gain of a constant gradient section is given by [6],

$$E_c = k_1 \sqrt{(P.l)} - k_2 .i. l$$

l is the length of the section (m) and P is the RF input power (MW). k_1 and k_2 are constants depending on the geometry of the section. To determine the required product $P.l$, the beam loading term (second term) can be neglected since the beam induced field is small compared with the generator field (first term) and 90° out of phase.

Assuming quality factor (Q) and shunt impedance (r) to be constant k_1 and k_2 depend only on the filling time. Numbers for $P.l$ (at E_c=8MeV) and k_2 for estimated values of Q=13000 and r=50MΩ/m are shown in Table 2. We see that at the cost of increasing filling time the product $P.l$ decreases. This means a shorter thus cheaper accelerator section and less RF power is required. However during the filling time an energy offset occurs due to the build up of beam induced field. For this reason we aimed for a filling time of 0.1 µs which is short compared with the beam pulslength (2.1 us).

Table 2, $P.l$ and k_2 values for E_c=8MeV,Q=13000,r= 50MΩ/m

Filling time (µs)	$P.l$ (MW.m)	k_2 (MeV/A.m)
0.10	9.93	1.68
0.15	6.84	2.50
0.20	5.31	3.29
0.25	2.09	4.06

Taking into account 15% RF power loss in the RWG network, a 10 MW RF power source combined with a filling time of 0.1 µs will result in a compressor section length of 1.16 m. For i=80 mA the maximum energy offset during the fill time due to transient beam loading is then 0.026%. Compared with the aimed energy spread of 0.1% for the whole beam pulse length this is quite an acceptable value.

Optimization of magnet size

To elongate the bunch as function of the energy spread the transfer function of the four magnet system must have a non zero (l|δ)-element (D) and should behave in both transverse planes as a driftlenght.A geometry as given in Fig.1 fulfills these requirements. In order to reduce the total system length, we allow,

$$T_y = \begin{pmatrix} -1 & Ly \\ 0 & -1 \end{pmatrix}$$

which means a crossover in the y plane in the centre of the system. The location of the ESC resticts the value of H (see Fig1) therefore an optimization of the magnet system was necessary. For some longitudinal dispersion values and maximum magnetic fields of the two centre magnets results of this optimization are shown in Fig.3.

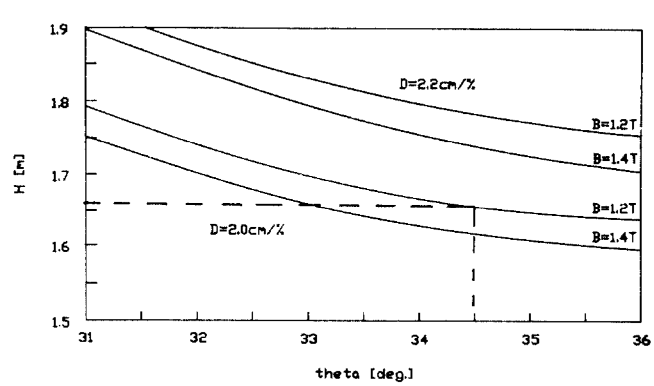

Fig.3, Variation of H (see Fig.1) as function of bending angle.

From this figure we conclude that Θ shouldn't be larger than 35 degrees; increasing the maximum magnetic field has a minor influence. This allows to adopt a moderate maximum magnetic field of 1.2 Tesla based upon a balance between magnetic field quality, magnet costs and electrical power costs. With Θ values below 35 degrees also second order aberrations are within tolerable limits. The longitudinal dispersion value has a much larger influence but this value is determined for other reasons as outlined above. The magnet parameters are given in Table 3.

Table 3. Compressor magnet data. M_1 & M_4 are the two outer magnets, M_2 & M_3 are the two central magnets.

	(M_1 & M_4)	(M_2 & M_3)
E_{max} [MeV]	900	900
B_{max} [kG]	8.57	12.0
ρ_o [m]	3.502	2.502
Θ [deg]	34.50	34.50
l_c [m]	2.1089	1.5064
l_{yoke} [m]	1.9838	1.4170
g (gap) [cm]	3	3
w (pole width) [cm]	21.0	21.0
good field region [cm]	+/- 2.5	+/- 2.5
radial field homogeneity	$5_{10^{-4}}$	$3_{10^{-4}}$

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