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THE AMSTERDAM PULSE STRETCHER

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1. SUMMARY

In order to increase the duty factor (d.f.) of the present 500 MeV electron linac from 2.5 % to > 90 %, it is proposed to add a pulse stretcher to the facility. By replacing 4 of the 12 existing 4 MW klystrons by 25 MW types, the injection energy will be increased to E = 700 MeV. A peak current of 40 mA will be injected during three turns with 365 pps. to yield an extracted beam current of 40 μA. The machine operates near a third order resonance. The chromaticity is non-zero. Extraction proceeds by changing the cavity frequency (2856 MHz); this will push the beam into the unstable region of the phase space. An energy compressor will reduce the momentum spread of the injected beam to $|dp/p| = 0.1$ %.

2. INTRODUCTION

An increasing number of electron scattering experiments performed at NIKHEF-K are coincidence experiments of the type (e,e'p). The efficiency of these experiments (i.e. increasing the real/random ratio) is greatly enhanced by increasing the d.f. of the incident electron beam. At present the d.f. of the MEA linac is 1.4 % at E = 500 MeV (pulse length τ = 40 μs at f = 350 Hz). The existing hardware allows an increase of the d.f. to 2.5 % (τ = 50 μs, f = 500 Hz). A further increase of the d.f. beyond this number with the current machine calls for extensive modifications and becomes very quickly prohibitively expensive. A pulse stretcher added to an existing linac is a cost-effective way to increase the d.f. to > 90 %. The mode of operation of such a combination is as follows: at repetition rate f a beam pulse of length τ and intensity $\hat{i}$ is injected into the stretcher of length L (and consequently will fold unto itself $n = \tau c/L$ times). The stored beam is slowly, and as uniformly as possible, extracted from the machine in the time between two consecutive injection pulses. The average extracted current is $\bar{i} = \hat{i} f \tau$ (if $\tau \ll 1/f$). A comparison of the conventional mode of operation of the linac and its operation in the stretcher mode is made in Table 1.

Energy	(MeV)	500	700
beam pulse length	(μs)	40	2.8
RF " "	(μs)	41.3	4.1
peak current $\hat{i}$	(mA)	10-15	40
repetition rate	(Hz)	500	365
beam duty factor	(%)	2	0.1
average current $\bar{i}$	(μA)	> 100	40
# RF stations (low power)		12	8
# RF " (high power)		-	4

Table 1. Some machine parameters of linac in present configuration (2nd column) and in stretcher configuration (3rd column).

3. MACHINE LATTICE

The layout of the machine is given in fig. 1. One straight section (length ∿ 100 m) is accommodated inside the accelerator vault; part of the left arc (length ∿ 40 m) is located in the beam switch yard. Each arc consists of eight identical $\Psi_{x,y}$ = 90 deg. cells of the type $\frac{1}{2}Q(x)S(x)B(x)Q(y)S(y)B(x)\frac{1}{2}Q(x)$, so $Q_x = Q_y = 2$ for each curve. In such a structure all 2nd order geometric and chromatic aberrations can be made to vanish simultaneously [1,2].

The straight sections are made up of FODO modules, each 10 m long ($\beta_x^{max} \sim \beta_y^{max} \sim 17$ m). At some places either one or two modules have been replaced by special-purpose insertions: extraction module ($l = 20$ m) where $\beta_x = 33$ m; RF module ($l = 10$ m) in which the cavity will be located. Since the cavity operates on f = 2856 MHz, its aperture should not exceed ∿ 3 cm. In the central region of this RF module therefore, $\beta_x = 2.6$ m and $\beta_y = 4$ m which ensures that beam excursions (e.g. during extraction) can be kept within acceptable limits.

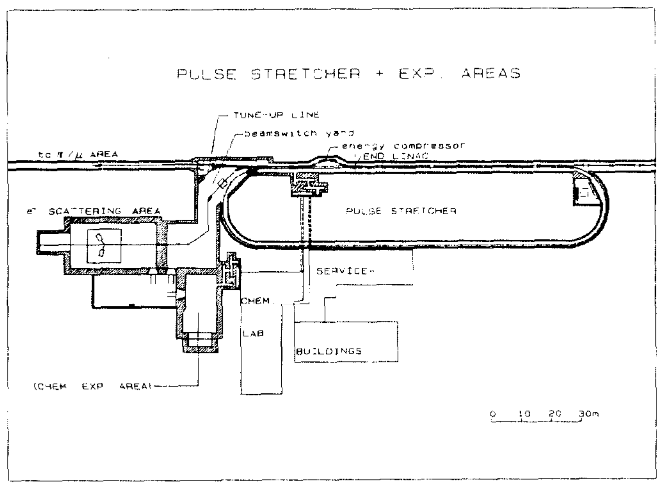

Fig. 1 Layout of proposed pulse stretcher

The FODO length in a curved section is ∿ 5 m; continuation of this cell length into the straight sections will result in an undesirably high number of quadrupoles in these sections. To avoid this, a three-quadrupole matching section (length 5 m) matches the curved section to the 10 m long straight sections. Schematically, the stretcher looks like (M: matching cell; S: straight cell; C: curve):

(M)(Extr)(S1)...(S6)(RF)(M)
(C) (C)
(M)(S1)(S2).....(S8)(S9)(M)

The machine functions of the upper part of the machine are given in fig. 3.

4. INJECTION AND EXTRACTION

The beam will be injected into the horizontal phase space during three turns. Three pulsed kickers displace the closed orbit (c.o.) in the injection area prior to injection to avoid the beam hitting the septum after the 3rd turn. The c.o. is made to coincide with the machine center again after ∿ 6 turns. Slow extraction of the beam is accomplished by exciting the 3rd integer resonance. This resonance does not possess a finite stopband. In order to avoid retrapping of already unstable (i.e. soon to be extracted) particles, a 'fake' finite stopband is simulated by creating a

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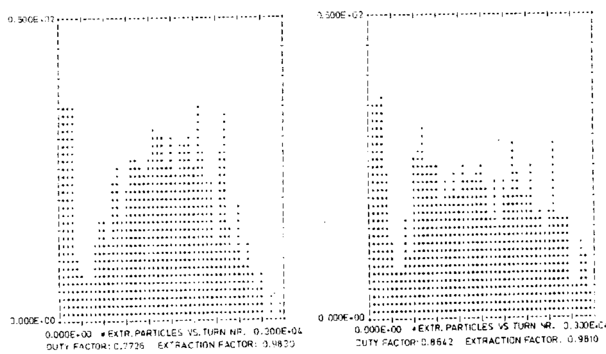

Fig. 2 Extraction simulation: uniform extraction speed (left) and extraction time divided into 10 equal bins (right).

hollow beam in the (x,x') phase space. One obtains such a beam if $(x,x')_{inj}$ does not coincide with $(x,x')_{c.o.}$ The damping times are sufficiently long (τ_d = 200 ms at E = 700 MeV) to sustain this desired shape while the beam is in the machine ($\sim$ 2.7 ms). Actual extraction is accomplished by slowly increasing the RF frequency of the cavity; the induced Δp relates to the applied Δf according to $\Delta f/f = -\alpha\ \Delta p/p$. The value of the momentum compaction α = 0.0196. The momentum reduction of the particles (both RF-induced and due to synchrotron losses) causes them to migrate into the unstable part of the phase space where they are intercepted by the extraction septum (monochromatic extraction). Since the chromaticity χ is not completely corrected (i.e. $\chi \neq 0$) the stable area A is a function of $\delta = p-p_o$. The spectral width of the extracted beam depends in this extraction mode on the steepness of the A vs. δ curve. This steepness is governed both by the tune and the chromaticity (which have been chosen such that the pitch at the extraction septum is $\sim$ 1-2 cm; the corresponding beam loss is $\sim$ 1.5 %). For the present machine $(\Delta E/E)_{ext} \sim$ .1 %. Extraction simulations show that in case of constant $\Delta f/f$ the d.f. $\sim$ .77 . In order to improve the d.f. we subdivided the extraction time interval into 10 equal bins and kept $(\Delta f/f)$ only constant in each bin. This increases the d.f. to .86, see Fig. 2 (the d.f. is here defined as: d.f. = $N/(n\sum_n \text{count}(i))$, N is total number of particles, n is number of bins - presently n = 50). Phase space area of the extracted beam is $\pi\varepsilon_x$ = 0.5 mm.mrad $(\varepsilon_x \sim \varepsilon_y)$.

5. R.F. SYSTEM

Energy loss due to synchrotron radiation and parasitic loss will be compensated by a single-cell 2856 MHz cavity. The cavity frequency is the same as is used for the accelerator. Higher order modes will be prevented by carefully shaping the cavity and the use of damping probes.

For 700 MeV and 120 mA the total power loss in the ring is 900 Watt due to 800 Watt synchrotron radiation and 100 Watt parasitic loss. For this amount of loss a generator power of 2.5 kW will be sufficient.

6. BEAM DIAGNOSTICS

In order to trace beam excursions accurately about 40 stripline beam position monitors will be installed. At two places in each curved section synchrotron light will be used to measure beam size and beam position. The current will be measured with a fast response (1 ms) DCCT type monitor. This device can also be used for calibrating intensity signals from other monitors like stripline monitors and synchrotron light monitors.

Transverse beam excitation forced by a kicker magnet will be detected by a position monitor during several revolutions. From its signal the tune will be calculated on line through fast Fourier transform analysis. In addition to the kicker magnet an electrostatic kicker in a feedback loop (damper device) will enable quasi non-interfering tune measurement.

7. ACCELERATOR ADAPTIONS

Microwave power - To realise the specifications for stretcher operation (Table 1) without disabling the present mode of operation, klystrons with low duty-factor (.15 %) and high peak power (20 MW) will be installed in parallel with the present low peak power (4 MW) klystrons. An R.F. power switch will allow either klystron to be connected to the accelerator guides. Figure 4 illustrates the simultaneous operation of both power modes. From this figure we see that four 20 MW klystrons are sufficient to meet the stretcher mode specifications if the present klystrons yield 5 MW instead of 4 MW. The present modulators have a modular structure with 40 identical solid state pulse forming networks (PFN) [3]. Upgrading the klystrons from 4 to 5 MW can be readily achieved by increasing the number of simultaneously discharged PFN's from 32 to 34.

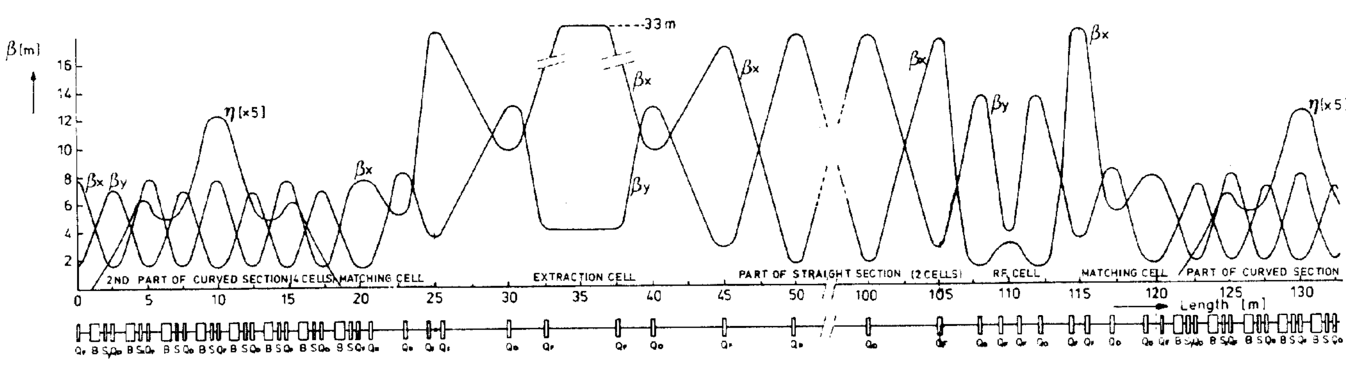

Fig. 3 Machine functions in upper part of machine lattice.

Energy spread - Concerning energy spread we have to distinguish between the first part of the beam pulse during one filltime (1.3 μs) and the rest of the beam pulse. Without precautions the filltime electrons would be completely lost because of extreme energy spread due to transient beam loading. In stretcher mode this would account for a loss of 45 % of the total accelerator current. Therefore this effect will be suppressed by distributed R.F. timing with fast R.F. switches. If the switch time is less than 100 ns the energy spread during filltime can be kept below 1 % [4].

Apart from the filltime electrons the present accelerator energy spread is .35 %. Enhancement of the peak current in stretcher mode will deteriorate this value to .6 % due to both widening of the injector bunch and reactive distortion in the accelerator guides. So the energy spread will be within 1 % during the whole beam pulse. The injected beam should have an energy spread of no more than .1 %. To reduce the energy spread to that value, a four-magnet energy compressor will be installed between the accelerator and stretcher. The R.F. power for the compressor will be coupled from one of the 5 MW klystrons.

Injector - The 40 mA beam current is still below the maximum specification of the present gun. Therefore major modifications of the gun assembly are not to be expected. The gun pulser electronics which is on high-voltage level has to be modified for two reasons:
- beam start must have the same switch time as the R.F. switches for suppressing transient beam loading
- the current stability must be improved because energy fluctuations are more serious for larger beam currents.

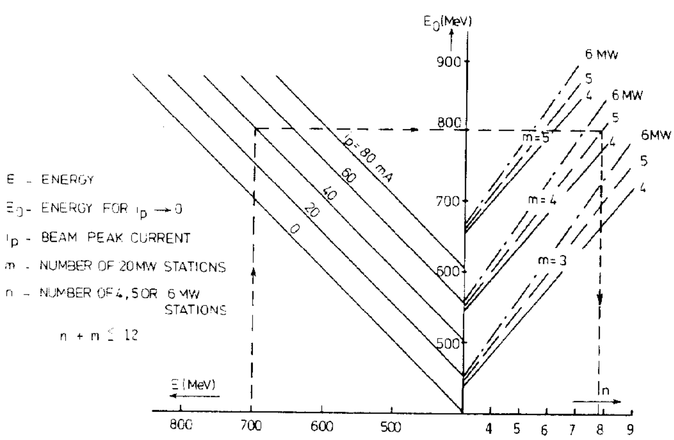

Fig. 4 RF peak power diagram for PS conditions (700 MeV, 40 mA).

8. MAGNETS

The lattice comprises of 32 dipoles, 88 quadrupoles and 32 sextupoles. To enable a future energy upgrade of the stretcher without having to replace all the magnetic elements, their maximum field corresponds to an energy of 1.2 GeV. The design shows relatively large coils and yokes but a low power consumption because the running costs of the magnets have been optimized against their capital costs. All dipoles will be of the rectangular H type. The yokes of both the dipoles and the focussing magnets will probably be laminated mainly to reduce hysteresis effects. To minimize the number of power supplies and to save on cabling, magnets belonging to the same functional family will be connected in series. Small orbit corrections will be feasible with additional trim coils on the dipoles and with a number of steering magnets. To enable extraction an electrostatic wire septum will be implemented. Several field-proven designs for the injection kickers and their power supplies are available from other laboratories but the choice has not been finalized yet.

9. VACUUM

Coherent and incoherent space charge effects induce tune shifts. The space charge is a function of the number of ions produced by the beam. As the P.S. will be operated near resonance the stability of the beam and therefore its life time is very sensitive to these tune shifts. Calculations [5] indicate that with a circulating peak current of 120 mA and a life time of 3 ms the vacuum should be better than 1.10^{-8} Torr. Synchrotron radiation will enhance thermal outgassing and will also induce photon-stimulated gas desorption from the vacuum chamber walls. Considering the required low pressure, special care therefore must be given to the choice of materials and the handling of vacuum components. Aluminium instead of stainless steel has been chosen to be applied as material for almost all vacuum components because of several advantages: low outgassing and desorption if treated properly, good thermal conductivity, ideal magnetic permeability, low residual radioactivity. All vacuum components will be thoroughly cleaned by means of degreasing, light etching and rinsing processes. Assembly and installation will be according to UHV standards. Ion getter pumps will be distributed along the stretcher to ensure adequate pumping. In order to facilitate maintenance the machine will be divided by valves into 4 sectors.

10. PROJECT STATUS

The proposal has been submitted to the funding authorities in 1984. A decision is expected by mid 1985.

ACKNOWLEDGEMENTS

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