# OPTICS OF THE AMSTERDAM PULSE STRETCHER (AmPS)

R. Maas and Y.Y. Wu

NIKHEF-K
P.O. BOX 4395, 1009 AJ Amsterdam, The Netherlands

## 1. Summary

The AmPS machine [1] has been designed as a dual-purpose machine: it will be used both as a Pulse Stretcher (PS) and as a storage ring for electrons. In the latter mode the stored beam will be used in conjunction with an internal (jet) target. Since the internal target will limit the lifetime of the beam to minutes, the storage requirements (e.g. vacuum) will be modest. In PS mode the energy range is 250 - 800 MeV; in storage mode the range is extended to 900 MeV. It is anticipated to store a current of up to 200 mA.

## 2. Lattice

The machine lattice consists of four curved sections, connected by dispersion-free straight sections. Each curved section comprises four identical cells of the following structure (Q is quadrupole, S is sextupole; subscripts refer to the two transverse planes) :

$$|Q_{h1})\text{-}(S_h)\text{--}(\text{Bend})\text{---}(Q_v)\text{-}(S_v)\text{--}(\text{Bend})\text{---}(Q_{h1}|$$

The phase advance of each cell is 90° in both planes, i.e. $\nu_x = \nu_y = 0.25$; the curved section, therefore, is achromatic. In this structure the two sextupole families can be set such, that all 2nd-order geometric and chromatic aberrations vanish identically (2nd-order achromat [2,3]). The dispersion function reaches its maximum value (2.7 cm / %) in the centre of the curved section. The length of the central orbit in the curved section is 20.8 m. Machine functions are given in Fig.1.

Each (achromatic) straight section comprises two matching cells; the beta functions increase gradually over the length of the matching cell, see Fig.2. The structure of a matching cell is :

$$|Q_{h1})\text{-}dr_1\text{-}(Q_{v1})\text{-}dr_2\text{-}(Q_{h2})\text{--}dr_3\text{--}(Q_{v2})\text{--}dr_4\text{--}(Q_{h3})\text{-}dr_5\text{-}|$$

$dr_n$ indicates a drift space; quadrupole $Q_{h1}$ is shared with the curved section, see above. Both the injection area and the extraction area are situated in the region where $\beta_x$ reaches its maximum value (i.e. in $dr_5$), thus avoiding unduly tolerance requirements on injection and extraction hardware. Both the RF cavity (or cavities, see below) and the internal target will be located in $dr_1$ (of different matching cells), since the β-functions in both transverse planes are small in this region. Tunes of the matching cell are $\nu_x = 0.4546$ and $\nu_y = 0.4025$; the tunes of the machine in PS mode, therefore, are $\nu_x = 7.637$ and $\nu_y = 7.22$. In storage mode the tunes are slightly different: $\nu_x = 7.61$ and $\nu_y = 7.15$. The length of the machine is 211.6 m ($\tau_{rev} = 0.71$ μs).

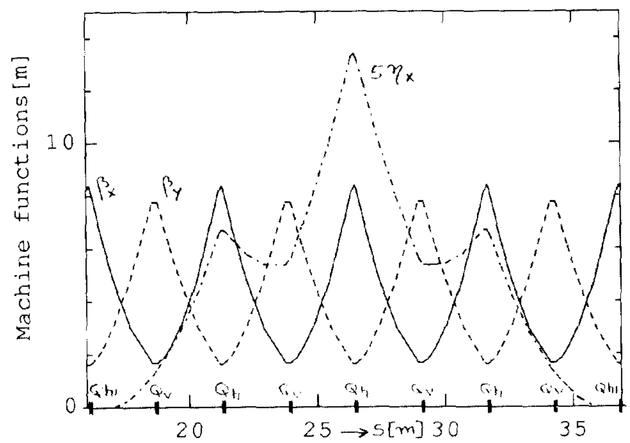


Fig. 1 Machine functions in curved section.

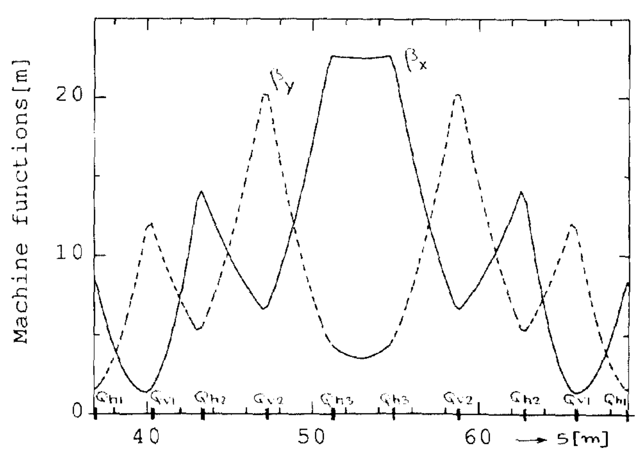


Fig. 2 Machine functions in straight section; each straight section consists of two matching sections.

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## 3. Stretcher operation

In Stretcher operation the linac, which delivers the electron beam to the machine, operates under the following conditions: E = 250 - 800 MeV; max. frequency $f_{max}$ = 400 Hz; $\tau$ = 2.1 $\mu$s; $I_{peak}$ = 80 mA. Under these conditions the *average* current $I_{av}$ = (2.1 / 2500) $\times$ 80 mA = 65 $\mu$A. Injection will take place over (almost) three turns. In order to avoid the beam hitting the injection septum after three turns, the closed orbit (CO) will, prior to injection, be displaced in the vertical plane by two fast electrostatic kickers. Injection is terminated after 2.7 turns, and the CO is restored fast ($\tau$ < 70 ns).

Third-integer resonance extraction is employed to extract the beam uniformly in the available 2.5 ms (corresponding to 2500 / 0.71 = 3500 turns) before the next pulse is injected. Four sextupoles, each located in one of the four (dispersion free!) straight sections can be used to excite the resonance. In our simulations only two have been used. With the two sextupole families located in the curved sections the chromaticities of the machine are set: $\chi_x$ = -15 and $\chi_y$ = + 0.2. By allowing the particles to lose energy, the negative chromaticity effectively brings the particles into the unstable region of the (in this case horizontal) phase space; extraction takes place by an electrostatic septum. The maximum possible energy loss is given by : $(dp/p)_{max} = (\nu_{res} - \nu_x) / \chi_x$ = - 0.2%. By phase modulating the RF voltage ($f_{RF}$ = 2856 MHz) during extraction [4], part of the captured particles are effectively placed outside the RF bucket and will lose energy due to synchrotron radiation. Tracking simulations [5] show that the resulting phase space area of the extracted beam is close to the expected value (showing that the extraction process is not very sensitive to the synchrotron motion). The duty factor in this case was 66 %. This can be improved by changing the value of $\nu_x$ to a value closer to $\nu_{res}$ (reducing the distance between the bucket and the unstable area). For the results presented in Fig's 3, 4 and 5 the following phase kicks (per 200 rev's) were given : N = 0 - 1000 : $\Delta\phi$ = 50°; N = 1200 - 2000: $\Delta\phi$ = 65°; N = 2200 - 3000: $\Delta\phi$ = 90°; N = 3200 - 3600: $\Delta\phi$ = 140°. The accelerator pulse (width $\Delta\phi$ = ± 30° after the Energy Compressor; height dp/p = ± 0.05%) is placed at $\phi$ = 230° and dp/p = -0.005% inside the bucket. This means that part of the injected particles will never be captured and migrate immediately towards the septum. Presently the energy of the injected beam is centred around dp/p = 0 (with a width of ± 0.05 %); it takes about 350 rev's (see Fig. 4) for unstable particles to cover the distance to $(dp/p)_{ext}$ (see Fig. 5: $(dp/p)_{ext}$ = - 0.16 %). Another area for improvement is the phase kick scheme: rather than administering a phase kick every 200 turns, a more continuous operation will be tried.

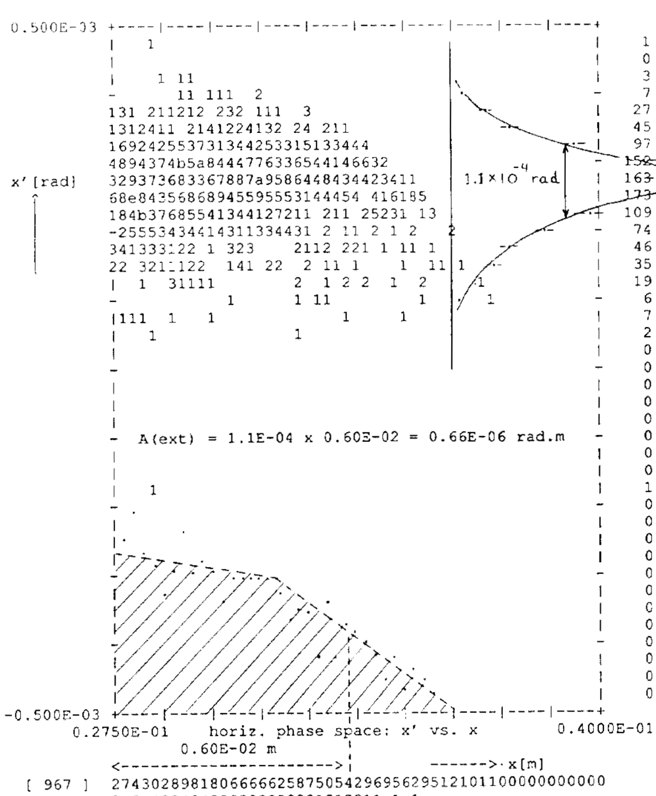



Fig. 3 Phase space area of extracted beam at E = 500 MeV; 1000 particles were tracked over $N_{max}$ = 3500 turns.

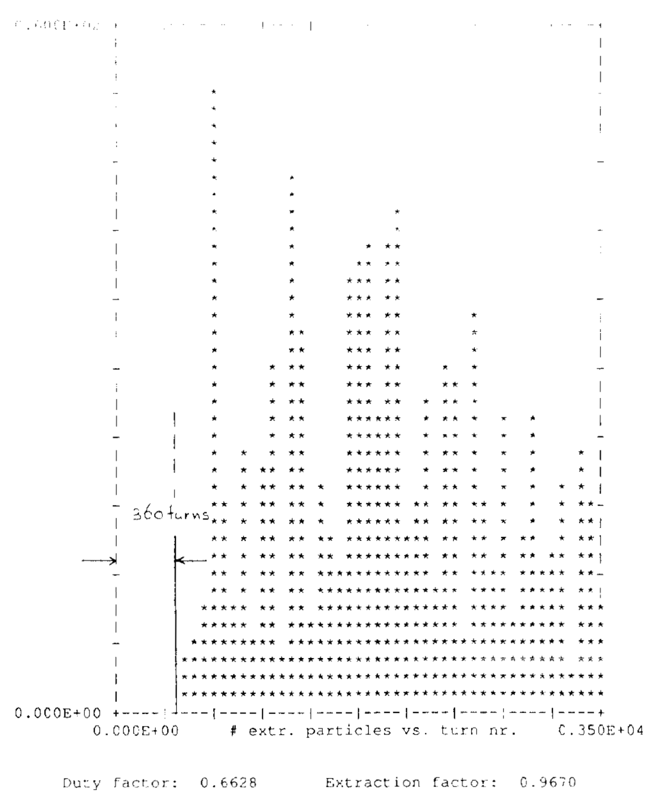
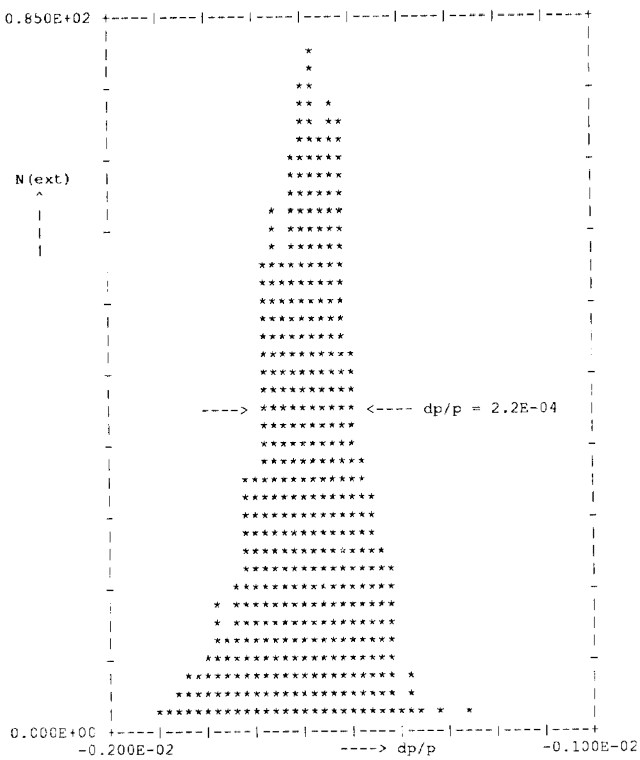



Fig. 4 Number of extracted particles vs. turn number ($N_{max}$ = 3500).




Number of extracted particles vs. dp/p

Fig. 5 Energy width of extracted beam at E = 500 MeV.

Misalignment simulations indicate possible CO deviations of up to 7 mm from the machine centre; in order to reduce these unwanted beam excursions to the level of 0.5 mm, an orbit correction scheme will be implemented. In total 32 pairs of x-y steering coils and stripline monitors (combined x-y) will be distributed around the ring (4 units in each curve: 4 units in each straight section).

## 4. Storage Mode operation

In order to ensure for a stored beam a quantum lifetime of the order of minutes, the height of the bucket should be at least 5 times that of the bunch [6]: $\tau_q = (e^x / 2x)\tau_\varepsilon$, $x = b^2/2$, $b = \sigma_b/\sigma_\varepsilon$. $\sigma_b$ and $\sigma_\varepsilon$ are bucket height and bunch height respectively; $\tau_\varepsilon$ is the damping time to reach $\sigma_\varepsilon$. In case E = 900 MeV ($\tau_\varepsilon$ = 36 ms, $\sigma_\varepsilon$ = 0.043 %), $V_{RF}$ > 400 kV for b > 5. In order to avoid such excessive RF requirements, it has been decided to use a lower frequency (e.g. f = 476 MHz) in storage mode; for the same requirements as given above, the required RF voltage in case f = 476 MHz is only 85 kV.

The program ZAP [7] has been used to study single bunch and coupled bunch instabilities. In order to calculate current thresholds, one needs to know the value (and frequency behaviour) of the longitudinal coupling impedance $|Z_{\parallel}/n|$ of the machine. As real data are not yet available, we assumed: $|Z_{\parallel}/n|$ = 10 Ω. Also, values of both shunt impedances and Q-values of the higher-order modes (and the fundamental one) of the RF cavity are needed. The code Urmel-t [8] was used to obtain these data. Preliminary results (the cavity design has still to be optimized) indicate the following values for the max. stored current:

Table 1 Current thresholds (total avarage current) for longitudinal coupled bunch instabilities; (values between brackets have been calculated assuming no bunch lengthening)

| E [MeV] | $I_{th}$ [mA] |
|---|---|
| 300 | 150 (20) |
| 500 | 70 (30) |
| 700 | 50 |
| 900 | 100 |

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