THE UNILAC AS A FAST SWITCHING, VARIABLE ION AND ENERGY ACCELERATOR

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Work is in progress to extend the Unilac heavy ion linear accelerator facility through the addition of a high current injector, a synchrotron (SIS), and a storage ring[1]. For efficient operation of these facilities the scheme of time share operation has been adopted for the Unilac: beams of differing ion species and current will be extracted from one of three injectors, be accelerated to the desired energies and be delivered into one of three experiment areas or to the SIS.

The performance of the Unilac under these operating conditions has been studied theoretically and experimentally, and it was found that d.c. powered focusing systems within accelerating tanks will accomodate the range of desired ions (Ne to U) and energies (3.6 to 16 MeV/u). RF-systems, transverse matching sections and switching magnets are to be operated in a pulsed mode with varying fields.

Introduction

The Unilac heavy ion accelerator is designed to produce beams of any ion with energies up to 20 MeV/u. It operates at 50 Hz with duty factors of typically 25 %, leaving 15 ms intervalls between beam pulses. As an injector for the heavy ion synchrotron SIS the Unilac will have to deliver on demand interspersed single beam pulses of different ion species, energy and current.

For this purpose, and with benefits to the ususal operation, the Unilac is now being modified for time share operation (similar to the Superhilac at LBL in Berkeley). The aims are, as development progresses, to deliver on a pulse-to-pulse basis varying ion beams:

- two or three low current beams of the same ion species, but of differing energy, to some experimental areas (energy switching)
- a low current and a (space charge dominated) high current beam of the same ion and differing energies to the experimental area and the SIS, respectively (current switching)
- independent beams of different ions, currents and energies (ion switching).

Pulsing the Unilac

1. RF-Systems: For proper ion acceleration, RF power-on/off, amplitude and phase must be controlled according to the kind of beam in each pulse. Electronics and control-system for some 30 RF stations are being adapted for this task. Means to solve the beam loading problem (up to 200 kW per cavity for uranium beams) are under study.

2. Transverse Focusing: The Unilac accelerating structures of the Wideröe-, Alvarez- and single gap resonator types (see fig. 1) employ periodic magnetic quadrupole focusing. Using their bandwidths over magnetic ion rigidity eliminates the need of pulsed field adjustment for the varying beams. This will be demonstrated below. However, transverse beam matching in nearly all transport sections requires pulsed lenses with field settling times of 15 ms.

3. Beam Diagnostics and Control System: The individual beam signatures per pulse ask for selective, synchronized magnet setting and beam diagnostics evaluation, which the present control system does not provide. A temporary solution for the beam diagnostics is to trigger their electronics only on the occurences of a selected kind of beam. Magnet power supplies will be connected to the sufficiently powerful new SIS-control system which is linked (by Ethernet) to the Unilac controls.

Bandwidth of Focusing in Accelerating Cavities

Energy Switching

Using the same ion, different ion energies are to be produced in the poststripper area. With the quadrupole field gradients set to design-values for the ion in use, constant phase advances of $\sigma_0 = 45°$ result in the Alvarez- and single gap resonators at full acceleration. Partial energies are achieved by turning off some cavities. While the beam drifts through these accelerator structures, the ion rigidity deviates more and more from the increasing design value with acceleration, leading to greater phase advances up to 90°. Due to the absence of rf defocusing and of emittance shrinking, the effective radial acceptances change. Fig. 2 shows the acceptances of Unilac cavities relative to the maximum beam emittance (1 π mm mrad normalized) over relative beam rigidities (with value of 1 for the accelerated "design ion"). The acceptance graphs were computed after the conservative periodic approximation model. Obviously there is no difficulty to accelerate ions or to transport them at 3.6 MeV/u without any change of the focusing strengths in the RF cavities. However, this is not true for the intertank sections.

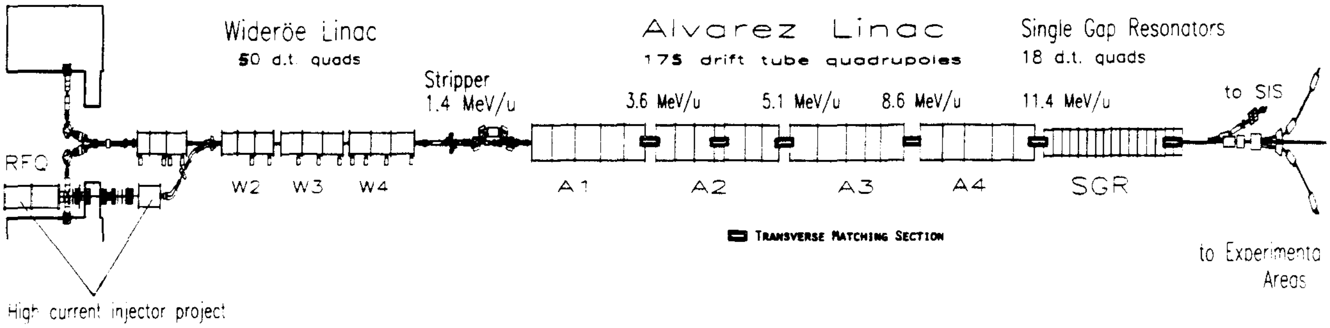

Fig. 1: Plan view of Unilac showing the different accelerating structures and pulsed transverse matching sections as specified for the poststripper area. Part of the new high current injector is sketched on the left.

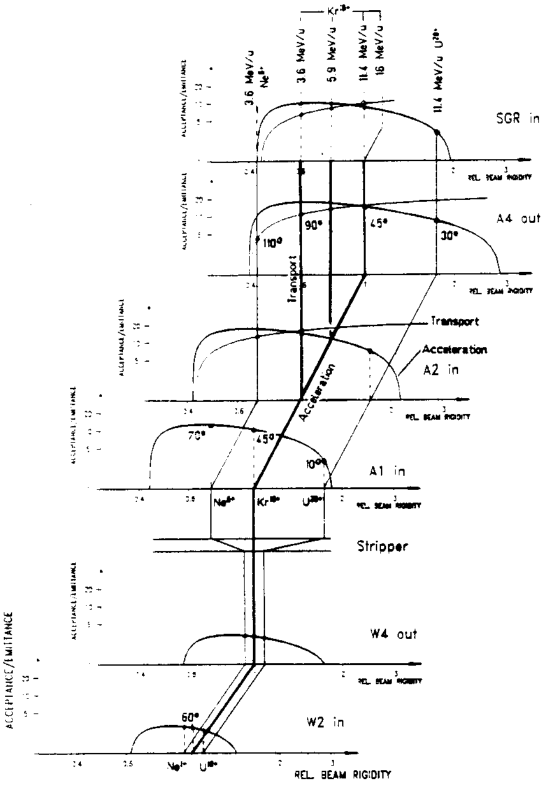

Fig. 2: Acceptance of Unilac accelerating sections over beam rigidity at fixed drifttube quadrupole fields. Acceptance is normalized to the maximum beam emittance of ε_n = 1 mm mrad, rigidity is relative to that of accelerated Kr^{16+}. Some ion paths for "energy switching" (fat lines) are shown together with extreme cases of "ion switching": full energy U beam and low energy Ne beam (light lines). Bandwidths are sufficient for this range of ions and energies. Transverse phase advances are indicated.

Ion Switching - Low Current

For the most of flexibility it is desirable to choose the ion species for different targets independently. With the same energies per nucleon at each section of the accelerator the ions span a range of rigidities equal to the range of their mass-to-charge ratios, which are 20 to 24 in the prestripper and 3.3 to 8.5 in the poststripper area. Choosing Kr as the design-ion and adjusting the focusing systems accordingly puts all the ions within the bandwidth of the accelerator as is depicted in fig. 2 by the light ion path lines. In addition, light ions of low energies (down to 3.6 MeV/u Ne) can be transported and extracted as is proven by the more accurate particle simulations. Note that in this scheme U-ions in the first Alvarez cavity lie close to the bandlimit with σ_0 ~ 10°, and an acceptance surplus of only 2 times the beam emittance results. Generally, if the two ion species to be accelerated are not Ne and U, best use of the acceptance could be made by choosing for the focussing magnet setpoints a design-ion with a mass-to-charge ratio half-way in between those of the beams.

Ion Switching - High Current

For complete filling of the SIS, peak beam currents of the order of 1 pmA are required in the Unilac. This is an increase by a factor of 1000 over the up-to-date performance. Appropriate beams will be provided by the new high current injector[2] for the Unilac, presently under construction.

High beam intensities, and bunch duty factors as low as 10^{-3} lead to significant space charge defocusing throughout the Unilac, ranging up to a factor of 2 over RF-defocusing. Resulting maximum transverse tune depressions are 45° → 30° in the poststripper and 60° → 30° in the prestripper sections; in the latter the quadrupole gradients may be increased by 20 % in order to obtain phase shifts of 90° → 75° and larger acceptances. In fig. 3 the fat ion path line is for the design ion under these conditions.

The acceptance bandwidths are drastically reduced on the high rigidity side only. Therefore the energy switching scheme may be applied simultaneously with any beam current switching. In ion switching mode under space charge the range of rigidities is limited to 1:2 in the poststripper section, which may be taken into account in the operating schedule.

However, even all-ion operation is still possible if the range of ion rigidities is reduced by using a pulsed gas stripper with lower gas pressure for light ions, leading to lower charge states at peak intensity (for example Ne^{4+} instead of Ne^{7+}). With the focusing systems adjusted to Sm^{23+} instead of Kr^{16+} the Unilac will then accept all ions.

The resulting ion schedule is included in fig. 3. Arbitrary choice of ion, energy and current of beams would be permitted at fixed focusing strengths in the accelerating cavities.

An improvement of the low acceptance in the Wideröe-tanks can be achieved by installing permanent magnet quadrupoles into the - now empty - drift tubes on the inner conductor (every other of all drifttubes). Focusing properties will then be very similar to those of the Alvarez cavities. The electromagnetic quadrupoles would still allow for sufficient fine tuning.

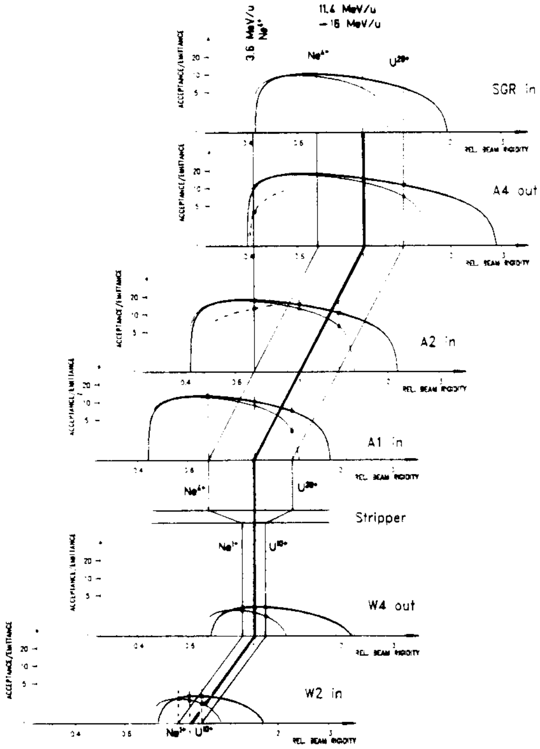

Fig. 3: Unilac acceptance plots (as in fig. 2) for zero and high beam currents. Light curves are for 20 mA U^{10+}/8 mA U^{28+} in the pre-/post-stripper section. Reduced acceptance bandwidths still allow all-ion operation if low charge states for light ions are used as shown.

Transverse Emittance Matching

Local acceptances at cavitiy boundaries were determined as the largest matched beam emittances fitting into the drifttube apertures. The transverse parameters of such beams show a strong dependence on the focusing strength (~ B'/Bρ) and on the defocusing parameter (by space charge and/or accelerating fields). At fixed gradients B' the dependence on beam rigidity is prominent. In symmetry positions of the focusing periods the beam ellipses are on axis and their parameters behave typically as shown in fig. 4; some resulting local acceptance ellipses are given in fig. 5. Matching between cavities is accomplished by separated magnetic quadrupole triplets, which transform such ellipses identically over the intertank distance. With a large aperture of 6 cm in the central quadrupole no loss of acceptance occurs in the matching section (fig. 5). Field strengths of the lenses are to be adjusted properly within 15 ms between beam pulses, depending on beam rigidity, current and cavity operating mode (acceleration or transport). An example for low current is seen in fig. 6).

Likewise, a pulsed quadrupole triplet is foreseen to match the beam into the 9 mm diameter stripper aperture. Beam parameters at the Unilac exit can be fitted to the beam line acceptance by four pulsed lenses in the single gap resonators.

Status and Perspective

Numerical studies using the particle trace code "Parmila" were performed for realistic beams with and without space charge. Results were even more favorable than the estimates in the periodic approximation model. Transverse focusing and matching methods for the energy and ion switching mode have been tested successfully in the Unilac poststripper. For this area, the necessary 30 laminated core quadrupoles, 20 steering magnets and their pulsed power supplies were purchased and are being installed into the accelerator during regular shut-down periods. Real time energy switching will be used to supply several target stations with different beam energies from 1987 on when all pulsed components of the poststripper linac will be installed.

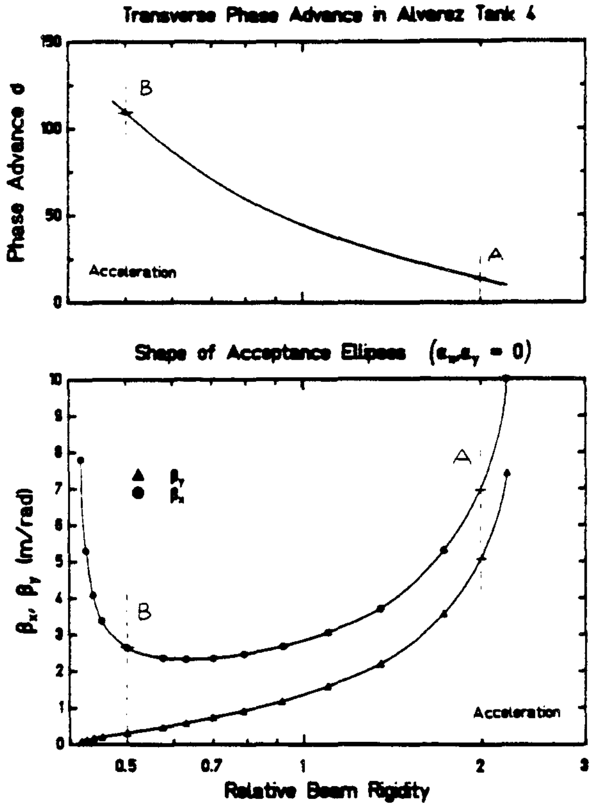

Fig. 4: Variation of matched beam parameters for static periodic focusing over beam rigidity. Extremes β_x, β_y of betatron functions determine acceptances and beam size.

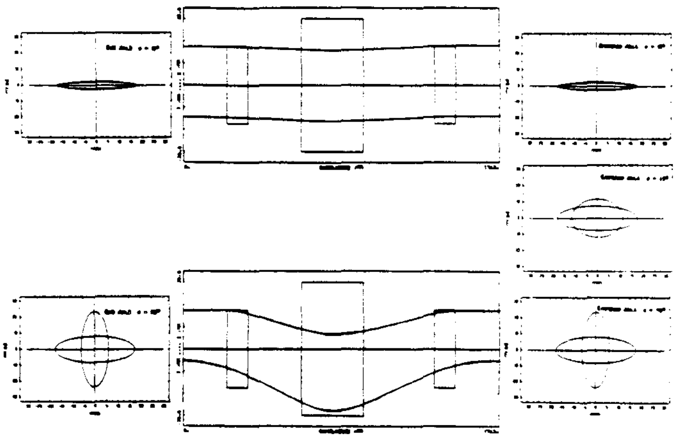

Fig. 5: Two cases of transverse matching between accelerating cavities for beams with a magnetic rigidity ratio of 4:1 and transverse phase advances of 10° and 110°. Transformation of accelerator acceptances is accomplished without loss. In figs. 5 and 7 these cases are marked by letters A and B.

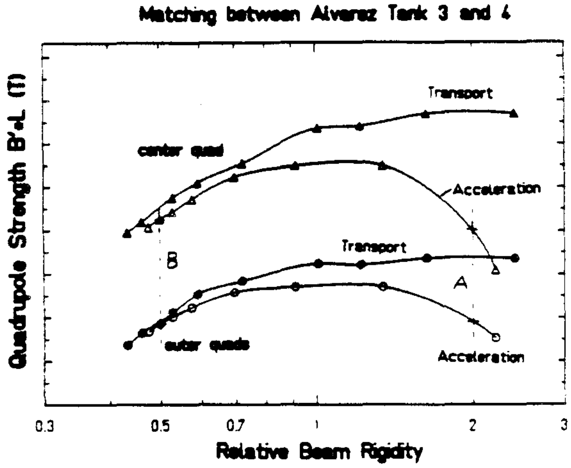

Fig. 6: Example of required quadrupole field strengths in a matching section over beam rigidity.

Space charge effects in the stripper area need to be investigated; this will determine how to rebuild or expand the charge analysis system for two-beam operation.

References

[1] K. Blasche, D. Böhne, B. Franzke, H. Prange, "the SIS Heavy Ion Synchrotron Project", in Proceedings of the 1985 Paricle Accelerator Conference, Vancouver, 1985, IEEE NS32, p.2657.

[2] J.Klabunde et al., "The Project of a High Current Injector at the Unilac", these proceedings.