THE UNILAC UPGRADING PROGRAM

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Summary

At the present time ions of the heaviest elements can be accelerated with the Unilac up to specific energies of 8.5 MeV/u with stripping in gas and up to 10 MeV/u with a foil stripper. Using a second foil stripper in front of the single-gap cavity structure 12.5 MeV/u can be reached. By adding two Alvarez tanks, the energy will be increased for the different operation modes to 14.5, 16.0 and 20 MeV/u respectively. Details of this energy increase project are described, which is to be realized by the end of 1981. Part of the upgrading program is also the modification of the Unilac for multi-ion beam operation and the construction of a new high-current injector.

Introduction

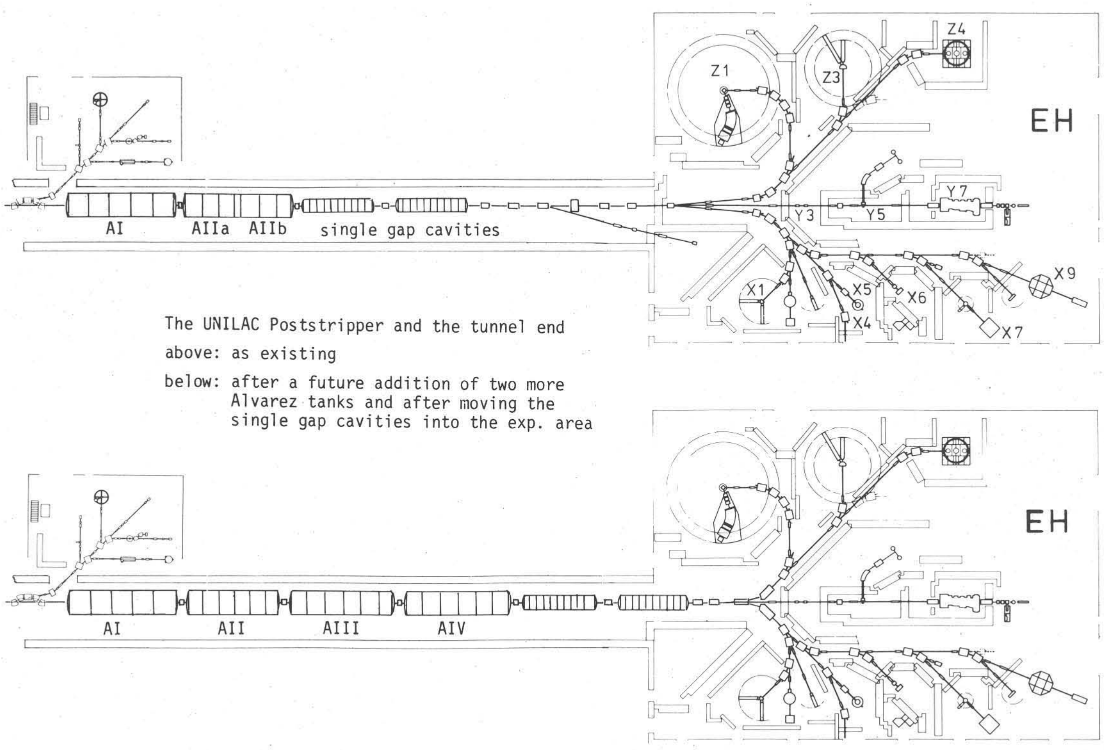
After four years of experiments with the Unilac two beam energy domains have developed which are mainly used for the experimental activities. One is the range from 4.5 to about 6 MeV/u. The other is the high energy regime from 8 MeV/u upwards, with a tendency to shift to the highest available energies. By using a second foil stripper at 5.9 MeV/u in front of the single-gap cavity structure experiments at even above the design energies have been done[1] up to 13 MeV/u with Kr. The experimental requirements for higher energies have been one reason to think about an energy increase of the Unilac. The other was that there are plans to build a synchrotron for relativistic heavy ions with the Unilac as injector. The output energy of such a synchrotron depends on the energy of the injected beam. In order to reach 10 GeV/u for uranium with the synchrotron concept which is being considered, an injection energy of 40 MeV/u will be necessary. Since this energy seems to be a very attractive extension for a lot of running research activities, a linac structure perpendicularly arranged to the existing Unilac was the favourite injector design for a long time. This linac[2] should accelerate the beam from 5.9 MeV/u to some 40 MeV/u for the synchrotron, with the possibility of transporting the beam back to the Unilac axis for further acceleration with the single-gap cavity structure for the existing experimental hall. This solution would even offer to introduce a further accelerating structure on the way back to get about 100 MeV/u beams at intensities of 10^{11} pps. Of course, other "booster"-concepts have been investigated too. All with the drawback that costs and personnel requirements are out of the running budget. When investigating the low energy capabilities of the synchrotron in connection with a new high current injector at the Unilac[3], it turned out that it can also deliver high intensities in the range between 40 and 140 MeV/u, namely 10^{11} pps for the heaviest elements, and even more for lighter ones, if an unstripped 1.4 MeV/u-beam is injected from the Unilac. On the other hand a decrease of the input energy to 20 MeV/u would lower the maximum output energy of the synchrotron to 8.8 GeV/u for uranium.

Concept of Energy Increase

In an early layout phase of the linac building, space was preserved at the end of the machine tunnel for an eventual future energy extension. At that time, a third group of single-gap cavities was envisaged, topping the maximum energy by an additional 2.5 MeV/u. The consideration of a third Alvarez tank instead was discarded at that time due to an overly complex rebunching scheme, which was felt necessary to provide the beam micro-structure restored in the whole energy span. This requirement is by far less vigorous now because the energy spread of the beam is lower by a factor of 5, in respect to the design assumptions, and the extension of the energy range by Alvarez cavities now seems to be a viable choice and a cheaper approach too.

In the meantime, however, the remaining space at the end of the tunnel is used up for different functions: a time-of-flight path for energy determination, a semiconductor counter device for the inspection of satellite energy peaks, a 13° beam deflection into a special beam line, a debuncher and a collimator system. Last, but not least, a good portion of the straight beam line in the tunnel is an inherent element of the beam splitting system. Those features have to be abandoned in favour of the machine extension by two more Alvarez cavities. A few features can be reinstalled in the downstream beam lines in the experimental area. This is almost certain for the time-of-flight path and the rebuncher, and it is under study concerning the beam splitting system, which tends to conflict with a kicker magnet of the synchrotron injection beam line. None of the target stations of the present experimental hall have to be moved.

Figure 1 shows the existing and the proposed future high energy end of the Unilac. The two additional Alvarez tanks number III and IV are of the same length and rf parameters as the existing ones. The stable phase was reduced to 25° and the g/L ratio was chosen to tune the cell frequency, keeping the diameter of each cavity cylindrical. (This was not the case in the original design.) The described extension of the machine results in an energy increase by 5.5 MeV/u. If one considers an additional foil stripper at the entrance of the single-gap cavity section, a final energy of 20 MeV should be attained for the heaviest elements. The energy graphs for different stripper options and lighter projectile mass numbers



The UNILAC Poststripper and the tunnel end
above: as existing
below: after a future addition of two more Alvarez tanks and after moving the single gap cavities into the exp. area

Fig. 1

are shown in Fig. 2. The additional intensity loss by the second stripper is only a factor of 2, when the well established multi-charge acceleration mode is used in the Alvarez section.

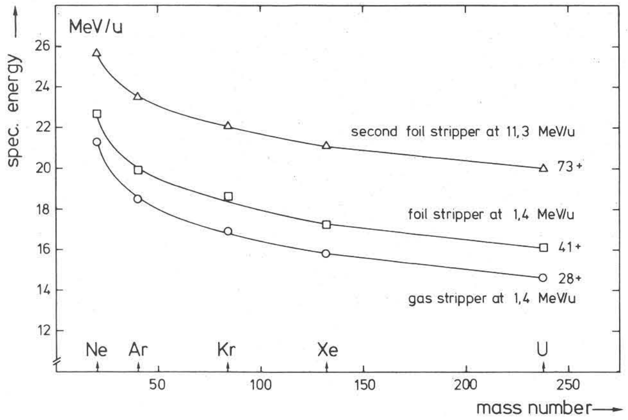


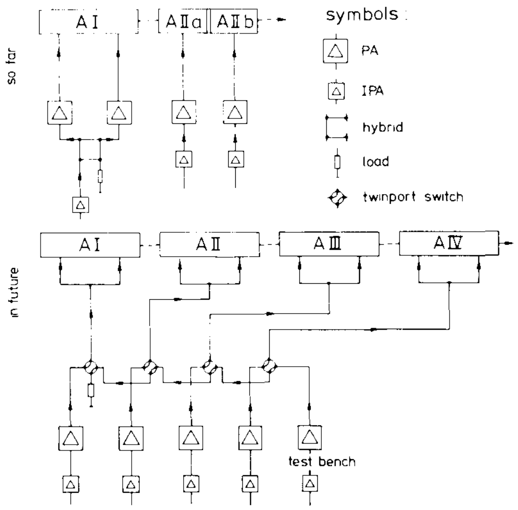
Fig. 2 Spec. energy versus mass number after extension of the Unilac by two more Alvarez tanks

Rf System

A frequency jump by a factor of two was briefly considered for the new Alvarez tanks. However, the design of a new rf amplifier system was felt to be inhibitive. But changes have largely been applied to the mechanical engineering details of the additional tanks, which will be reported separately^4.

For the extension of the rf amplifier system, space reserves equivalent to those available in the machine tunnel could not be found. The original free space in the rf gallery is presently occupied by an indispensable test bench for the Alvarez tube testing program and for 5 additional rebuncher amplifiers. Alternate solutions in remote building areas are considered to be too inconvenient for maintenance and trouble-shooting activities. It is therefore envisaged to use the existing four final amplifier installations to power four cavities, instead of only two which is presently the case. This implies the success of the amplifier improvement program, aiming at a pulse power of 1.6 MW per amplifier unit. A reduction in duty factor from 25% to 15% is unavoidable for the heaviest ions and gas stripping, however, because the existing anode power supplies have to be reused. Figure 3 shows the existing rf system above and the proposed new configuration below. Each cavity is powered by its own amplifier chain. Two coupling loops per cavity will be maintained; they are fed via a power-dividing network. Both halves of tank two have to be unified by eliminating the rebuncher cell. The physical location of the amplifier stages and the downgoing power lines will remain unchanged; space is available in the tunnel basement for the downstream propagation of the power lines. A new feature will be the proposed installation of a rf line switch-yard, by which the output port of the test bench amplifier can be branched to each of the 4 cavities in case of a severe amplifier breakdown.

The amplifiers of the single-gap cavity section also remain in their present location. Extended rf cables will be routed downstream in the tunnel basement.

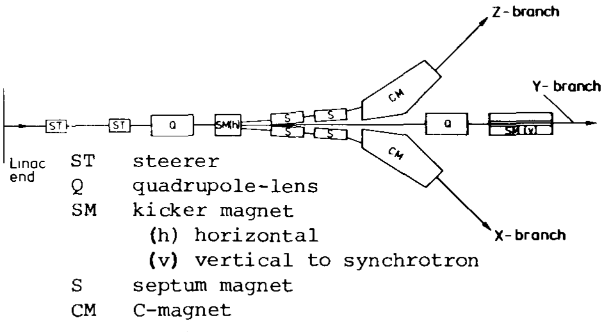


Modification of the rf system for the UNILAC Alvarez section

Fig. 3

Modifications of Beam Transport

The upgrading of the Unilac requires the change of the existing beam transfer system between accelerator and experimental area. The beam splitting system has to be reconstructed for space reasons. Figure 4 shows a schematic layout of the modified configuration. A pair of steering magnets provides for corrections of beam position followed by a quadrupole lens after which the beam is either bent to the X- or Z-yard by a switching-magnet, through two septum magnets and a C-magnet, or is transported straight to the Y-yard. The switching magnet can be operated either dc or pulsed. This allows the delivery of parasitic beams by both time -sharing and beam-splitting modes of operation of this system.



ST steerer
Q quadrupole-lens
SM kicker magnet
(h) horizontal
(v) vertical to synchrotron
S septum magnet
CM C-magnet

Fig. 4 Beam switch-yard at the end of the extended Unilac

The beam to the synchrotron is deflected downwards by an additional kicker magnet in front of the Y-yard to the beam transfer line to the synchrotron which will be installed in the basement of the experimental hall.

The existing beam transport system to and in the experimental area is designed for a maximum magnetic rigidity of 4.4 Tm. Hence it can transport beams of U^{28+} ions with an energy of up to 11.0 MeV/u. Therefore, when using a gas stripper for the heaviest masses, one cannot transport the highest energies obtainable with the upgraded Unilac. But the beam transfer line to the synchrotron will be designed for a higher magnetic rigidity in order to use the higher intensities which are possible with a gas stripper in the whole energy range.

Beam Parameters

At the exit of the accelerator the energy resolution will be 1 - 2 x 10^{-3} and the bunch width 200 - 400 ps for high energies. Output energy is attainable in the range between 3.0 MeV/u and maximum. If variation is required around 3.6 MeV/u, special care must be taken in tuning the prebunchers and Alvarez tank I in order not to exceed an energy spread of 3 x 10^{-3}, which is the limit for the proper refocusing of the bunches into the single-gap cavity section. For this matching a rebuncher cell is foreseen between Alvarez tank II and III. The bunch structure of the other intermediate Alvarez energies, i.e. 5.9, 8.5 and 11.3 MeV/u can be matched to the single-gap cavities without additional rebunching provisions.

For the target stations Z3 through Z5,and X7 through X0 (see Fig. 1), the usual bunch focus of $\leq$ 300 ps can be expected. The helix cavities in the Z and X branch will be used instead of the abandoned rebuncher at the tunnel end. For maximum energies, the required rebuncher voltage of 1 MV may eventually set a limitation. For all intermediate Alvarez energies, one particularly selected single-gap cavity may serve as a rebuncher, restoring a time focus at the other target stations not mentioned above.

Multi-Ion Acceleration

If the Unilac should be simultaneously used both as an accelerator for low energy experiments (< 20 MeV/u) and as an injector for the heavy ion synchrotron, there should be as little interference between these two functions as possible. Ideally, one should be able to choose isotope and energy for these two purposes independently. For each accelerating cycle of the synchrotron it is necessary to change the operating parameters of the Unilac for the acceleration of the appropriate ion during one macro-pulse. Basic requirements for this are first, that the two injectors simultaneously deliver different ion species, second, that the accelerating rf fields can be switched from one pulse to another to accelerate different charge-to-mass ratios, and third, that the focusing channels can be fast-adjusted.

The existing 320 kV preaccelerators allow for alternating injection of different ion species into the Unilac by just pulsing the already laminated 12.5^0-switching magnet. Provision is also made for a fast change of amplitude and phase of the rf-fields. But there are no pulsed focusing or steering elements installed at the Unilac. From this fact result severe limitations for a present multi-ion operation. Only ion species with not too different atomic numbers could be accelerated simultaneously. This is mainly due to the fact that the mass-to-charge ratio after the stripper depends on the atomic number of the ions. Table 1 shows, for ion species which are injected into the Unilac with a mass-over-charge ratio near to A/ζ = 22, the corresponding values after stripping in gas at 1.4 MeV/u.

Prestripper		Poststripper	
Ion	A/ζ	Ion (Gas Stripper)	A/ζ
$^{20}Ne^{1+}$	20	$^{20}Ne^{7+}$	2,8
$^{40}Ar^{2+}$	20	$^{40}Ar^{10+}$	4
$^{46}Ti^{2+}$	23	$^{46}Ti^{13+}$	3,5
$^{65}Cu^{3+}$	21,7	$^{65}Cu^{15+}$	4,3
$^{84}Kr^{4+}$	21	$^{84}Kr^{17+}$	4,9
$^{107}Ag^{5+}$	21,4	$^{107}Ag^{19+}$	5,6
$^{132}Xe^{6+}$	22	$^{132}Xe^{21+}$	6,2
$^{154}Sm^{7+}$	22	$^{154}Sm^{23+}$	6,7
$^{208}Pb^{9+}$	23,1	$^{208}Pb^{26+}$	8,0
$^{209}Bi^{9+}$	23,2	$^{209}Bi^{26+}$	8,0
$^{238}U^{11+}$	21,6	$^{238}U^{28+}$	8,5

Table 1: Mass-to-charge ratio (A/ζ) for different ion species in the prestripper and poststripper section of the Unilac

Besides a complete redesign of the stripper section with the charge-analyzing system, about 25 focusing and steering elements must be prepared for pulsed operation. The corresponding modifications of the control systems have to be done in parallel to achieve an independent tuning for different ion beams.

This multi-ion program will be supplemented by a third injector, which will be designed for a low duty cycle and high peak currents[3]. Thus one can both preserve the very important redundancy for the existing injectors and increase the intensities for injection into a synchrotron by about three orders of magnitude for the heaviest elements.

Schedule and Cost

The aforedescribed measures leading to the desired energy increase and the outlined reconfiguration of the beam distribution system in the experimental hall are lined up in an ambitious time schedule. One reason for that is the already existing demand for beams of energies in excess of 10 MeV/u. One other substantial reason is enforced by manpower limitations. The energy increase should be completed when the multi-particle modification and the high-intensity injector project are due to start in order to meet the synchrotron commissioning schedule. Component procurement of the Alvarez tanks and rf power lines should be completed at the end of 1980. Installation in the tunnel will require a 4-month shut-down period, until beam operation can be resumed end of 1981. It is likely to occur that the new generation of rf amplifiers are not yet operational at that date, which means a slip of half a year in the time schedule for the availability of the energy increment for the heaviest elements.

The cost for the energy increase project is estimated to roughly MDM 4.7. The expenses for prototype activities for rf and hardware are already in the authorized budget for 1979 and 1980. The estimated manpower effort, mostly from internal resources, totals up to 44 man-years.

The pulsing of focusing and steering elements for the multi-ion acceleration can be partly done in the frame of an already started improvement program for the magnet power supplies. Also the changes in the beam diagnostic and control system will not cost too much so that it can be realized with the yearly budget within another two years till end of 1983. All other reconstruction, for instance, a new stripper section and a third injector, depend on funding of the synchrotron.

References

1 D. Böhne, "Status Report on the Unilac", these proceedings.

2 B. Franczak et al., "Linear Accelerator with Intertank Focusing", these proceedings.

3 R.W. Müller, "Work on Rf Quadrupole Focusing Structures at GSI", these proceedings.

4 D. Böhne et al., "Cavity and Drift Tube Technology for the Upgraded Unilac", these proceedings.

Discussion

Knapp, LASL: I didn't understand how the 140 MeV per nucleon energy range, shown in the figure, is achieved.

Angert: It is given by the tuning range of the synchrotron rf cavities.