IEEE Transactions on Nuclear Science, Vol. NS-30, No. 4, August 1983

STATUS REPORT ON THE UPGRADED UNILAC

N. Angert
GSI, Gesellschaft für Schwerionenforschung mbH
D-6100 Darmstadt / Fed. Rep. of Germany

Summary

By adding two Alvarez tanks to the Unilac poststripper maximum energies can be achieved of 19 MeV/u for uranium, and more than 20 MeV/u for ions of medium mass (A < 150) using a second stripper in front of the single-gap cavity resonators. The injector beam transport system was modified, too, resulting, together with ion source developments, in an increase of beam intensities of about one order of magnitude. Operating experience of the first year after the upgrading is reported.

Introduction

The Unilac heavy ion linear accelerator started operation in 1976. At that time it was the only facility which was capable to accelerate uranium ions above the coulomb barrier up to 10 MeV/u.
Throughout all the years more than one third, in some years more than half of the operation time was devoted to beams with masses above A = 200. To extend the current research fields to higher energies and to improve it's suitability as an injector for a proposed heavy ion synchrotron accelerator facility an upgrading of the Unilac was decided in 1979.

Unilac Upgrading

The Unilac upgrading program has been described earlier.[1/2]. The essential parts of this program have been the extension of the poststripper accelerator, and the improvement of the injector. Fig. 1 shows the old (a) and new (b) poststripper of the Unilac. The old structure consisted of two Alvarez tanks with output energy of 3.6 and 5.9 MeV/u respectively, and two groups of ten single-gap cavities each, followed by a debuncher and a beam switching and splitting system. By reconstructing the splitting system and combining the single-gap cavities in one group of seventeen, space could be provided for two additional Alvarez tanks of 13 m length with a rebuncher inbetween to assure proper matching for lower energies to the single-gap cavities. The two Alvarez tanks no. 3 and 4 provide up to 47 MV additional accelerating voltage. For maximum energies a second stripper after Alvarez tank 4 is required increasing the charge states accelerated in the variable energy single-gap cavities. Fig. 2 shows maximum energies of some existing very heavy ion accelerators.

In addition to the extension of the poststripper the injector was partially rebuilt and a new generation of Penning ion sources introduced. The major change on the PIG source, compared to the previous version, was an increase of the height of the anode slit, from 15 to 45 mm, following the LBL developments[3]. A microprocessor controlled emittance measurement device was installed, immediately behind the source, so that plasma and extraction conditions can be controlled on-line in order to get a good matching to the accelerating column and the low energy beam transport line. By increasing the apertures of some of the quadrupole lenses to 80 mm and the gap of the inflector magnet to 60 mm a normalized acceptance of A = .6 mm mrad could be achieved for the beam transport system between ion source and first Wideröe tank.
The extension of the poststripper accelerator, the reconstruction of the injector and additional improvements of the rf-system were completed during a 5 months shut-down in the second half of 1981. The entire Unilac-upgrading costs were approximately 5 MDM.

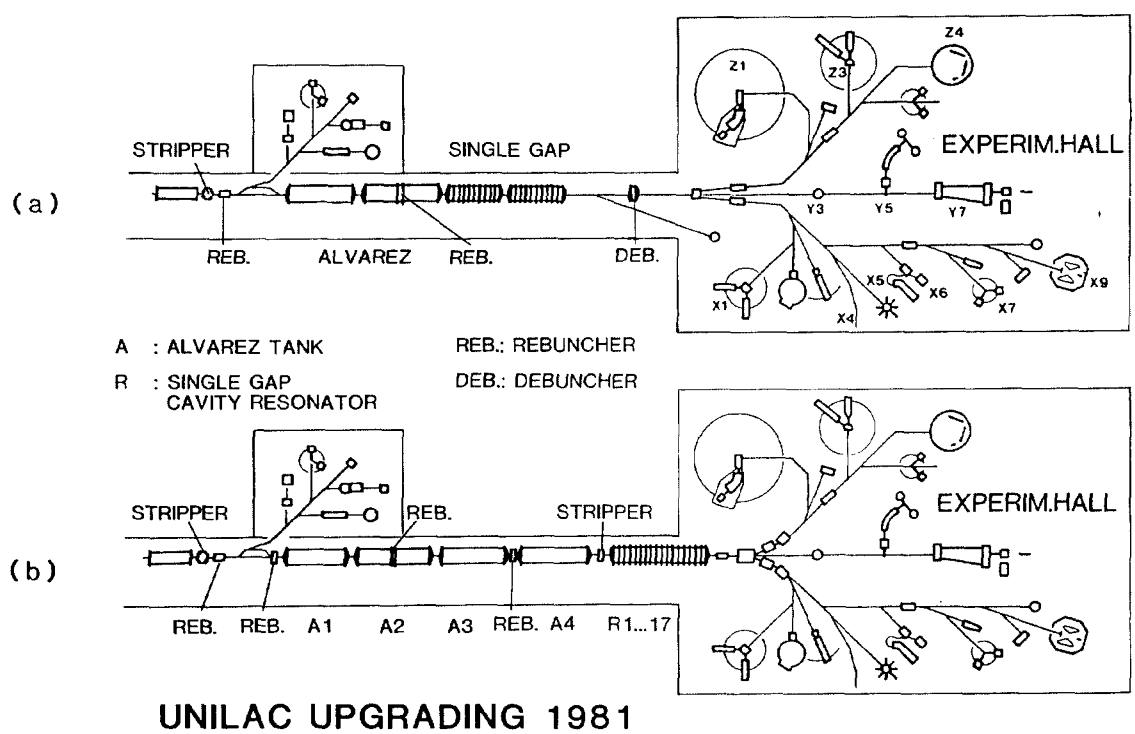

Fig. 1: The Unilac poststripper before (a) and after (b) the upgrading in 1981.

0018-9499/83/0800-2980$01.00© 1983 IEEE

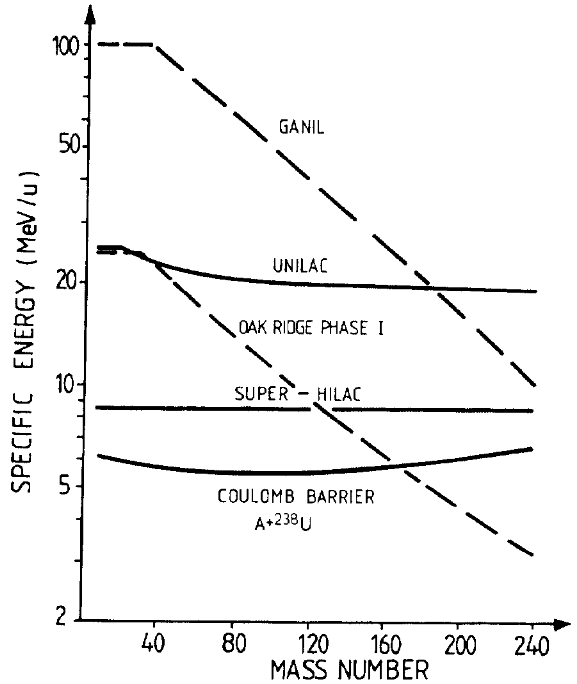

Fig. 2: Specific energy vs mass number of the upgraded Unilac and other very heavy ion accelerators.

Operation Performance

The design output energies of the four poststripper Alvarez tanks are 3.6 MeV/u (tank 1), 4.7 and 5.9 MeV/u (tank 2a and 2b), 8.6 MeV/u (tank 3), and 11.4 MeV/u (tank 4). Beam energies between 2 and about 20 MeV/u can be delivered by deceleration or acceleration in the single-gap cavity structure. By proper reduction of the rf fields in tank 3 and 4 well defined intermediate energies of 6.6 and 7.1 (tank 3), and 9.5 (tank 4) respectively can be achieved in addition to the design output energies.[4] Fig. 3 shows for several tank field levels of tank 4 the deviation of the tank output energy from the design energy vs the relative entrance phase. These calculations assumed ideal tank flatness. The curves show for a field level about 30 % below the normal field a plateau on which for particles which start near to the stable phase acceleration to 9.5 MeV/u is possible. A detailed consideration reveals that the particles move about 400° off their initial reference phase. This feature of the new tanks is due to their "shortness". Particles experience only about half a phase oscillation. Even though the new tanks are of much simpler design than the previous ones they show a very good rf behaviour up to peak powers of 1.6 MW.

The increase of the maximum energy of the Unilac towards 20 MeV/u offers the possibility to make experiments with very high charged ions. Stripping krypton at 19 MeV/u in a 500 μg/cm² carbon-foil yielded 50 % helium-like ions, 10 % hydrogen-like ions, and even 1 % of fully-stripped krypton. Fig. 4 shows a xenon spectrum after stripping at Alvarez tank 4 energy (11.4 MeV/u) in a carbon-foil. This spectrum indicates that ionization states in the L-shell can be reached for medium masses with the second stripper. However, thick stripper foils are required to reach these high charge states. Increasing the foil thickness from 90 μg/cm² to 300 μg/cm² made us gain an average charge state which was about three units higher. For 17 MeV/u uranium charge states up to U^{82+} could be achieved. Further results are given elsewhere[5]. The Unilac offers also the possibility to decelerate very heavy ions stripped at energies up to 11.4 MeV/u. This is very advantageous for some experiments with highly charged ions in atomic physics.

To achieve the highest energies a second stripping process is required at 11.4 MeV/u. This results in an additional intensity reduction of the beam. Therefore, a necessary condition for the successful operation of the Unilac at the highest energies was the injector improvement program. Table 1 shows recent data from the PIG ion source measured for various elements[6] on the high voltage platform. The increased acceptance of the beam transport system between ion source and Wideröe structure has considerably improved the transmission. However, due to aberration effects, especially if isotope separation for very heavy elements is required, there is still an intensity loss by factor of up to 3 between source and Wideröe entrance. The higher intensities allow now higher charge states be accelerated from the ion source for the heaviest elements than before. This reduces the stress of the prestripper accelerator. U^{10+} can be used e.g., instead of U^{9+} before the upgrading, with about tenfold intensity, giving average Unilac output intensities of up to 3 • 10^{11} pps at 25 % duty cycle. The injector improvement has also considerably increased the efficiency when running enriched rare isotopes. The production of element 109 with the available amount of enriched ^{58}Fe was only possible due to these improvements. Beams of ^{48}Ca have been produced with up to 10^{12} pps requiring less than 1 mg/hour of enriched material in the ion source.

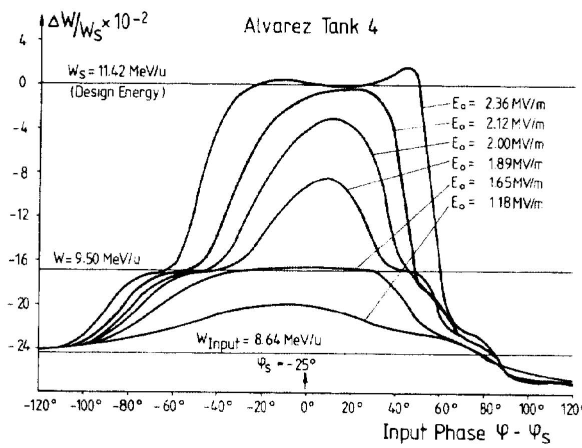

Fig. 3: Relative particle energy after Alvarez tank 4 vs input phase at different levels of the tank field.

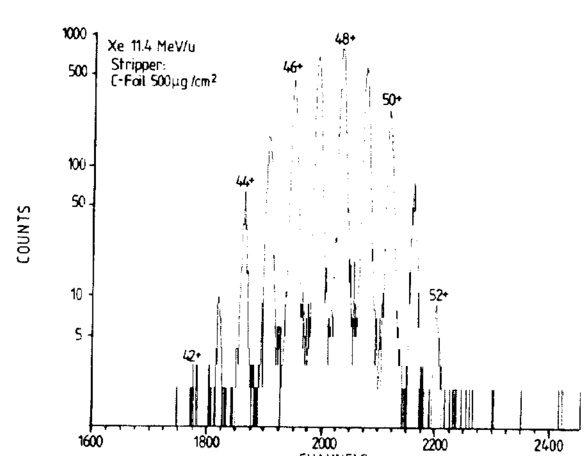

Fig. 4: Charge state distribution of 11.4 MeV/u (Alvarez tank 4 energy) xenon after a 500 μg/cm² carbon foil.

Ion	Arc V/A	Sput.Volt. V/A	Extract.Volt. kV	el. Current µA c.w.	Anode Slit mm^2	Emittance mm mrad
U^{10+}	450/5	200/ .8	12.5	100	40 x .8	286
Pb^{9+}	800/5	200/ .6	10.2	130	40 x .8	313
Au^{6+}	600/5	400/ .8	15	1500	45 x 2.0	
Xe^{6+}	500/9	--	24	1500	45 x .5	
Xe^{7+}	500/8.8	--	23.8	1050	45 x .5	
Ni^{4+}	250/7	1000/ .8	13.2	140	40 x .8	
Fe^{4+}	800/5	800/1.6	13.4	400	45 x .8	
Ca^{3+}	990/5	400/ .3	14.9	1000	45 x 1	266
Ar^{3+}	400/8.3	--	13.1	4000	45 x 2	1100

Data from UNILAC injector ion source, pulse operated: 50 Hz, 5 ms.

Table: Ion currents on the 300 kV ion source platform. To get the peak currents the c.w. values must be multiplied by four.

Accelerator Development

Ion Source

In standard source operation solid state materials are sputtered in natural composition from a 4 x 45 mm^2 electrode, 2 to 3 mm thick, with argon or neon as auxiliary gas. For ferromagnetic materials like iron or nickel the magnetic field in the discharge channel was distorted by the solid sputter electrodes leading to a limitation of the maximum arc current, and thus to a limitation of the ion beam current. This could be cured by using submarin-steel, an iron/maganese alloy with 80 % iron content. A "home-made" nickel/molybdenum alloy (80/20) helped to increase considerably the nickel beam intensities. Special dilution techniques are applied when preparing sputter electrodes for enriched isotopes as ^{48}Ca, ^{58}Fe or ^{50}Ti to get high source efficiency.[6]

Beam Transport

Matching of the ion beam from the source to the accelerating column has been made easier by an emittance measurement device on the high voltage platform. By another emittance measurement in the transport line to the Wideröe structure beam parameters are received after preacceleration and isotope separation for a computer program. This program calculates quadrupole parameters for the matching of the beam to the acceptance of the Wideröe structure and sets automatically the quadrupoles of the whole prestripper accelerator.[7] For the operator the Wideröe accelerator is a "black box". He can only correct beam misalignment. A similar automatic procedure is applied for the more sophisticated beam lines in the experimental area, and is under test for the poststripper accelerator.

Beam-Micro-Structure

Methods have been developed, using capacitive pick-up probes, which allow the calculation of the longitudinal phase space ellipse after each accelerating resonator in the poststripper. The procedures are described in another paper of this conference.[8] The principle is similar to the radial emittance measurement with a quadrupole lens and a profile monitor. Recently these methods have been supplemented by a time of flight measurement with surface barrier detectors so that also minute satellite-peaks can be detected.

RF-System

The Alvarez tanks no. 1, 3, and 4 are powered by 1.6 MW (108 MHz) amplifiers equipped with the Siemens RS2074SK tube. The two amplifiers for tank 2, which need half that power, have still Thomson TH518 tubes. All the Alvarez tanks achieved their full peak power ratings for the acceleration of gas-stripped uranium end of 1982. The upgrading of the final amplifiers for the single-gap cavity resonators to reach 240 kW pulsed power is still going on. The status of the Alvarez rf amplifier development is described in detail in another contribution to this conference.[9]

Computer Control

The major change in the computer control of the Unilac was the installation of the microprocessor based control system for the 40 rf-amplifiers during the upgrading in 1981. Due to the limited capacity of the local PDP computers with an old fashioned system software (RSX11-G) it was built up as a stand alone system, controlled by touchpanel. There is only a V24 link to the T85/Σ6 main computer.

Multiple Beam Option

The Unilac is going to be prepared for multiple beam operation in order to provide beams both with different energies for the different beam lines in the existing experimental hall and for the proposed heavy ion synchrotron facility SIS. Modifications of the control system for the magnets and the rf-amplifiers are under test, as well as kicker magnets for the beam switchyard at the end of the Unilac. The according beam diagnostics and the control system are being developed. First tests with energy switching for the experimental hall are planned for end of 1983. Parts of the beam transport line to the SIS have already been ordered. The first part, which serve also as a test line for Unilac beam development, will be installed by end of this year.

References

[1] N. Angert, D. Böhne, J. Klabunde, H. Trautmann, The Unilac Upgrading Program, Proc. 1979 Lin. Acc. Conf., Montauk, N.Y., BNL 51134, p. 17.

[2] N. Angert and D. Böhne, Status Report on Operation and Upgrading of the Unilac, Proc. 1981 Lin. Acc. Conf., Los Alamos, N.M., LA-9234-C.

[3] B. Gavin, S. Abbott, R. MacGill, R. Sorensen, J. Staples, R. Thatcher, A High Current Pulsed Ion Source for Metallic Ions, Proc. 1981 Part. Acc. Conf., IEEE, NS-28, No. 3, June 1981, p. 2684.

[4] J. Klabunde, Operating Modes of the Alvarez Tanks at the Unilac. GSI Scientific Report 1982, GSI-83/1, p. 268.

[5] B. Franzke, Charge State Distributions of Argon, Krypton, Xenon, and Uranium after Solids of Energies up to 18.7 MeV/u, GSI Scientific Report 1982, GSI-83/1, p. 162.

[6] M. Müller, Application of Multiply Charged Ions to Small Accelerators, Proc. 7th Int. Conf. on Small Part. Acc., Denton, TX, Nov. 1982, IEEE, NS-30, April 1983.

[7] L. Dahl, Computer-Aided Tuning Procedures at the Unilac, Proc. 9th Int. Conf. on Cycl. and their Application, 1981, F-Caen, p. 575.

[8] P. Strehl, A New Method for Longitudinal Emittance Measurements, these Proceedings.

[9] G. Hutter, Comparison of Three 108 MHz Systems for 1.6 MW, these Proceedings.