THE PROJECT OF A HIGH-CURRENT INJECTOR AT THE UNILAC

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GSI is going to extend the accelerator facility by a synchrotron and an experimental storage ring over a period of four years.[1] The UNILAC will serve as injector. In order to take advantage of the space charge limit of the synchrotron, a new injector at the UNILAC will be constructed. An increase of beam intensity by about three orders of magnitude is expected. The different sections of the new injector will be described.

Introduction

After 10 years operation of the UNILAC, the extension for the accelerator facility by a synchrotron (SIS 18) and an experimental storage ring (ESR) was officially approved in April 1985. The new accelerator complex will allow unique experiments with heavy ions up to 2 GeV/u. A new class of experiments such as generation of hot matter and ion pumped short-wave lasers are only possible if the injected current now available from the UNILAC will be increased by up to three orders of magnitude even for the heaviest elements. Therefore, in parallel to the construction of the synchrotron, an upgrading program for the UNILAC has been started. An increase of the beam intensity to the required level can only be achieved by a new injector.

In the following, the basic design of the high current injector (HSI-Hochstrom-Injektor) will be described. Several subsystems have already operated and their performance will be reported below. For some components, e.g. rebunching systems, stripper device, short accelerator sections, alternatives are possible.

General Considerations

Present UNILAC output intensities are typically 10^{11} pps for very heavy and 10^{13} pps for light ions. Due to the reduced synchrotron duty cycle of about 10^{-4} the output intensity of SIS would be in the range 10^{7} to 10^{9} pps.

In order to take advantage of the maximum possible intensity for the synchrotron (Fig. 1), the particle flux from the UNILAC has to be increased at least by a factor of 1000 even for the heaviest elements. At the UNILAC high charge state ion sources are presently used. They do not have the peak current performance for the SIS filling burst for mass numbers beyond Argon.

Another limitations results from the rf accelerator structure. The rf acceleration starts at 11.7 keV/u with the π-3 π Wideröe structure. The first tank is the bottelneck of the rf linac. The space charge limit was theoretically and experimentally found[2]:

$$I_{max} = 0.4 \cdot A/\zeta \text{ emA}$$

A = Mass number, ζ = Charge state.
The Wideröe linac accepts ions with a minimum charge-to-mass ratio $\zeta/A = 0.04$. In case of uranium, a current of ca. 10 mA U^{10+} would be accepted in the UNILAC prestripper accelerator, about a factor of two too low for the required intensity.

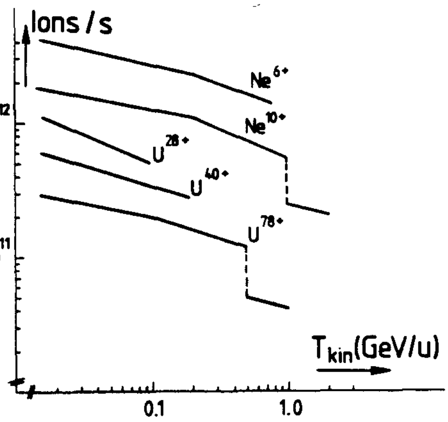

Fig. 1: Beam intensity of SIS 18, when filled up to the space charge limit at injection. The drop at 0.5 GeV/u comes from the reduced ramping rate when power supplies are paralleled.

To overcome the indicated difficulties, two facts have a determining influence on the modification of the UNILAC. Firstly, low charge state heavy ion sources deliver the required intensities. Over the last years sources for singly charged ions with excellent beam characteristics - high intensity with high brilliance, especially for gaseous ions - have been developed. Secondly, for the first stage of rf acceleration, the newly invented radio frequency quadrupole structure offers many advantages. Effective acceleration and transverse focusing even in case of high intense beams start at low velocity. MAXILAC, a high current ion RFQ accelerator, is being constructed at GSI. This low frequency RFQ with a unique split coaxial resonator has proven to be well suited for an injector at the UNILAC.

On the basis of these new developments, different schemes for a new high-current injector have been studied.[3]

In Fig. 2a the high intense beam from MAXILAC, with output energies in the 100-150 keV/u range will be injected into the UNILAC low energy beam transport system.

The first Wideröe tank is split into two sections. In normal operation both sections would continue to be rf excited. In the high-current mode, the first section would be used only for beam transport and acceleration would start with the second section at the appropriate injector energy. Gas stripping is foreseen directly behind the RFQ. The beam transport from MAXILAC to the Wideröe, questions of rebunching and charge separation were examined extensively. Prospects for transmission and acceleration of a MAXILAC beam for further acceleration at the UNILAC seem very good. This injection scheme is the easiest to install and probably the least expensive version. However, the division of Wideröe tank 1 into two electrically separate segments must be studied in more detail. Future operation of the UNILAC calls for the use of multiple ion species with a change from pulse to pulse. The pulsed operation of the Wideröe quadrupoles would be difficult.

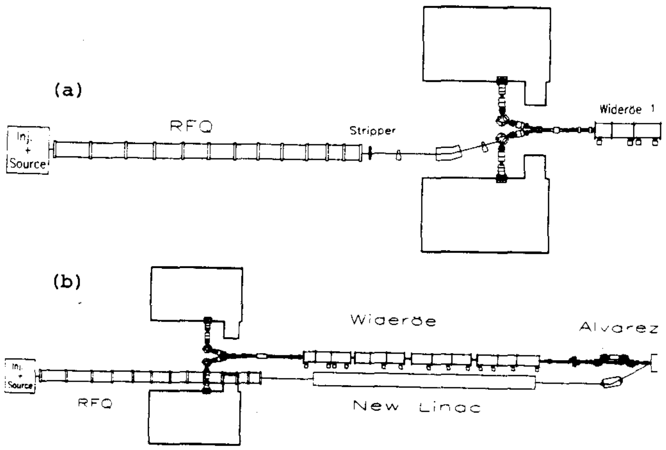

Fig. 2: Different layouts of the high-current injector
a) Beam from MAXILAC, after stripping will be injected into the LEBT of UNILAC.
b) A complete new prestripper accelerator.

In a second injection scheme (see Fig. 2b), an entire new prestripper is foreseen. The beam from MAXILAC could be injected into a duplicated Wideröe linac. A separate 2 βλ-Alvarez accelerator has also been considered. Studies indicate that an Alvarez linac at 108 MHz is not unrealistic. For an input energy of 130 keV/u and an output energy of 1.4 MeV/u the resulting design is about 25 m long, has 126 cells and requires 1.6 MW. The significant cost penalty excludes this version.

The now projected injector accelerates the high intense beam up to 216 keV/u, further acceleration takes place in the second Wideröe tank. This design will be described below.

The Design of the New Injector

The scheme of the high-current injector is shown in Fig. 3.

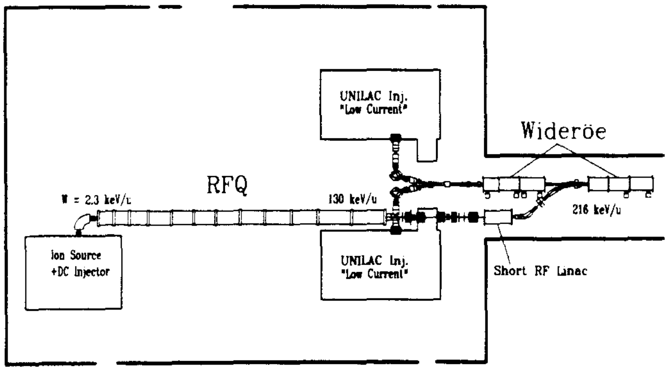

Fig. 3: Plan view of the high-current injector

The injector system consists of a 300 kV DC preaccelerator with a high-current ion source. The following 13.5 MHz RFQ structure will accelerate the ions from 2.3 to 130 keV//u. At that energy the ions are stripped to charge states comparable to the ones delivered from the Penning ion sources. After charge analysis the ions will be accelerated by a short new accelerator. At the energy of 216 keV/u the ions will be injected into the Wideröe tank 2 for further acceleration. In the following sections the design status of the different subsystems will be reported.

Ion Source and Preaccelerator

The source system CHORDIS (Cold or HOt Reflex Discharge Ion Source) will be used. Two basic versions exist, a cold one for gases and a hot one for not volatile substances at room temperature. The performance of these ion sources will be reported in a separate contribution to this conference[4]. The source system is capable of delivering high-current, high brightness ion beams of a large variety of elements. For all gaseous elements the achievable output currents can be delivered with a large safety margin for the injector. Iodine, lithium and bismuth have been produced with an intensity above 30 mA. Recently, a sputter version based on HORDIS was tested for the first time, 2.4 mA Al^{1+} was measured. The required intensity for U^{2+} (about 25 mA) could not be achieved with the HORDIS up to now, source development is still continuing.

A new kind of ion source has been developed recently at Berkeley, with which high current beams of metal ions have been produced.[5] The MEVVA source (MEtal Vapor Vacuum Arc) can produce long pulse ion beams from any solid electrically conducting material. A beam current of over 1 A uranium has been extracted. Recently the MEVVA source has been operated at GSI.[6] 40 mA of uranium, at an extraction voltage of 40 kV, has been transported through a single-gap accelerating column at a voltage of about 150 kV, 4 mA of U^{4+} and 5 mA of U^{3+} could be measured at the exit of RFQ. Further development of the MEVVA source is needed to achieve the reproducibility standard necessary for stable accelerator operation.

For the preacceleration an experimental test injector, designed as a prototype for the two UNILAC injectors, will be modified to get the technical standard as existing at the UNILAC injectors. A development has been started to combine extraction and preacceleration to one system in order to avoid aberrations of the beam. The first experimental results are encouraging.

Beam Transport

Behind the preaccelerator a mass separator system follows. Full beam transmission and mass separation is only possible if a high degree of space charge compensation can be achieved. Beam experiments were carried out at a test stand with krypton and xenon beams.[7] The beam was extracted with 30 kV and transported through a 90° bending magnet. The measured mass resolution indicated a high degree of space charge compensation in this experimental set-up. For the injection into RFQ section a beam transport system has been designed. The bending magnet will be installed directly behind the DC preaccelerator, magnetic quadrupole lenses will be installed for beam transport to the RFQ input end. For the transport line the quadrupoles are designed for full space charge dominated beams by the following reason. In beam experiments at GSI[8] it was found that the transport of a partially space charge compensated beam in a quadrupole channel may deteriorate the beam quality. Though the space charge force was reduced, the measured emittance growth was higher than it was measured with an equivalent full space charge dominated beam. Beam experiments are planned with the designed transport line. Clearing electrodes are foreseen to remove the electrons from the beam.

RFQ Accelerator

The RFQ accelerator for the high-current injector will accelerate the ions from 2.3 to 130 keV/u. The theoretical current limit is $0.2 \cdot A/\zeta$ emA (A = atomic mass number, ζ = charge state). The minimum charge-to-mass ratio is 0.008. Singly charged ions will be

injected up to xenon, for heavier elements the charge state of at least two is required. The total length of the RFQ section is 26 m and consists of 12 modules. The present status of the RFQ development will be reported in a separate paper of this conference. Now 5 modules were assembled. At the output energy of 45 keV/u a current of 4.5 mA Ar^{1+} was achieved. Work is continuing to get the predicted current of about 8 mA Ar^{1+}.
The most important parameters of the RFQ structure are summarized in Table 1.

Table 1: Parameter List of RFQ Accelerator

Design Ion	up to xenon 1^+ up to uranium 2^+
Current Limit	$\leq 0.2 \cdot A/\zeta$ emA
Frequency	13.55 MHz
Input Energy	2.3 keV/u
Output Energy	130 keV/u
Total Length	26 m
Mean Aperture Radius	6 mm
RF Voltage Amplitude	$A/\zeta \cdot 1.2$ kV
Kilpatrick Number	2.0
Average Acc. Gradient	$A/\zeta \cdot 5$ kV/m
Transverse Acceptance	0.6 π mm mrad
Longitud. Emittance	80 π deg keV/u

Beam Transfer from RFQ to Wideröe

Immediately behind the RFQ tank a gas stripper will be installed to achieve the charge-to-mass ratio required for acceleration in the UNILAC Wideröe tanks. The stripping energy was extrapolated from measurements at the UNILAC; the lowest energy there was 216 keV/u. Most recently measurements have been carried out at 45 keV/u with the RFQ beam. In Fig. 4 the measuring points for xenon and argon are plotted and are compared with earlier measurements.

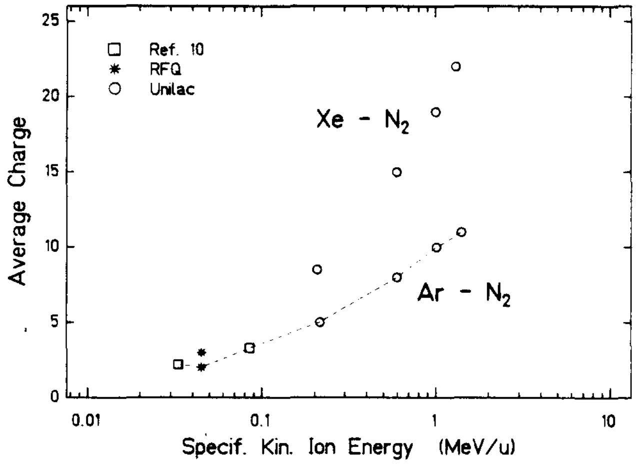

Fig. 4: Average charge states for Ar and Xe at different stripping energies

The measurements confirm the selection of the stripping energy, the charge states 2+ for Ar and 6+ for Xe should be achievable at 130 keV/u. The behavior of the stripper at high current load could not be studied so far. The output intensity of the RFQ linac has to be increased, high intensities of Xe^{1+} up to about 20 mA are only possible if a new rf transmitter will be installed.

Due to the stripping efficiency of 20 - 30 % and the increase of the charge state, about the same electrical current will be expected for the charge state used for further acceleration. A bending magnet, positioned directly behind the stripper, separates the charge states.

A short accelerating section will increase the energy from 130 keV/u to 216 keV/u, the input energy for Wideröe tank 2. At present there are two alternatives under discussion: a short 27 MHz Wideröe tank in π-π-mode or a 27 MHz four-rod RFQ with spiral resonator geometry, developed at Frankfurt university. For the Wideröe the additional installation of permanent quadrupoles in the drift tubes mounted at the inner conductor would increase the space charge limit. A decision between the both structures is not made up to now, man power and time schedule constraints have to be taken into account.

For the longitudinal matching from the 13.5 MHz RFQ accelerator to the 27 MHz structures, two versions are under discussion. The first version maintains the 13 MHz bunch structure by 13.5 MHz- and 27 MHz-cavities. A reduction of high peak current by a factor of two can be obtained if the RFQ beam is debunched and then rebunched at 27 MHz.

The reduction of space charge would facilitate the beam transport and acceleration along the machine.The overall efficiency of both versions have to be examined in further detail. The design will be fixed at the end of 1986.

The bunching cavities will be developed at Frankfurt university. For the 27 MHz resonator a spiral loaded cavity is foreseen. The required rf voltage of about 500 kV will be achieved with about 80 kW rf power. A coaxial resonator has been proposed for the 13.5 MHz buncher. An optimization of this type is not yet finished, space limitations complicate the task.

Unilac Modifications

The high-current capability requires modifications at the UNILAC, too. The rf transmitter have to upgrade for the high beam loading. A new rf amplitude control electronics has to be developed. Beam diagnostics capable for high beam intensities have to be installed along the Unilac. In addition, non-destructive beam transformers and high power faraday-cups will be installed.

The UNILAC will be prepared for time sharing operation. Energy, ion species and also beam intensities should be variable from pulse to pulse. This project will be described in a separate paper of this conference.[11]

Schedule

The complete conception of the high-current injector should be fixed until the beginning of 1987. After a construction time of about 2.5 years first operational tests are scheduled for the end of 1989.

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