UNILAC MODIFICATIONS FOR AN IMPROVED SYNCHROTRON INJECTOR PERFORMANCE

N. Angert, L. Dahl, J. Glatz, J. Klabunde, M. Müller, B. Wolf
GSI, Gesellschaft für Schwerionenforschung mbH
Postfach 11 05 52, D-6100 Darmstadt, FRG

Abstract

The 15 year old UNILAC is used as an injector linac for the new synchrotron/storage ring facility SIS/ESR at GSI. For this purpose a 150 m beam line to the SIS ring was installed. In addition, energy and intensity switching modes from pulse to pulse were introduced. This allows e.g. to inject once per second a 11.4 MeV/u high intensity pulse into the SIS whilst the remaining 49 pulses/s can be provided for a low energy heavy ion physics program (3.6 to 20 MeV/u) at the UNILAC. Modifications of the present injectors for low duty cycle high current operation have been made as well as first commissioning tests of a high charge state ion source (U^{28+}) for a new 1,4 MeV/u injector, that will allow simultaneous acceleration of two ion species in the UNILAC poststripper section.

Introduction

GSI has extended its accelerator facility by a heavy ion synchrotron (SIS) and an experimental storage ring (ESR). Fig. 1 shows a plan view of the GSI facility.

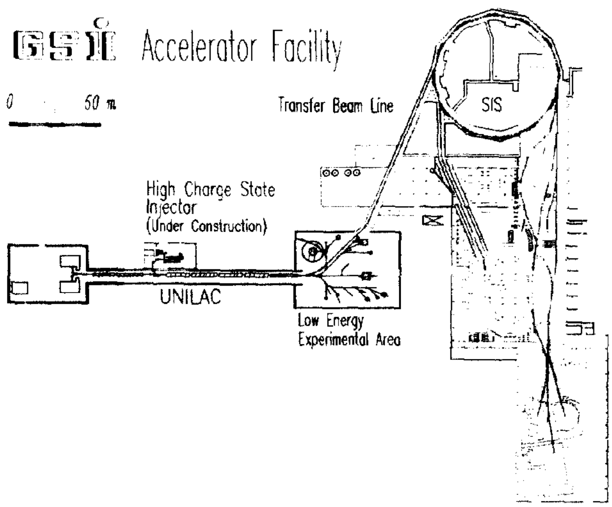

Fig. 1: Plan view of the GSI accelerator facility

First beam was injected into the synchrotron at the end of 1988, storage of ions in the ESR has been started in April 1990. The UNILAC is used as injector for the synchrotron. It has been upgraded to supply beams for these new machines while also serving low energy physics research.

A 150 m long beam transfer line from the UNILAC to the SIS was installed, design and performance will be described below.

For efficient operation of the GSI accelerator facility, the scheme of time-share operation has been adopted for the UNILAC: beams of differing ion species and currents will be extracted from the injectors, be accelerated to the desired energies and be delivered into the UNILAC experiment areas or to SIS on a pulse-to-pulse basis.

In a first step, the UNILAC poststripper accelerator was modified for time-share operation. The concept was described in [1]. With the commissioning of SIS, energy switching was available for routine operation.

Fast switching of ion species will become available with the installation of a new injector from which a first beam is expected at the end of 1990. This beam will be injected into the UNILAC poststripper accelerator alternating with that from the present prestripper linac as selected by a fast switching magnet.

The demands on beam intensities differ for the SIS injection and the low energy experiments. The present intensities from the UNILAC do not allow to reach the space charge limits of SIS for medium and heavy mass ions. They are too low by up to three orders of magnitude and can only be achieved by a future high current injector. Conceptual studies have been started for this project.
For low duty cycle injection into SIS, modifications of the present UNILAC injectors have been made in order to achieve higher intensities especially for metal ions from the PIG source. By pulsing the switching magnet which combines beam lines from the two existing injectors, intensity switching is possible already with the both existing DC injectors.

Beam Transfer to SIS

The location of the beam transfer line can be seen in the plan view shown in fig. 1. Behind the single gap cavities of the UNILAC, a fast switching bending magnet deflects the beam pulses into the transfer line. Further magnets bend the beam horizontally to a total angle of 67.5 degrees off the UNILAC axis. The focusing is provided by 10 magnetic quadrupole doublets arranged to a FODO transport system. At the end of the 150 m beam line a quadrupole triplet and four singlets provide the matching for the synchrotron injection. All magnetic elements can be pulsed at a maximum frequency of 5 Hz, therefore energy and ion species can be switched for SIS injection. Some parameters of the beam line are listed in table 1.

Table 1: Parameters of the transfer line

Length of beam line	146 m
No. of bending magnets	5
Bending angles:	5, 8.75, 8.75, 22.5, 22.5 deg
No. of quadrupole lenses	29
Maximum rigidity	4.6 Tm
Quadrupole lense parameter:	
Aperture radius	4 cm
Max. poletip field	0.6 T
Magnetic length	354 mm
Radial acceptance (norm.)	8 π·mm·mrad
Radial emittance (norm.)	< 1.5 π mm·mrad
Maximum pulse rate of magnets	5 Hz
Beam pipe diameter	10 cm
Vacuum pressure	~ 10^{-7} hP

Along the beam line various beam diagnostic elements were installed for efficient beam tuning: Faraday cups, profile harps, current transformers, capacitive pick-ups, emittance measurement device. The capacitive pick-ups allow an accurate energy measurement by time-of-flight measurement of the beam bunches. Due to the long distance of the capacitive pick-up from the last accelerating gap (maximum up to 170 m), the energy stability can be measured precisely. Automated beam optimisation programs support the operation of the new beam transport line. Furthermore, two features are important for the SIS operation: a carbon foil stripper can be used for increasing the charge state for higher SIS output energies and a fast chopping system tailors the beam pulses for the multiturn injection into SIS, the beam pulse length can be varied in a range from 1 to 400 µs. The chopper device is described in [2].

Injectors

At present two DC preaccelerators with PIG ion sources deliver the beam for injection into the rf Wideröe linac. After stripping at 1.4 MeV/u and acceleration to the desired energy (for SIS routinely 11.4 MeV/u) the following intensities (averaged peak values) are now available for SIS injection and low energy experiments:

$^{20}Ne^{7+}$ 100 eµA, $^{40}Ar^{10+}$ 100 eµA, $^{129}Xe^{21+}$ 10 eµA, $^{208}Pb^{26+}$ 2 eµA, $^{197}Au^{25+}$ 5 eµA, $^{238}U^{28+}$ 5 eµA.

Especially in case of heavier elements and all metal ions, higher intensities are required for SIS injection. Operation of the PIG source with an uranium sputter electrode at a lower repetition frequency resulted in higher yield for U^{10+} - up to a factor of 50 in intensity could be achieved. This mode of source operation requires a higher repetition frequency for the main discharge. Therefore, an increase of intensity for gaseous elements was not successful, experiments with a cold cathode PIG source have been started.

The assembling of a new preaccelerator has begun in 1989. The layout of the new linac is shown in fig. 2.

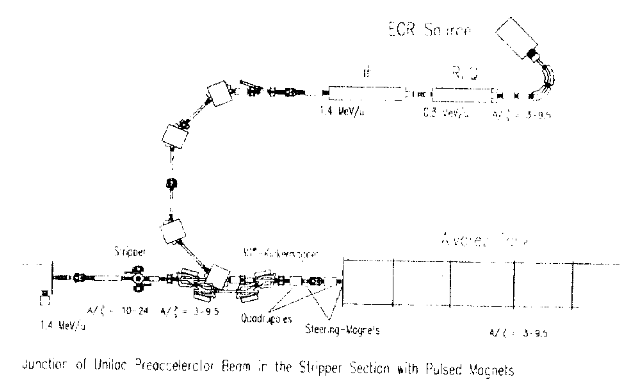

Fig. 2: Layout of the new 1.4 MeV/u injector

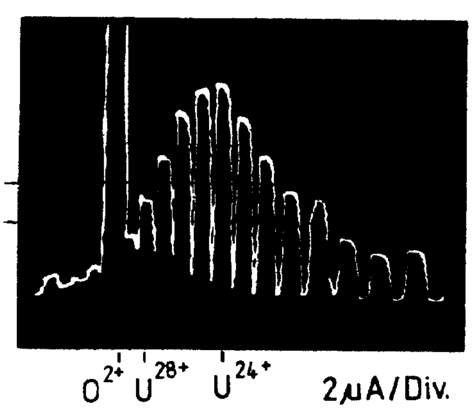

Fig. 3: Uranium from the 14 GHz ECR source

The injector consists of an ECR source followed by an RFQ and an IH structure. The 1.4 MeV/u beam will be injected via a pulsed kicker magnet into the Alvarez postaccelerator. All components were ordered, the rf tanks are ready for copper plating. First beam will be expected at the end of 1990.

Commissioning of the ECR ion source confirmed the expected intensities for highly charged ions. Fig. 3 shows the measured spectrum for uranium, the design current of 5 eµA for U^{28+} was exceeded.

Time-share Operation

In order to meet the new requirements on the UNILAC, the scheme of time-share operation with beam property switching has been introduced. It allows supply up to four users in any sequence with pulses of beams differing in energy (1.4 to 20 MeV/u), intensity (range > 1:100), pulse length, bunch length, bunch suppression (1:9), and soon also in ion species. This includes switching of preinjector and injector beam lines as well as target beam lines. Appropriate for the pulse repetition rate of 50 Hz the switching of beams is generally performed in less than 15 ms as follows:

Energy and bunch structure: - Turn on/off of rf-power to accelerating structures (Alvarez- and single-gap resonators, bunchers)

Focusing: - Control of 50 pulsed quadrupole and steering magnets between accelerating sections

Intensity: - Control of ion source arc current or sputter power
- Selecting for acceleration one of the two preinjector beams, tuned to proper currents, by means of a switching magnet.

Pulse length: - Activation of a low-energy beam chopper for reduction of beam power

Beam line: - Activation of kicker magnets to guide the beam to target-stations or into the transfer line to SIS.

Ion species (near future): - Selection of one of two Unilac preaccelerators, each delivering beam of 1.4 MeV/u, but of different ions.

In the following, these functions will be described in more detail. Fig. 4 gives the locations of some pulsed elements.

Energy switching: With the commissioning of SIS it became routine to produce for SIS single beam pulses of 11.4 MeV/u on request at ~ 0.5 Hz, interrupting the chain of pulses for experiments at 3.6 to 15 MeV/u. The two kinds of beam were identical from the ion source up to the Alvarez section; by synchronized powering of some of the Alvarez-cavities (for coarse energy steps) and of the single-gap resonators (for energy fine tuning) the different beam energies were produced. Also, bunchers or rf-choppers could be employed selectively for one or both of the beams if necessary. This mode of operation did not require switching of rf amplitudes or phases, as each accelerating section was used for a specific energy step (or none).

Switched focusing and acceptance: The quasi-periodic d.c. quadrupole focusing system within the Alvarez cavities is designed for full acceleration. Operating one or more cavities without power causes increased focussing strength on now too-low-energy beams. The possible regions of stable beam transport at varying energies were calculated and presented previously [1].
In the case of energy switching the transport stability limits are wide and the resulting overall accept-

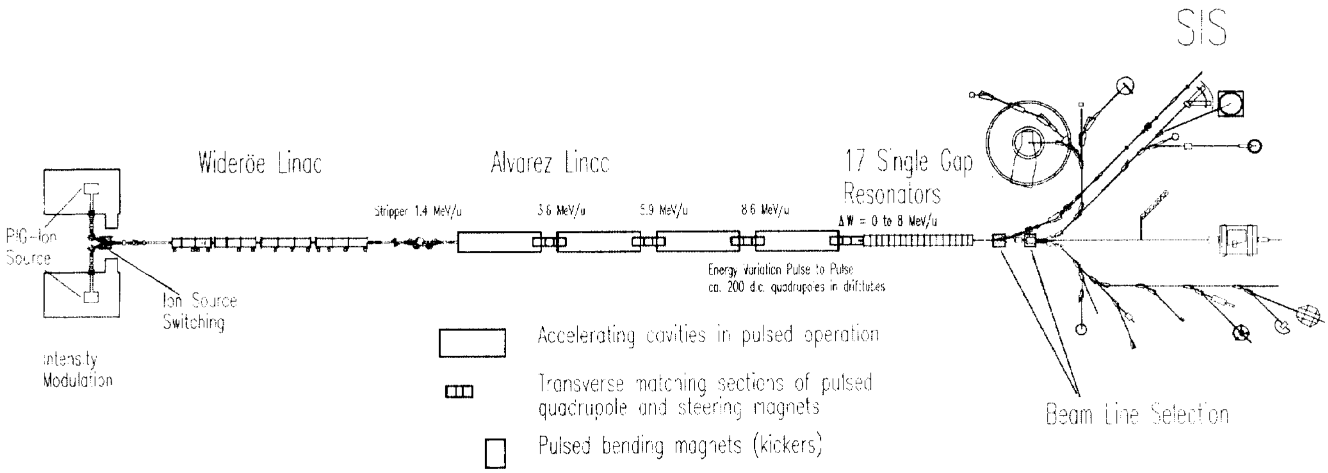

Fig. 4: Plan view of the UNILAC. Emphasis is on pulsed ion sources, rf-systems and magnets, whose working points or set-points are modulated in switched operation.

ance of the Alvarez section is around 10 π mm·mrad (normalized) when producing any energy > 2 MeV/u, which is very comfortable for the usual beam emittance of < 1 π mm·mrad. However, variable acceptance matching between cavities, depending strongly on beam energies, had to be provided by installation of pulsed quadrupole triplets.
The use of calculated field gradients for the d.c. and the pulsed quadrupole magnets has proven very successful, yielding a high transmission without fine tuning. D.c. quadrupoles are even kept out of reach of the machine operators. Generally, tuning is only necessary on the beam alignment at the end of the accelerator by means of pulsed steering magnets.

Intensity switching: Pulsed adjustment of beam current to the user's needs is done by controlling beam production or attenuation, both in the preinjector area. With noble gases, source output current modulations over a factor of 5 could be achieved by use of an additional arc power supply fired correctly in time. Recently, by pulsing the injector switching magnet, it became possible to alternatingly accelerate beam from one of the two PIG ion sources, both operating at 50 Hz and producing the proper beam current. The required matching of both beam lines to the Wideröe accelerator without pulsed elements presented no problems. The same magnet was also used to reduce intensity by controlled deflecting the beam over a downstream analysing slit. Due to the peculiar beam optics, beam alignment throughout the machine stays nearly unaffected. This is a simple, reproducible way of intensity modulation over a wide range.

Pulse length: Protective beam power reduction (from as much as 0.5 kW instantaneously) is required when measuring profiles with harps, when unused beams would create radioactivity in a beam stopper or when pulse length must be tailored for SIS. In the preinjector beam line, where beam power is low, an electrostatic chopper (rise time ~ 200 µs) cuts the pulse length for each kind of beam separately; there are also some operator-independent activation mechanisms.

Ion switching: The future high charge state injector of the Unilac provides sufficiently highly charged ions (for instance U^{28+}) as to allow injection into the Alvarez-section without stripping. It therefore bypasses the charge separator that is used with the Wideröe preaccelerator (see fig. 3). Time-shared selection of one of the two beams is accomplished by pulsing the (new) last 30°-bending magnet of the separator. Its full settling time will be ≤ 35 ms, implying a loss of one beam pulse per rise and fall. Switching of Alvarez rf amplitudes will be required, and also of the rf phase relation to the preaccelerators. The quadrupole focusing systems, except for the matching sections, remain d.c.-operated. In spite of this restriction: even with widely differing ion rigidities as of Ne^{6+} and U^{28+} the switching mode seems to be practical at reasonable acceptance values also for various final energies (fig. 5) due to the large focusing bandwidth.

A matching section of 5 pulsed quadrupole magnets will form the two beams to match the transverse acceptance of the first Alvarez section which is determined by the mass/charge ratio of each beam separately.

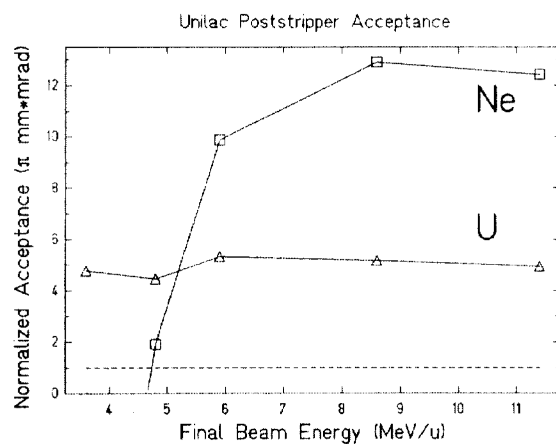

Fig. 5: Calculated overall acceptance of the UNILAC poststripper section for simultaneous acceleration of Ne^{6+} and U^{28+} to various energies in "ion switching" mode. The dashed line indicates the maximum beam emittance.

References

[1] J.Glatz, "The Unilac as a Fast-Switching, Variable Ion and Energy Accelerator", in 1986 Linear Accelerator Conf., Proc., 1986 , SLAC-Report 303, p. 302

[2] U. Blell, H. Eickhoff, "Description and Status Report of the Chopper", in Scientific Report 1986, GSI 87-1, p. 332