TWO-ION TIME SHARE OPERATION OF THE UNILAC

N. Angert, J. Glatz, L. Dahl, J. Klabunde, H.Schulte, P. Spädtke
GSI, Gesellschaft für Schwerionenforschung, D-64220 Darmstadt, Germany

Abstract

The UNILAC has achieved the full performance defined for it as a part of the GSI heavy ion accelerator facility. It gained the capability to accelerate on a pulse-to-pulse basis beams of differing ion species to individual energies and to deliver them to the low energy experimental area (LEA) and to the synchrotron (SIS). Injection of different ion beams into alternate cycles of the SIS has been used for experiments. Several 'virtual accelerators', defined by their respective ion sources, target beam lines, beam energies and intensities, can be scheduled to operate in a variety of sequences. Progress will be reported on beam intensities due to optimized modes of ion source operation and improved modelling of the accelerator.

Introduction

Since 1987 the Unilac, originally built as a DC-operated linac for nuclear physics research, has been augmented and modified to serve also as an injector for the heavy ion synchrotron SIS (Fig. 1) [1, 2],the major contributions being:

- installation of pulsed focusing systems in the post-stripper section of the accelerator
- addition of the 'high charge state injector' (HLI) with ECR ion source
- addition of the beam transfer channel to the SIS (TK)
- implementation of a 'pulsed' fast control and timing system

As a result, the Unilac now uses two injectors (see Fig. 2) which both can produce 1.4 MeV/u beams of any ions with suitable mass-to-charge state ratios (< 8.5 in the HLI < 27 in the Wideröe injector). The beams are injected, one at a time, into the common main acclerator of Alverez-type cavities and single gap resonators. The accelerated beams are distributed into the three beam lines of the experiment area and into the transfer line to the SIS. ls).

Generally, the research programs at the SIS and in the LEA ask for different ion species; these can be provided by the two injectors and can be chosen for acceleration alternatingly. By use of fast switching magnets for the beam path definitions from source to destination, the beam pulse stream to the LEA need be interrupted only rarely and shortly for the insertion of one (different) beam pulse to the SIS.

Included in this frame of two-ion operation is the possibility to control beam energy, intensity and pulse length individually. Moreover, the same or a different kind of beam may be sent to any other of the LEA beam lines in a pulsed manner; and the SIS transfer line, equipped with pulsed magnets, can even accept a different beam for any SIS-cycle. Time share operation of the Unilac has greatly enhanced the flexibility to respond to the experimenter's needs.

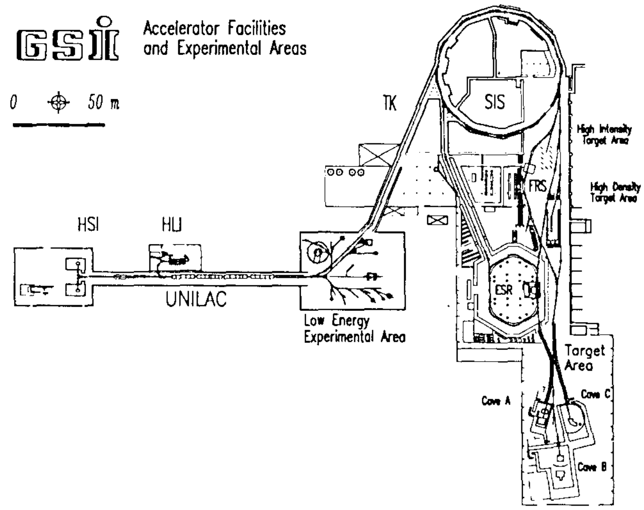

Figure 1: GSI accelerator facility

Operating Mode of the Unilac

The Unilac is now operated in a time sharing mode in which the state of the accelerator is redefined every 20 ms by means of a 'virtual accelerator' number. The 'virtual accelerator' specifies the beam to be produced by its ion source (one out of three), the target beam line or TK (one out of four), a final beam energy (3.6 to 20 MeV/u), a pulse length and a beam intensity. The beam path from the source to the destination is selected by fast kicker magnets. Beam energy is varied by on/off-control of rf-cavitites in the main accelerator section and the intensity may be modulated by appropriate defocusing the beam before an aperture. Ultimately, each 'virtual accelerator' is represented by a table of setpoints for all active elements along the beam path.

The active 'virtual accelerator' may change at a 50 Hz rate. However, switching from one injection line to the other requires an additional waiting time of 20 ms. The

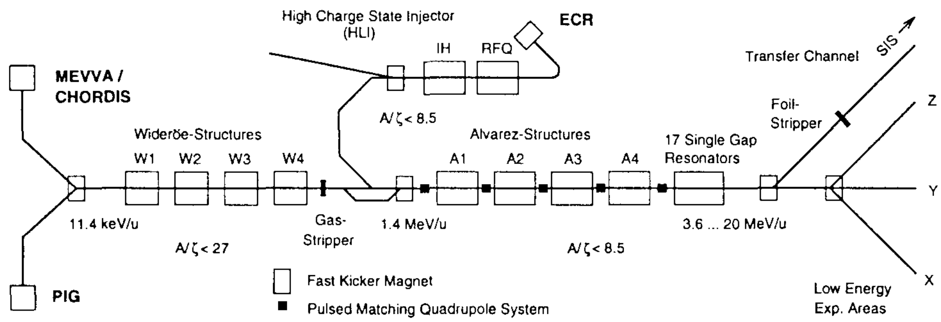

Figure 2: Functional scheme of the Unilac

ion sources must be operated at constant repetition rates optimized for maximum yield and life time. The operator-defined beam schedule is evaluated every 20 ms, considering the ready-status of required ion sources, the beam requests from the SIS or experiments, and existing interlock conditions, to determine the next active 'virtual accelerator'. A parallel development beam, restricted to an injection line, may be generated. Unused time slices may be filled with rf-heating cycles in order to avoid tank detuning during long beam intervals.

Broad Band Acceleration in the Alvarez-Linac

The main accelerator consisting of 4 Alvarez type cavities and 17 seperately driven single gap cavities is used in common by all beams and has to cope with a wide range of beam rigidities and particle velocity profiles. For the acceleration of variing beams to various energies all rf fields can be scaled or turned on or off from pulse to pulse at 50 Hz. However, for transverse focusing the section is equipped with about 200 drift tube quadrupoles which cannot be powered in a pulsed manner according to the variing ion rigidities. Instead, use is made of the broad transverse acceptance bandwidth at fixed quadrupole settings [3], which covers a relative rigidity range of about 1 to 4 with a sufficient acceptance margin (Fig. 3). Between rf-cavities the drift tube quadrupole sequence is interrupted and matching must be applied: Depending on the beam rigidity the periodic focusing structures in the cavities show specific eigenvalues of the transverse betatron and acceptance parameters (β_x, β_y and A_x, A_y). These acceptances must be matched between every two cavities. This is achieved with 3 pulsed quadrupole lenses which are set to field gradients appropriate for the respective type of beam. The beam itself may not always be exactly matched to the acceptance but may rotate safely inside. At injection into the first Alvarez tank the beam can be matched properly with the help of an emittance measurement. Altogether only 21 lenses need be pulsed.

As an example the (normalized) acceptance of Alvarez tank 1, as given in Fig. 3, compares favourably to a typical beam emittance of 0.5 $\pi mmmrad$ in a rigidity range equivalent to the post-stripper mass-to-charge state ratios between 2.5 and 8.5. Acceptance ellipses at the band limits - corresponding to transverse phase advances of 10^o and 110^o - are shown in Fig. 4 together with matched beam envelopes between tank 1 and 2. Matching at intermediate phase advances works as well. When a new 'virtual accelerator' is installed all its pulsed magnet setpoints are calculated in dependence on the actual DC-quadrupole settings and stored in data tables. They become effective when that 'virtual accelerator' is executed.

Ion Source Performance

The order of magnitiude of beam intensities and duty cycles demanded by Unilac or SIS experiments, respectively, can be roughly given as up to some 10 μA at 50 Hz with 5 ms pulse length and some mA at 1 Hz, 0.3 ms respectively. In some instances beam stability or source life are of dominant importance. Such requirements can be met to a large extent for a specific atomic element by one of the four types of ion sources in use at the Unilac (see Table 1). Beams of high duty cycles are taken from the PIG and ECR sources, the PIG source being the 'work horse' for virtually any element, while the 14.5 GHz ECR source provided very stable and reliable beams specially of gaseous materials. In the high current, low duty cycle regime the PIG sources, by careful tuning, delivered currents significantly above the long duty cycle values (a factor of 6 for Uranium). The low charge state ion sources CHORDIS and MEVVA for gases and metals, respectively, reached yields of many mA up to mass numbers of 70. Lately the MEVVA intensity

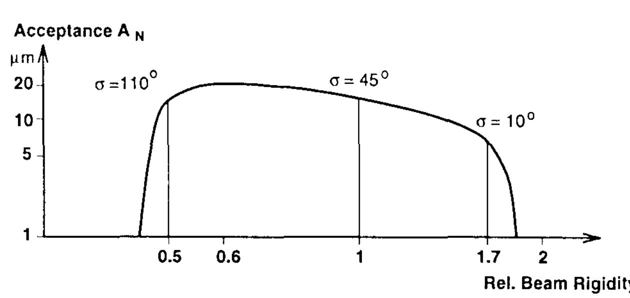

Figure 3: Transverse acceptance of Alvarez structure 1 vs. relative beam rigidity (normalized to 1 at phase advance of 45^o)

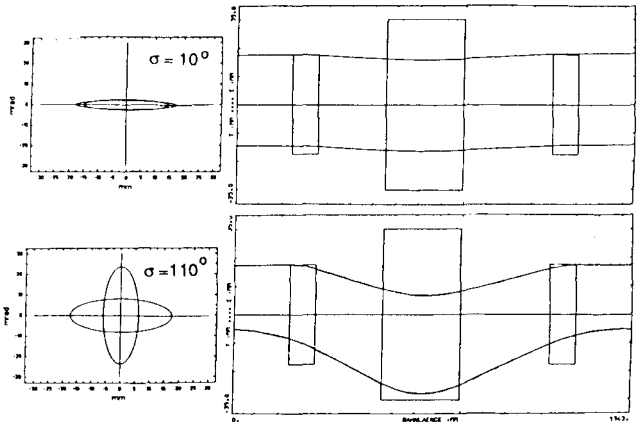

Figure 4: Alvarez 1 acceptances and beam matching envelopes to tank 2 for phase advances of 10° and 110°

and stability could be improved [4]. Promising development work on all types of sources is in progress.

Operations

Two-ion, three- or four-beam operation is normal practice. Pulse sequences as varied as in the example of Fig. 5 are executed: Energy, intensity and pulse length are switched from beam to beam. The 'funneling' of injector pulse streams of differing ions into the main accelerator section and their seperation into the beam lines is sketched. Standard final beam energy is 11.4 MeV/u (output of Alvarez tank 4) for the SIS, while the Unilac beams for nuclear or atomic physics are accelerated to 3.6 ... 20 MeV/u, centered around 6 MeV/u. Frequently changes of energy are required.

In an average 5 weeks operation block there are typically 5 to 8 machine reconfigurations due to a change of the ion species. Normally, the change is done with little or no disturbance to an ongoing experiment using the beam from the other injector. In order to reduce manual tuning times, efforts were made to enhance the reliability of calculated machine setpoints. Essential was a revision of the (20 year

Table 1: **Examples of Ion Source Yields**

Source Type	Operation	Beam	Example
PIG	high duty cycle 50Hz/5ms	$50\mu A$	U^{10+}
	low duty cycle 20Hz/0.5ms	$300\mu A$	U^{10+}
ECR	cw	$3\mu A$	U^{28+}
	afterglow mode 25Hz/0.2ms	$5\mu A$	U^{28+}
MEVVA	low duty cycle < 1Hz/1ms	$2mA$	Ni^{3+}
	or on request	$10mA$	Ti^{2+}
CHORDIS	any duty cycle	$20mA$	Ne^{1+}
	up to cw	$20mA$	Ar^{2+}

old) magnet calibrations, of power supply adjustments and of magnet alignments. Also, the beam optics in the Unilac were revised and the method of acceptance matching was applied in the accelerating sections. The problem of beam steering has been removed largely by introducing alignment stations and procedures. Now manual and computer aided tuning is restricted to the longitudinal and transverse beam matching into the accelerator sections and in the experiment and transfer beam lines.

References

[1] N. Angert, L. Dahl, J. Glatz, J. Klabunde, M. Müller, B. Wolf, 'UNILAC Modifications for an Improved Synchotron Injector Performance', EPAC 90, Nice, 1990, p. 503.

[2] N. Angert, et al., 'A New 1.4 MeV/u Injector Linac for the UNILAC', Proc. of 1990 Linear Accelerator Conf., Albuquerque, LA-12004-C, p. 749, 1991.

[3] J. Glatz, 'The UNILAC as a Fast-switching, Variable Ion and Energy Accelerator', Proc of 1986 Linear Accelerator Conference, Stanford, SLAC-Report 303, p. 302, 1986.

[4] P. Spätdtke, H. Emig, M.M. Khaouli, K.D. Leible, B.H. Wolf, 'High Current Ion Sources at GSI', GSI Annual Report 93-1, p.294, 1993.

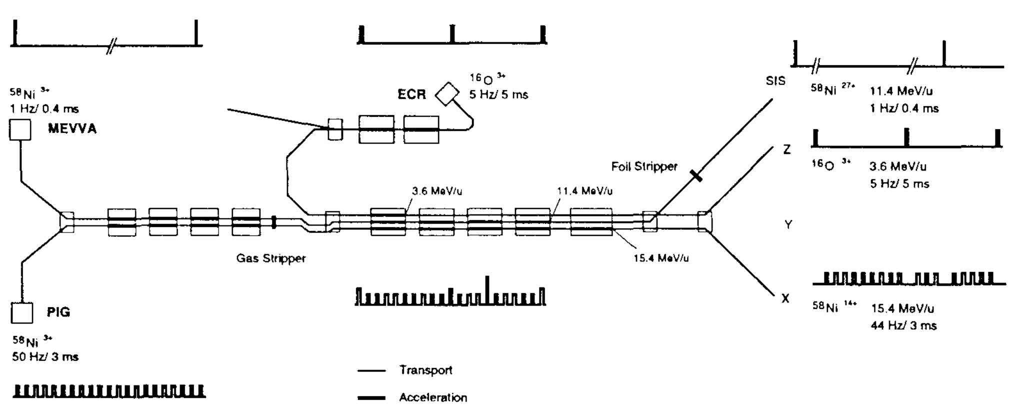

Figure 5: Example of Two Ion - Three Beam Operation