The GSI Intensity-Upgrade Program

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Abstract

At the heavy-ion accelerator complex of GSI an intensity-upgrade program is under way with the goal to fill the synchrotron SIS up to the space charge limit for all ions up to uranium. This project will increase the beam intensity especially for heavy ions by two orders of magnitude compared to the present situation. This upgrade program includes various steps:
ion source development, combined electron cooling and multiturn-injection at the synchrotron SIS and the replacement of the UNILAC prestripper structures by RFQs and IH-structures.

1) Introduction

An increase of ion intensities both at low and high energies is mainly demanded by the following experiments:

- formation of superheavy elements
- nuclear spectroscopy with rare isotopes at the 'fragment separator'
- plasma physics to achieve target temperatures above 10 eV.

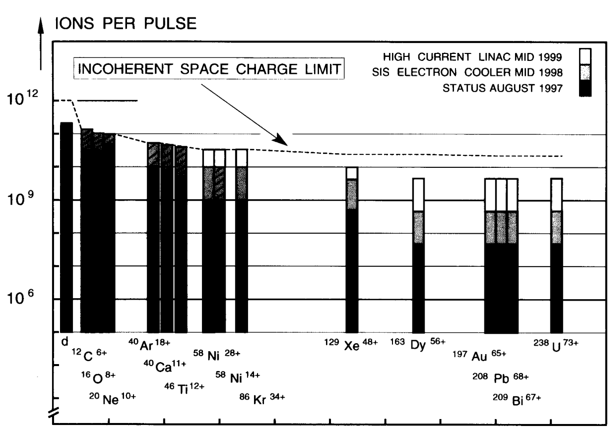

Fig. 1: SIS Beam intensities for various ions

Fig. 1 shows the design intensities in the synchrotron after the modifications are finished.
The requirements mainly aim at an intensity increase by a factor of 100 in the medium and high ion mass range. At present the Wideroe-prestripper section of the UNILAC is designed to accelerate ions up to a mass/charge ratio of 28. This structure limits the particle current, as only low charged ions will provide the intensities to fulfill the requirements. As a consequence the low energy accelerating sections will be replaced . At an intermediate state a new accumulation precedure for the synchrotron will be established in '98 to optimize the injection efficiency.

2) Ion source developments

At GSI various ion sources are used to provide the demanded beam properties from protons up to uranium. Beside the Penning and the ECR source, which are mostly activated for the present experiments dedicated high current sources designed for short pulse operation have been developed. Whereas The CHORDIS source [1] can provide low charged ions from a gaseous state like Ne or Ar, the MEVVA source generates an ion beam from solid state materials. The CHORDIS was used for high current experiments in the synchrotron SIS; 3 mA pulse currents of Ne 10+ (after stripping in the SIS injection line) were achieved, which was sufficient to get close to the space charge limit with conventional multiturn injection.
To get the same intensities with the MEVVA source for uranium a pulse current of 10 mA (U 4+) has to be delivered from this source. The experiments show that these currents can be achieved with sufficient beam properties for the succeding accelerator sections (0.4 π mm mrad normalized emittance)

3) Modifications of the preacceleration sections

The main modification in the preacceleration sections is the replacement of the existing Wideröe structure by a combined an RFQ and an IH-DTL structure.

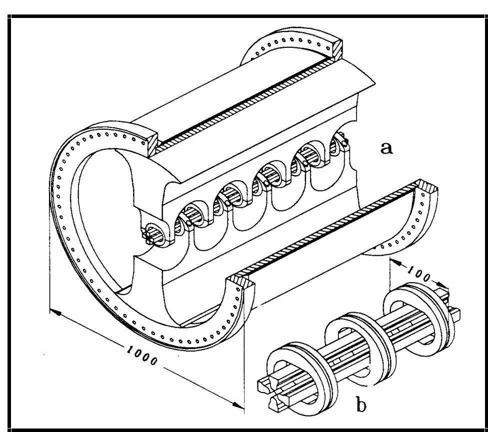

Fig. 2: New prestripper RFQ-structure

Whereas the RFQ will accelerate the ion beams from 2.2 up to 120 keV/u, 2 IH drift tube linacs are used to accelerate to the final prestripper energy of 1.4 MeV/u.
Both structures are designed for a maximum mass/charge ratio of 65, which will allow to make use of the high ion source currents available for low charged heavy ions like $^{130}Xe^{2+}$or $^{238}U^{4+}$. The accelerating components of the poststripper sections (Alvarez- and single gap resonators) remain unchanged.
A novel type of RFQ structure ('IH-RFQ') was developed that has essential advantages in comparison to conventional RFQ designs, like high shunt impedance and small tank sizes.

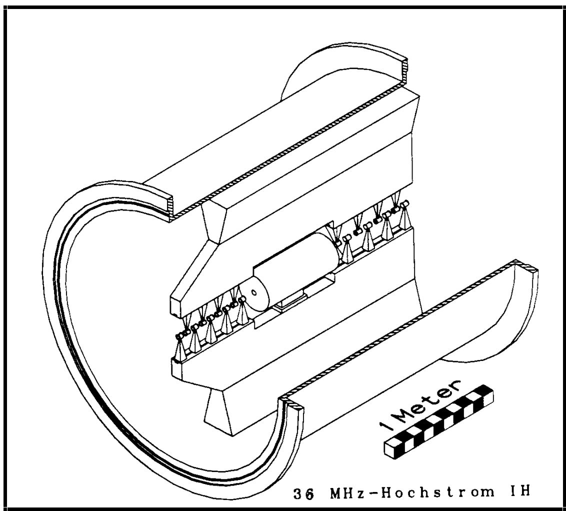

Fig. 3: New prestripper IH-DTL-structure

The RFQ is matched to the IH-DTL by two short quadrupoles and a 'super lens', consisting of a 10 cell RFQ structure. The quadrupole tripletts are completely integrated into the drift tube structure of the IH-DTLs. To provide the acceleration of different ion species on a pulse to pulse base all magnets are laminated.

	RFQ	IH
* **Inj. energy (KeV/u)**	**2.2**	**120**
* **Extr. energy (MeV/u)**	**0.12**	**1.4**
* **Frequency (MHz)**	**36.1**	**36.1**
* **tot. length (m)**	**9.4**	**19**
* **Tank diameter (m)**	**0.76**	**1.8/2.0**
* **max. beam power (kW)**	**126**	**1370**
* **max. power RF loss (kW)**	**290**	**2100**
* **eff. acc. voltage (MV)**	**7.7**	**43**
* **max. A/Q-ratio**	**65**	**65**

Table. 1: RFQ and IH-parameters

Optimization of the cavities have been performed by means of the MAFIA computer code; extensive beam calculations with PARMILA result tolerable emittance blow up and a beam transmission of 90 to 100 %
The following table summerizes some essential parameters of the high current beam operation

		Ne	U
* **Beam current (source)**	**(mA)**	**5.4**	**16**
* **A/q (before UNILAC-Stripper)**		**20**	**59.5**
* **Strip.-eff. (UNILAC-Strip.)**	**(%)**	**40**	**12**
* **A/q (before Str. Inj.-Line)**		**2.8**	**8.5**
* **Strip.- eff. (Inj. line)**	**(%)**	**90**	**15**
SIS-Injection			
* **Pulse current**	**(mA)**	**3.2**	**4.6**
* **Multiturn intens. factor**		**20**	**20**
* **Injected Ions**	**($/10^{10}$)**	**20**	**4**
* **Inj. Energy**	**(MeV/u)**	**11.5**	**11.5**
* **max. norm. emitt. (hor)**	**($*10^{6}$)**	**0.8**	**2.5**
* **A/q**		**2**	**3.3**
* **Beam power (pulse)**	**(MW)**	**0.18**	**0.41**

Table 2: Parameters for high current operation

4) Modifications at the synchrotron SIS

In order to extend the synchrotron injection time of the routinely used multiturn injection (in the horizontal phase space) this procedure will be combined with elctron cooling.
A new electron cooler has been manufactured in a collaboration of the Budker INP (Novosibirsk) and GSI. This cooler will mainly be used for the multiple multiturn-injection process (MMI); by beam cooling at an intermediate energy a further improvement of beam properties (emittances and momentum spread) on extraction level is expected.

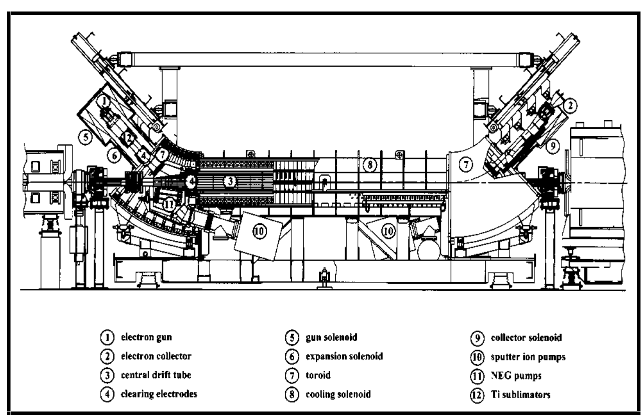

Fig. 4: Detailed layout of the SIS electron cooler

After the multiturn injection the beam covers an emittance of 150 π mm mrad in the horizontal phase space. The electron cooler will reduce this emittance within about 100 ms down to 30 π mm mrad; this reduction allows for a second multiturn injection process with another cooling at the end. This sequence, which will continue several times, increases the stored beam intensity by more than one order of magnitude compared to the conventional injection process.

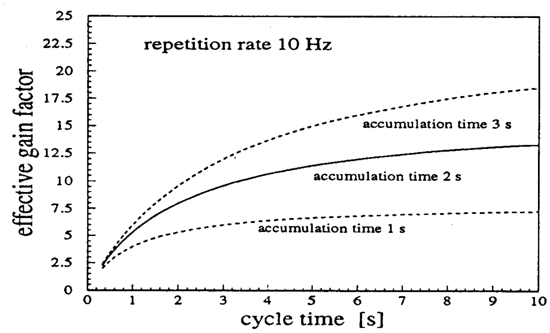

Fig. 5: Intensity increase due to electron cooling

The lower electron energy is designed for a SIS injection energy of about 11 MeV/u: the maximum electron energy corresponds to an intermediate cooling at about 70 MeV/u.

∗ **length of cooling section**	**3.36 m**
∗ **Electron energy**	**5 - 35 keV**
∗ **max. electron current**	**2 A**
∗ **max. electron density in cool. sect.**	**$4*10^8$ cm^{-3}**
∗ **electron beam diameter**	**25 - 70 mm**
∗ **max. B-field in cooling sect.**	**1.5 kG**
∗ **exp. factor of B-field**	**7**

Table 3: Parameters of the SIS Electron cooler

5) Additional Modifications

Beside the described modifications various additional activities will take place:

∗ The beam transport lines in three sections of the UNILAC have to be modified

∗ A fast beam deflecting system at the foil stripper of the SIS injection line has to be realized in order to limit the heating up of the foils at high intensity operation.

∗ Additional high current beam stoppers have been designed

∗ New non destructive beam diagnostic devices have been (position monitors, 'residual gas' monitors)

∗ A new interlock system based upon beam transmission control will be installed

∗ Feed back systems to cope for transverse and longitudinal instabilities are investigated presently.

∗ for plasma physics experiments a new compression cavity for reaching high target temparatures is under discussion.

6) Status and Schedule

In addition to the design and construction of the described new hardware components accelerator experiments took place, that are relevant for high intensity operation[4]. At the SIS $1*10^{11}$ Ne^{10+} ions could be injected over a 22 turn accumulation with a multiturn efficiency of about 80 %; with a new working point a maximum number of $8*10^{10}$ Ne-ions was accelerated to an energy of 300 MeV/u.

The effect of resonances on beam losses especially during the RF-capture process was studied carefully. These investigations led to a design study of correction elements in order to compensate these resonances, that are critical due to the incoherent tune spread at high current operation. Within the first half year of 1999 pairs of correction quadrupoles, skew quadrupoles and skew sextupoles will be installed in the synchrotron.

∗ The SIS electron cooler has been successfully tested and installed in the synchrotron; operation will start in april '98.

∗ From January to July 1999 the new prestripper accelerating sections will be installed. After a commissioning high current operation up to uranium will be available near the end of '99.

References:

[1] B.H. Sun et al., Study of a Microwave Plasma Cathode, Rev. Sci. Instr., Vol. 63 (4, II), 1992

[2] B. Krietenstein et al. , Numerical Simulations of IH-accelerators with MAFIA and RF Model Measurements, 18. LINAC, Geneva, 1996

[3] D. Böhne, Status Report on the SIS Beam Intensity Upgrade, GSI Scientific Report 1996

[4] K. Blasche et al, SIS Status Report, GSI Scientific Report 1997