The Heavy Ion Synchrotron SIS - A Progress Report

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Abstract

A brief description is given of the Heavy Ion Synchrotron SIS, which is part of the new SIS/ESR facility at GSI. A survey of the ions that were accelerated in 1992 is presented showing the respective beam energies and intensities. Plans to increase the available beam intensities are shortly discussed. Progress in the supercycle operation for a time-shared use of up to 16 machine settings and commissioning of the beam line from the ESR back to the SIS with storage and future postacceleration of cold ESR beams are summarized. In addition, the results of recent machine experiments are presented: they include new data on Q-values for the dynamic change-over from triplet focusing at injection to doublet focusing at extraction and on machine chromaticity as well as beam profile measurements for the circulating SIS beam, which yield information on the transverse beam emittances. Finally some aspects of the present and future experimental program are discussed.

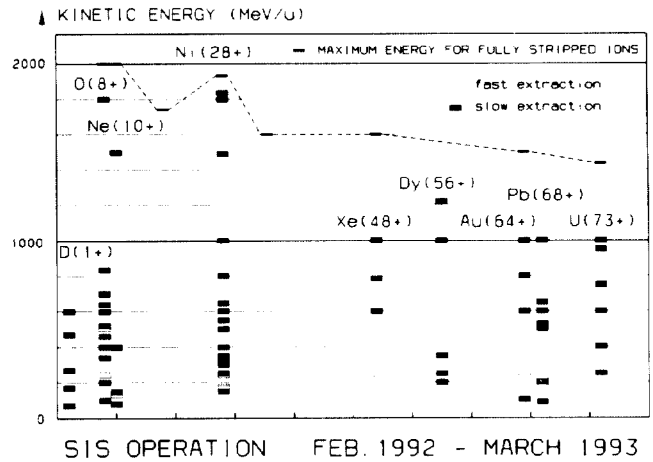

Figure 1: SIS operation from February 1992 until March 1993. The dashed line indicates the maximum energies for fully stripped ions.

1 INTRODUCTION

The heavy ion synchrotron SIS is part of the new GSI accelerator facility [1], [2]. As shown in the plan view of Fig.2 the Unilac, which is in operation since 1975, provides low energy beams up to 20 MeV/u. The new SIS/ESR facility was conceived for acceleration, storage, and cooling of high energy heavy ion beams. Construction of the new facility had begun in December 1986. Since January 1990 it is fully used for experiments.

The SIS is designed for the acceleration of all kinds of heavy ions to maximum energies between 1 and 2 GeV/u. The high energy beams can be delivered either directly to several experiments in the target area or to the ESR via a beam line with stripper target and charge separator. A third way for the SIS high energy beams leads to a production target at the fragment separator (FRS), where secondary beams can be produced by projectile fragmentation. The FRS prepares pure beams of any interesting nuclear fragment, which can either be studied at the final focal plane or can be injected into the ESR for ring experiments.

The Unilac was up-graded for its role as SIS injector. A new injector with an ECR ion source, a short RFQ section, and an IH linac was installed midway in order to provide two ion beams of different species: one for a low energy experimental program and another one for SIS injection.

2 ENERGIES AND INTENSITIES

In Fig.1 the status of SIS operation is summarized for the last year until March 1993. It can be seen that slow resonance extraction was used in a broad energy range, while fast extraction mostly for the ESR storage ring took place between 150 and 300 MeV/u. The maximum energies at $(B\rho)_{max}$ = 18.4 Tm are 2 GeV/u for light ions with q/A = 0.5 and about 1 GeV/u for heavy ions, e.g. U(73+), according to the charge state after stripping at 11.4 MeV/u SIS injection energy. For fully stripped ions, which will be stored and cooled in the ESR, higher energies will be available, e.g. 1430 MeV/u for U(92+).

As shown in Fig. 3 maximum intensities range from 10^7 ions per spill for heavy ions up to $1 \cdot 10^{10}$ for neon or oxygen. These intensities, which were reached until end of 1992, are restricted by the available Unilac currents, typically about 100 μA for Neon (10+) or 1 μA for uranium (73+).

It is planned to raise the available SIS intensities roughly by a factor of 20 until the end of 1994. This goal shall be approached with an improvement program for ion source operation, Unilac transmission and SIS injection. In the course of this program the SIS space charge limit will be tested for light ions up to $2 \cdot 10^{11}$ ions per cycle. For very heavy ions new developments are necessary. One way to increase intensities by a factor of 100 would be the construction of a new RFQ injector and a 35 m long IH linac

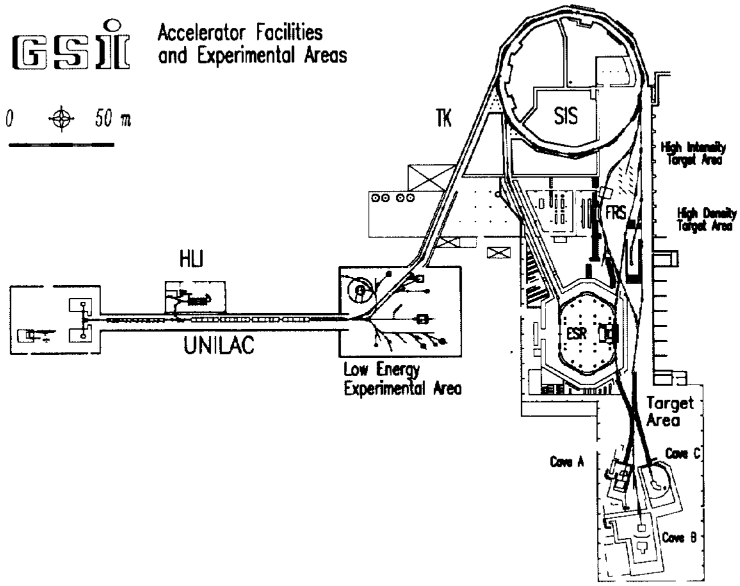

Figure 2: Plan view of the GSI accelerator facility

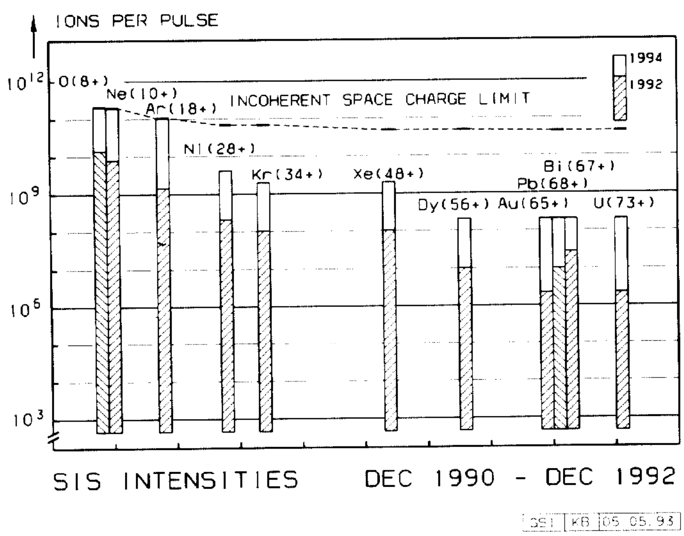

Figure 3: SIS beam intensities at the end of 1992 and prospective intensities for the end of 1994. The incoherent space charge limit is indicated for $\Delta Q = 0.25$.

for the acceleration of low charge ion beams like uranium (3+) up to 1.4 MeV/u [3]. It was shown that such a linac should accelerate uranium (3+) up to about 10 pmA, while filling of the SIS to the space charge limit of $4 \cdot 10^{10}$ ions would require only $10 p\mu A$ of uranium (73+) and 2 pmA of uranium (3+) respectively.

3 STATUS OF MACHINE OPERATION

Usually the SIS has been used in a time-shared mode with slow extraction of ion beams for target station experiments at the same time as fast extraction to feed the ESR. These modes are combined on a pulse-to-pulse basis, so that with ESR filling usually needing only a few hundred pulses every hour, most of the SIS capacity was available for target station experiments. It is also possible to run several machines with slow extraction in a time-shared mode, e.g. four machines with energies of 200, 270, 330, and 400 MeV/u have been used to provide depth variation of the Bragg peak in a thick PMMA plastic block (Fig. 5).

In January 1993 commissioning of the reinjection line ESR/SIS was started. The following uses are planned: (1) Acceleration of fully stripped heavy ions to maximum energies above 1430 MeV/u. (2) Slow standard and stochastic extraction of cold ion beams. (3) Transfer of intense short and cold ESR ion bunches through the SIS to the target station for high energy density experiments.

In the first round of commissioning it was possible to transfer ESR beams and to store them in the SIS. It is foreseen to optimize the operation of the reinjection line in a second round with argon ions in July 1993 and to store the reinjected ESR beam in the SIS with high efficiency. In addition, it will be tried to test acceleration and slow resonance extraction for cooled low emittance beams.

4 RECENT MACHINE EXPERIMENTS

The standard focusing scheme for acceleration is pure triplet focusing at injection with a change-over to doublet focusing at high energy keeping the Q-values constant. During the last year the Q-measurement system has been improved [4]. Narrow band measurements of the beam transfer function (BTF) provide an accuracy of 10^{-4} for the tunes, and signal processing at a fixed intermediate frequency of 50 MHz will allow dynamic tune measurements within less than 1 ms for each data point along the acceleration ramp. In Fig. 4 first results at three energies are plotted, which show that the precision of tune setting

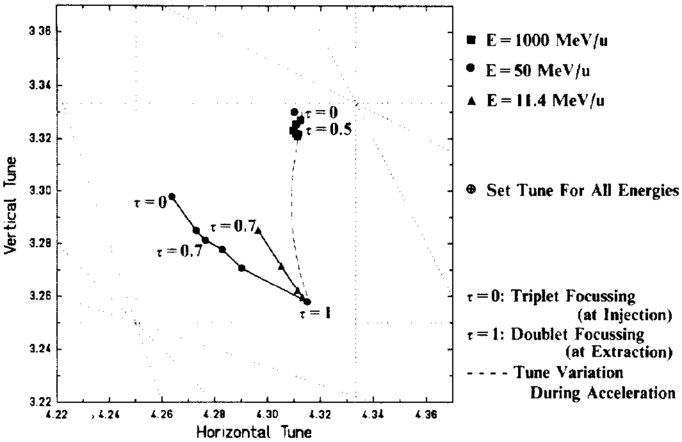

Figure 4: Tune measurements for three SIS energies with different settings for triplet(τ=1)/doublet(τ=0) focusing.

is not yet perfect at low energies. At injection energy the measured vertical tunes Q_v are about 0.06 below the set tunes while the horizontal tunes deviate mainly for doublet focusing. The variation of the tunes on the acceleration ramp is small for Q_h and rather large for Q_v. The observed tuning errors at low energy are probably due to a linear approximation of the magnetization curve, which has to be refined according to the magnetic measurements for the SIS quadrupoles.

The BTF method was also used to study chromatic effects. The observed values of $\xi_h = -0.74(T), -1.77(D)$, $\xi_v = -2.13(T), -2.11(D)$, were compared to the calculated natural machine chromaticity $\xi_{h,n} = -0.95(T), -1.54(D)$ and $\xi_{v,n} = -1.88(T), -1.43(D)$. It was necessary to include a sextupole term of B"l/Bρ = $0.04 m^{-2}$ in all 24 SIS dipole magnets, which is larger than the measured sextupole term, in order to achieve good accordance of the theoretical data with the measured chromaticities.

For chromaticity correction two families of sextupole magnets are foreseen, which can be used to correct horizontal and vertical chromaticity separately. It was shown that the observed chromaticity correction is in good agreement with machine theory.

In another machine experiment movable beam scrapers were used to measure the current on the scraper jaw as a function of its position with respect to the beam axis. From the beam width and height the horizontal and vertical beam emittances were deduced. At injection energy of 11.4 MeV/u a horizontal beam emittance of $120\pi mm \cdot mrad$ was observed, which corresponds to the machine acceptance with the present positions of the injection and extraction septa. The vertical emittance of 20 $\pi mm \cdot mrad$ after multi turn injection was larger by a factor of 4 than the Unilac beam emittance. Probably the beam matching to the vertical machine acceptance was inadequate, since the beam profiles at high energy show a broad shoulder and a high intensity core of 0.5 $\pi mm \cdot mrad$, which corresponds to the Unilac beam emittance with the correct $\beta\gamma$ transformation. The high energy horizontal emittance of $7\pi mm \cdot mrad$ is even smaller than the expected value of 10, which may be explained with beam losses and corresponding emittance reduction during rf beam capture.

5 EXPERIMENTAL FACILITIES

It is planned to extend the experimental facilities shown in Fig. 2 in the following way: (1) A direct beam line from the FRS to the target hall is under construction. It will provide a direct way for secondary FRS beams to the target hall. (2) A dilepton spectrometer HADES was proposed. It shall be installed in the north east area of the target hall. (3) In front of the new HADES cave a detector test facility is foreseen, where SIS beams and also secondary beams will be available. (4) North west of cave A a new radiotherapy cave is planned. It will have direct access from a new building west to the targt hall, which can be used for the medical care of patients.

For the radiotherapy program the development of an active three-dimensional scanning technique is underway. In a first step it had been demonstrated that a homogeneous two-dimensional dose distribution could be achieved with magnetic scanning. The second step was energy variation of the SIS and the beam transport system on a pulse-to-pulse basis. It was also shown that the three-dimensional dose distribution can be well controlled using the PET technique to spot positron emitters produced by projectile fragmentation in the target volume [5]. Fig. 5 shows the dose distribution in a plastic block (PMMA) for an ^{16}O beam.

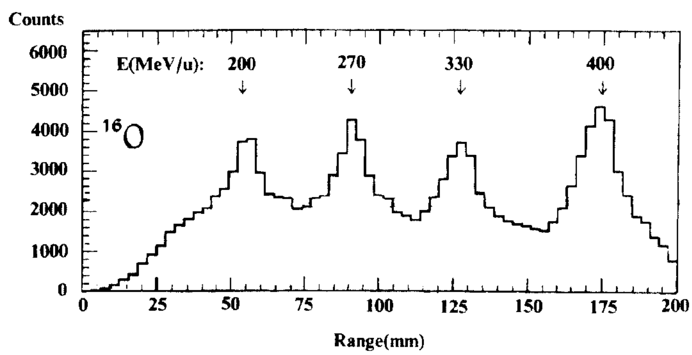

Figure 5: Dose distribution in a plastic block (PMMA) for an ^{16}O beam with four different energies.

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