SIS Status Report

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1. Status of Operation

In 2000 sixteen different ion species – ^{1}H, ^{2}D, ^{12}C, ^{14}N, ^{18}O, ^{26}Mg, ^{40}Ar, ^{56}Fe, $^{58,60}Ni$, $^{84,86}Kr$, ^{92}Mo, ^{124}Sn, $^{129,132}Xe$, ^{197}Au, ^{208}Pb, and ^{238}U – were accelerated in the SIS. Altogether 6155 h of beam time were provided for experiments, often with one or more high-energy target experiments and the ESR running in a pulse-to-pulse timesharing operation mode. Another 211 h were used for accelerator tune-up and development. The total down-time of 354 h (5,3 % of the total operation time) was to a large part caused by a vacuum break-down in one of the experiment set-ups.

The total user time of 6155 h was distributed to radiotherapy with carbon ions (1437 h or 23 %), to production runs for target experiments (3681 h or 66%), and to the ESR (1031 h or 17 %). SIS intensities for very heavy ions like U^{73+}-ions were still restricted, since the new high current injector HSI at the front-end of the Unilac has not yet reached the design injection current of 2 to 4 mA. With the available current of 150 µA the SIS provided about $2\cdot10^{9}$ U^{73+}-ions per machine cycle instead of $2\cdot10^{10}$. A comparable beam intensity has been achieved with much lower injection currents using beam accumulation with a series of multiturn-injections based on electron cooling. In this scheme the intensity was limited to about $2\cdot10^{9}$ U^{73+}-ions due to the onset of coherent transverse beam instabilities, which are typical for cooled low-emittance beams.

A new record beam intensity of $1.2\cdot10^{11}$ Ar^{11+}-ions was delivered for a FRS experiment. In this machine run the Unilac provided an injection current of about 3 mA, since no additional stripping of Ar^{11+} was necessary for the low energy of 500 MeV/u used in the experiment. The available beam intensity was close to the space-charge limit of $1.6\cdot10^{11}$ Ar^{11+}-ions.

The new HSI has been designed for low-charge-state heavy ions with A/q = 65. However, it could be shown that the Unilac can still provide light ions like ^{2}D-beams of about 1 mA for injection into the SIS, which will give about 2 to $3\cdot10^{11}$ ^{2}D-ions per machine cycle.

SIS operation with high intensity ion beams demands a careful control of beam losses. The efficiency of the multiturn injection will be controlled by a new interlock system, which was ordered in 2000. Beam losses during resonance extraction and along the beam transport system especially from the SIS to the FRS will be studied carefully using additional beam loss monitors in the extraction channel (diamond detectors) and along the beam-line (plastic scintillators).

The usual slow-extraction scheme is third-order resonance extraction with two fast extraction quadrupoles, which gradually shift Q_h towards 4 1/3 driving the coasting ions into a betatron resonance. Meanwhile an alternate scheme with operation at a constant Q_h close to the resonance was tested. A transverse rf noise voltage is used to knock out ions by excitation of large radial oscillations, which lead into resonance [1]. The new scheme provides excellent position stability for the extracted beam and an easy way to interrupt the spill and to proceed with slow extraction after a short pause. Both features are useful for the radiotherapy program. Further studies will show if the efficiency of the slow extraction process and the spill-structure can be improved, too. The complete device with an rf-noise-synthesizer locking onto the revolution frequency, newly developed power amplifiers and integration in the SIS control system is almost ready for routine operation.

2. SIS Machine Development

In 2000, a new device for precise dynamic tune measurement has been tested. Fig. 1 shows the measured horizontal and vertical tunes recorded in one machine cycle. It can be seen that the variation of both tunes is about 0.02 during acceleration, whereas on the flat top the vertical tune is constant and the horizontal tune increases slightly. The new Q-meter will be used for further precise tuning of the Q-values along the acceleration ramp, where the focusing scheme is shifted from triplet focusing at injection to almost duplet focusing at high energy.

Acceleration of protons to the maximum energy of 4.7 GeV requires a dynamic shift of the transition energy on the ramp, which is realised by a gradual change-over from 12 to 6 superperiod focusing. This scheme was successfully tested. Protons could be accelerated to 4.7 GeV without any beam losses on the acceleration ramp, since passing of the transition energy was avoided. On the flat-top the focusing scheme was reversed tuning 6 superperiod focusing back to the standard scheme with 12 superperiods, which is required for slow extraction. It could be shown that the coasting beam passes the transition energy without losses and phase-space degradation.

In 1999, it has been shown that transverse phase-space is kept constant during acceleration. However, in the longitudinal phase-space a blow-up by a factor of 3 is observed mainly during the rf-capture process (Fig. 2). Therefore the capture process has to be improved during the next time. At present the reduction of momentum spread due to the new debuncher system (36 MHz) in the SIS injector line does not yield the expected small momentum spread of the accelerated beam.

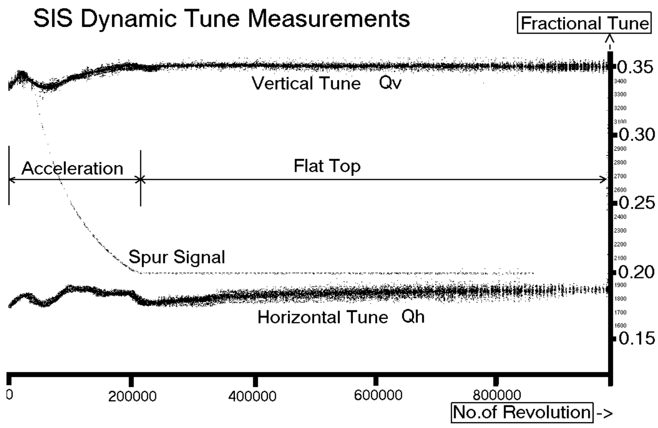

Fig. 1: Dynamic tune measurement for a SIS machine cycle.

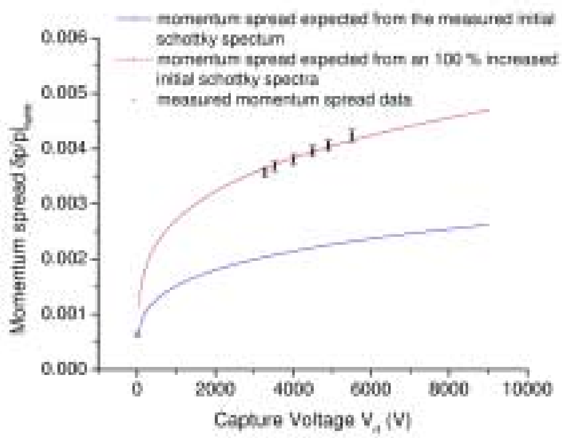

Fig. 2: Longitudinal phase space during RF-capture in the SIS. The measured momentum spread exceeds the calculated values by a factor of 2.

It is very important to maintain the small phase space volume of the injected ion beam during RF-capture, acceleration, and debunching in the SIS, since a very low momentum spread is necessary for an effective use of the new bunch compressor system.

The acceleration of low charge-state ions e.g. Ar^{11+}-ions and especially U^{28+}-ions is used to provide very high beam intensities. Table 1 shows the 1/e beam life time for U^{28+}-ions at low energies and at 150 MeV/u as measured in 1996 and 2000. In 1996 the life-time was considerably larger than in 2000, although the measured average pressures $<p_{tot}>$ did not differ very much. It is assumed that the content of heavy molecules in the rest gas mass spectrum has increased since 1996.

Table 1: Beam life time (1/e) for U^{28+} ions at low energy and at 150 MeV/u as measured in 1996 and 2000.

Energy (MeV/u	τ (sec)	$<p_{tot}>$ (mbar)	N_0	Date (year)
6	1.2	$5\cdot10^{-11}$	?	1996
8.7	0.56	$5.6\cdot10^{-11}$	$3\cdot10^{8}$	2000
150	1.6	$5.6\cdot10^{-11}$	$1.5\cdot10^{8}$	2000

Fig. 3 shows the resulting beam losses during acceleration, which amount to about 40 % with the present rather slow ramp rate of dB/dt = 1,5 T/s. However, with the vacuum of 1996 these losses can be reduced to 3 to 10 % for the SIS12 and SIS18 operation mode, if the design ramp rates of 10 and 4 T/s would be used. In any case, further improvements of the SIS vacuum system are planned for the future.

3. SIS Component Replacement and Development Program

In 2000 a complete set of new vacuum-chambers for the 24 dipole-magnets has been ordered. The 14 years old original chambers made from 0.3 mm thick stainless steel sheet reinforced with stiffening ribs have approached the fatigue limit. As a consequence of 5-10 bake out procedures they are all compressed by 5 to 10 mm and the vertical aperture is reduced from 70 to 60 mm.

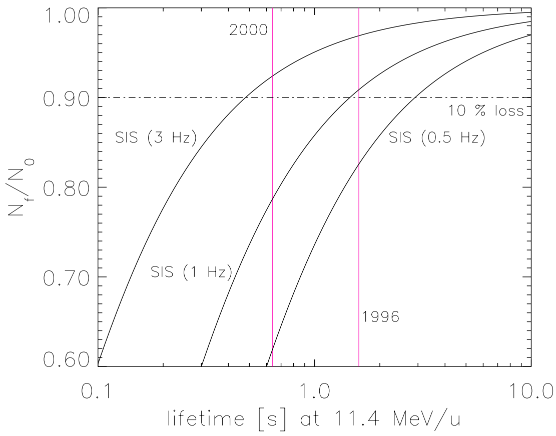

Fig. 3: Fraction of injected ions after acceleration versus beam life time at injection energy for three SIS operating modes.

In addition, three or four vacuum-chambers developed leaks during the bake out. The design of the new vacuum chamber removes the deficiencies of the original chambers, e.g. a long tube is used instead of three short welded sections and the stiffening ribs are strengthened. The installation of the new dipole chambers will be part of an extensive program that shall lead to a lower average vacuum pressure of about $1\cdot10^{-11}$mbar and to a reduction of heavy molecules in the residual gas.

In addition to the vacuum improvement program the following projects are under way:

1. a transverse feedback system,
2. a feedback system around the power amplifiers of the accelerating cavities,
3. a set of new correction coils, and
4. four bunch-compressor cavities.

The transverse feedback system shall be used to damp coherent transverse instabilities observed during operation with cooled ion beams e.g. with $2\cdot10^{9}$ U^{73+}-ions. It is planned to extend the range for stable operation with cooled beams to about $5\cdot10^{9}$ ions. The feedback-system includes two of the existing position monitor probes as pickup-system, a new feedback kicker, a new DSP processing stage (100 MHz, 12 bit), new power amplifiers, and a closed orbit suppressor system (CERN). All components are ready for tests of the complete system in March/April 2001.

The feedback systems around the power amplifier are developed to reduce the impedance of the two installed cavities from $R_p \simeq 3$ kΩ to below 1 kΩ. A complete SIS accelerating station has been built up for this development. Many components of the power amplifier stage were redesigned and adapted to the new requirements.

The set of new correction coils was designed to compensate and control the resonances Q_V = 3 1/3, Q_V = 3 1/2 and Q_h-Q_V = 1 to prepare SIS operation at a new high current working point (Q_V = 4.2, Q_h = 3.6), which allows operation with $2\cdot10^{11}$ Ne^{10+}-ions and $4\cdot10^{10}$ U^{73+}. The control of the difference resonance Q_h-Q_V = 1 will be used to optimise multiturn-injection and rf-capture and to manipulate the horizontal and vertical beam emittances. The correction coils are in production and the necessary power supplies will be ordered soon. It is planned to commission the complete system in the first quarter of 2002.

The four bunch compressor cavities will be installed to produce a short high intensity bunch before fast extraction e.g. a bunch

with $2 \cdot 10^{11}$ U^{28+}-ions of 50 ns or 10 m pulse width [2,3]. Fig. 4 shows the design of the new bunch-compressor cavities.
Each compressor cavity has an inductive load of twelve cores made of amorphous metallic alloy (MA core). VITROVAC 6030F from Vakuumschmelze (Hanau) is an appropriate material and two prototype cores will be delivered soon. The submission for the complete set of 48 cores is underway. The cavities are inductively coupled to the power amplifier stage by the anode cable led around the MA cores. For the low duty cycle operation the Thomson RS2054 is an adequate RF-tube. The components of the power amplifier stage were ordered and a prototype stage will be built soon.

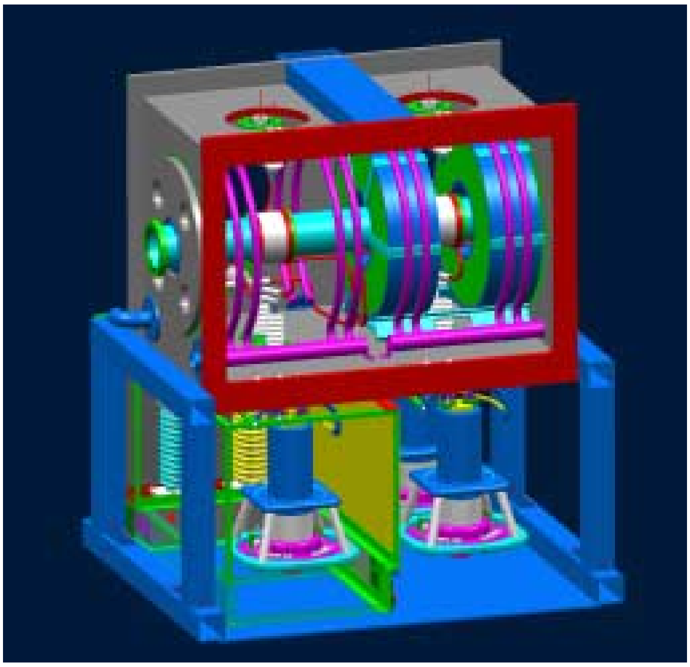

Fig. 4: Design of the SIS bunch compressor cavity based on magnetic alloy cores. Two out of four cavities are shown. Each cavity (top) is driven by a final amplifier stage in push-pull operation (bottom).

4. High Energy Beam Transport System

In 1998 a pion production target with a new beam line to the target area and the new HADES set-up have become part of the high energy facilities. At that time power supplies of the existing beam lines had to be used for sixteen additional beam line magnets to keep investment costs low. Meanwhile first experiments with the new pion beam line and with HADES have shown that power supply switching and the resulting strong restrictions for time sharing operation are a strong disadvantage for an efficient use of the high energy facility. Therefore it was decided to order all necessary power supplies. Installation was realised during the winter shut down 2000/2001. Now time sharing operation is available and with polarity switching different secondary beams like π^+, π^- or $\bar{p}$ can be provided easily.
In the beam line from the ESR to Cave A five new scintillator screens were installed.
In the SIS extraction beam line two prototype diamond detectors were installed. The first one is a square (30 × 30 mm) carrying nine parallel strips to show the horizontal beam profile and the second one is a smaller square (20 × 20 mm) with 16 pixels in a 4 × 4 array arrangement to monitor the (x,y) distribution of the beam intensity. At present both detectors are only 30 mm apart. Fig. 5. shows the pulse signals from a single uranium ion at an energy of 200 MeV/u passing the two CVD-diamond detectors [4]. The signal in the second detector is delayed by 200 ps according to the 30 mm distance showing the excellent time resolution of diamond detectors. As soon as both detectors will be fully equipped with 2 GHz broadband amplifiers, pulse shaping and pulse frequency dividers, the new diamond detectors will be used to monitor the beam intensity with high precision, and at the same time transverse beam-profiles as well as the time resolution of the spill-structure.

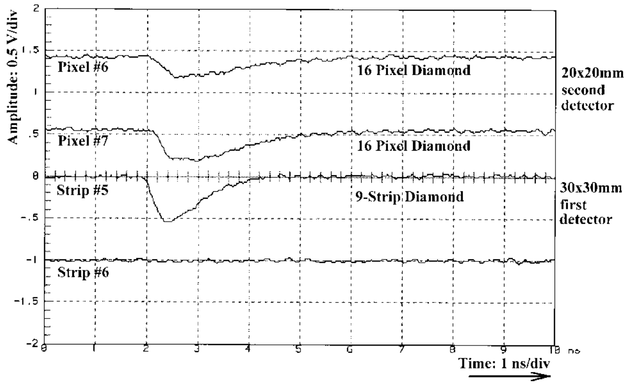

Fig. 5: Diamond counter signals from a single uranium ion at 200 MeV/u (v = 0.57 c) passing through two detectors. The first detector (lower two traces) is passed first at one strip, the second detector (upper two traces) is passed last. The ion trajectory in the second detector lay between two pixels and the signal was recorded coincidentally on two pixels of the same detector.

References:

[1] K.Hiramoto and M.Nishi; Resonant beam extraction scheme with constant separatrix**;** NIM A, 1992, pp. 154-160

[2] K.Blasche et al., Proceedings of the 6th EPAC, (1998) 1347

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