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THE FIRST YEAR OF SIS/ESR OPERATION

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The commissioning period of 1989 and the first year of routine operation of the SIS are described. The planned fast switching of final energy, extraction mode and beam line selection was achieved. The fast extraction and beam transfer to the storage ring have been demonstrated to work well. Efficiency and time structure of the slow extracted beam are still problematic. Cooling of argon beams in the ESR was successful right from the start. Theoretical thresholds for intrabeam scattering and longitudinal instabilities were approached. The outlook on future beam-intensity improvements is given in the context of planned target experiments.

1 THE SIS

The new GSI accelerator facility is described in Refs. 1–7 with periodic updating of the project's progress. Its potential for HIF beam experiments is covered in Refs. 8 and 9.

The synchrotron was assembled in 1988. There was adequate time for careful magnetic measurement and heat treating of vacuum components off line, because the initial settlement of the buildings was still in progress. First injection tests in November 1988 revealed that the magnet polarities were right and no obstacles were left in the vacuum chamber. Commissioning of the main magnet power supplies went on in the first quarter of 1989. It was not difficult to obtain the specified current accuracy of 2×10^{-4} in the ramping mode, although numerous malfunctions and ambiguities in the controls had to be eliminated. In the same period, cabling of the vacuum bake-out circuits continued; the duration of this activity had been greatly underestimated. Even now, the baking installation is not complete because the laborious refurbishing of the heater jackets is always the last (and often incomplete) activity after a maintenance period. As a consequence, parts of the ring have sometimes run only at 10^{-9} mb which excludes the acceleration of barely stripped, very heavy ions.

The commissioning of SIS-18 began in April 1989. The planned closed-orbit measurements, a reasonable first step, could not be done because the beam position monitors were not operational, except for one unit. With the aid of a fast beam transformer and a DC transformer for monitoring the accumulated beam, multiturn injection was set up immediately. Injection of 20 turns resulted in a current increase of a factor of 12. Steering of the beam from the injection line into the ring was difficult and alignment imperfections were suspected. In the year thereafter, it was not

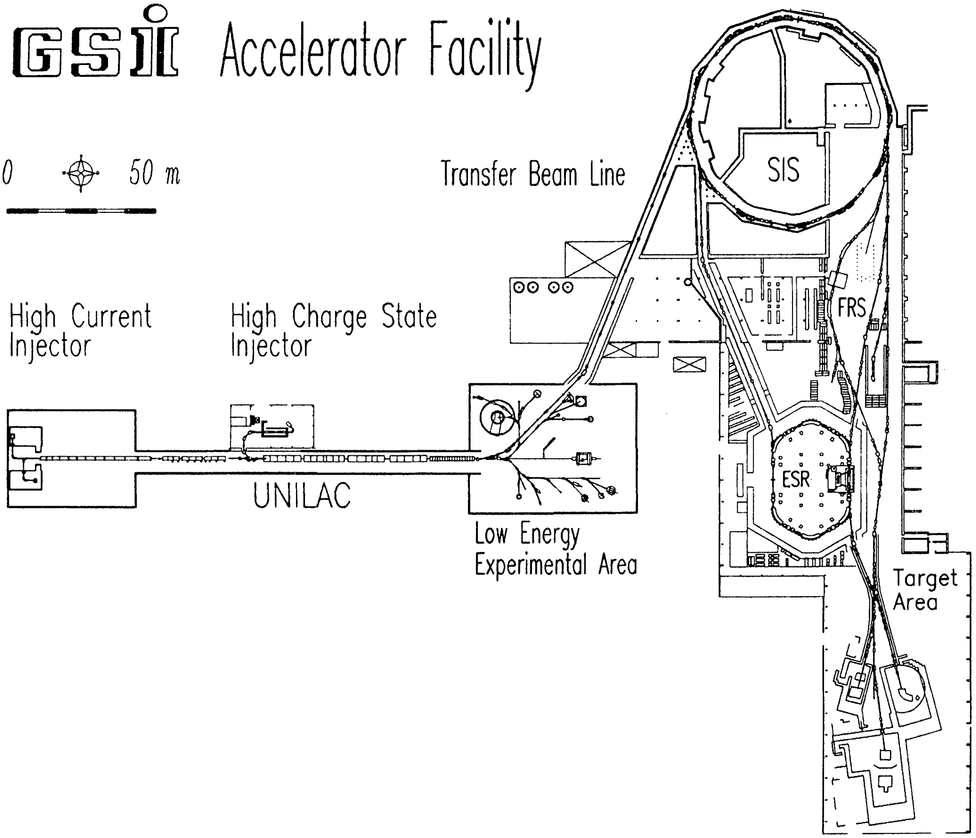

FIGURE 1 The GSI accelerator complex. The high current front end of the Unilac on the left side is scheduled for 1993. Presently the two source terminals are still in that place, one Penning source for low intensity heavy ions, the other will be equipped with a high intensity Ne source. In 1991 the high charge state injector at the middle of the Unilac will replace the old prestripper section for the very heavy ions. The cave between the SIS and the ESR on the far right hand side is dedicated for HIF target experiments, receiving short bursts from the SIS. In this context, high intensity Ne beams will be injected directly from the Unilac into the SIS, or accumulated very heavy ion beams, stacked and cooled in the ESR, can be reinjected into the SIS, compressed and fastly extracted to the high temperature experiment. The fragment separator, conceived to deliver radioactive beams to the ESR, is partly in operation. The left cave in the target area is dedicated for bio-medical research, the two other caves are fully operational for the bulk load of nuclear physics experimences.

intended to increase the number of injected turns and the multiturn efficiency to their ultimate values, because other problems seemed to be more pressing.

As a next step, the rf voltage was switched on and perfect beam bunching was observed immediately. Sometimes the beam was lost after rf capture, indicating that the increased momentum spread moved the working point into an unexpected resonance. As in many other machines, the precalculated and measured Q values did not agree. In the following weeks the optical properties of the ring lattice were empirically adjusted. Then acceleration was tried, ramping up the magnet fields and raising the rf according to digital function generators, reading tabulated values from memory. The control feedback loop for the frequency was not closed. Acceleration to the full magnetic rigidity came immediately. This unexpected success without frequency tracking revealed that the hardware worked with the planned precision. The control loop is now available. When it is used, only the bunch oscillation during the early acceleration cycle can be suppressed, not the so-far unexplained beam loss by a factor of 3 early in the cycle. Another feature is unusual for a synchrotron: the whole parameter set can be varied from pulse to pulse. For instance, different energies can be delivered from cycle to cycle. This again is a proof of the extreme reliability of modern accelerator hardware.

The next step in the commissioning sequence was the demonstration of extraction. Fast extraction, typical for large-scale HIF drivers, worked immediately and perfectly. At the SIS, fast extraction is only requested for beam transfer to the storage ring and for short beam-pulse delivery to the high-temperature target experiment. For all other physics and biology experiments, the slow extraction mode is a necessity. This mode turned out to be unexpectedly difficult. The trimming of the third-integer resonance used required additional sophisticated Q-diagram investigations. The time structure and the efficiency of the beam spill did not meet the specification, a half-second long external beam quite constant throughout the pulse.

Although the commissioning accomplishments during the nine months in '89 may seem unsatisfactory, it should be mentioned that this activity had to fit in with Unilac service for low-energy physics beams of very heavy ions; the low intensities of these beams that are available are useless for SIS machine experiments. Thus, there were only 8 weeks available in which the SIS commissioning crew could request high-intensity Ne or Ar beams from the Unilac.

In February 1990, the SIS started its first year of routine operation. In April the official inauguration of the new accelerator complex terminated the construction phase. The inadequate beam-spill performance took considerable time to be remedied. Current ripple on several quadrupole supplies was the reason for the unfavorable short pulse structure of the external beam. A painstaking realignment of all ring components eliminated the low extraction efficiency and many other problems as well. Ar, Ni, Kr, Xe, Au and U beams were delivered to the fragment separator, the 4π detector, the kaon spectrometer and the biomedical cave. The majority of users were still in the phase of detector testing and were satisfied with moderate intensities. When particle fluxes below 10^{-4} pps were required, the SIS ran stably for days without any beam diagnostic signal. While the Unilac still needs one or two shifts to tune up, the synchrotron is put into operation in less than one hour. This is a virtue of the new control system, which allows for a presetting time of 16 different parameter tables. Only 5 such virtual machines have been used so far. The feature of different energies, intensities[1] extraction modes and beam lines from pulse to pulse has been widely used, allowing for three experiments at the same time. On the other hand, the majority of breakdowns were caused by software and timing problems, which were difficult to locate in the sophisticated controls architecture.

2 THE ESR

The commissioning of the ESR began in May, 1990 and continued with about one week per month. Argon beams were preferred because of the higher intensities. The beam energy was limited to 220 MeV/u because of voltage limitations in the e-cooler section. Beam lifetimes were found to be many hours and the machine experiments required only one or a few SIS pulses every 15 minutes. Q and chromaticity measurements went on rapidly because of the high level of instrumentation, with Schottky and beam transfer-function measurements. Electron cooling worked from the beginning, though the two beams were poorly aligned with respect to each other initially. The relative momentum spread was easily reduced from 10^{-3} to 10^{-5}. When the intensity was increased by cooling-stacking up to the mA range, the predicted ears showed up in the longitudinal Shottky spectra. When the cooling was switched off, momentum broadening occurred from intra beam scattering just as expected. A very small fraction of the beam, which was converted from Ar^{18+} to Ar^{17+} due to electron capture in the cooling section, was collected on a spatially resolving counter and showed a beam spot size of less than one mm, which transforms into a transverse emittance improvement by a factor of 100 achieved by the electron cooling. RF stacking, which was on the experimental program in the last run, was barely successful due to a randomly unstable VCO. By shifting the ion beam energy using the cooling beam energy, the momentum acceptance of the ring was scanned and found to be in agreement with the lattice calculations (2%).

Thus the ESR has proven to be a useful test facility to fill in the answers of the HIF questionnaire concerning storage-ring beam performance, as envisaged nearly 10 years ago[8,9]. The interplay of the SIS and ESR, fast extraction out of the former and kicking injection into the latter ring with the inherent synchronisation of the bunch into bucket transfer (as in the HIF multiple ring scenario) work as designed.

3 INTENSITY SCHEDULE

Presently the SIS accelerates 10^8 Ar ions per cycle. This will soon be improved by about a factor of 5 when injection and trapping losses are cleared up. The Unilac still could deliver a factor of 10 more intensity for Ar beams. But there is a pronounced reluctance at present to authorize such beam intensities with the traditional high repetition rate, until a major upgrading of interlocks and beam inhibit devices is operational. Too many bellows, pick-ups and valves have been destroyed recently. In case of Ne beams, which could be more intense by a factor of 10–100, this situation is still more regrettable. The high-current front end of the Unilac, which could also deliver similarly dangerous intensities for very heavy ions, is vastly delayed. There is a tentative time schedule for it now, with crucial components coming into a prototype phase only in mid-1991. At best, this high-current injector could be operational at the end of 1993.

Of course, there is still the option of receiving high-intensity heavy-ion beams by accumulating and cooling the presently available low-intensity beam in the ESR, reinjecting it into the SIS for further acceleration and bunch compression. However, there is still the uncertainty about cooling partly stripped ions with respect to electron capture, and therefore beam lifetime. The reinjection line will not be available before autumn 1991, and from there on nearly another year will elapse until this sophisticated operation mode is mastered.

For the interim period, the strategy is: In May 1991 the high-charge-state injector will come into operation. It will replace the present Unilac prestripper section and will deliver the same intensities for very heavy ions for the continuing low-energy physics program. It is adequate as a synchrotron injector for low-intensity beams as well. The old prestripper section is then free for light-ion beams with a particular high-intensity source, which is then operated at about one pulse per second as a dedicated injector for the SIS, the poststripper section being used for both beams in a pulse-to-pulse scheme. The low repetition rate of the high-intensity beam relaxes the beam power problem. The future existence of the high charge state injector with its maintenance-free ECR source will bring the freedom and a relaxed time schedule for the alteration of the old prestripper section to a high-current injector for very heavy ions. Thus, the HIF target experiment and machine studies will be done with Ne ions first.

4 FUTURE PLANS AT GSI

At present, a study of a relativistic heavy-ion collider in an underground tunnel is underway. The two 400 T · m superconducting rings can be used, one as a slow cycling accelerator and the other as an accumulator. With the addition of a small Bi^+ linac the Unilas-SIS injector chain could provide a circulating beam of $4 \cdot 10^{14}$ Bi^+ particles, accumulated at 170 MeV/u in the second collider ring. However, due to the 1-min acceleration time in the first ring, the whole filling cycle would take 10 hours. Because of charge-changing processes in a conventional ultrahigh vacuum regime, this overly long stacking time is excluded. In addition, the large rf system for compressing this beam into a short burst useful for target experiments cannot be accommodated in the ring lattice, which is primarily optimized for colliding-beam experiments. Therefore no enthusiasm has developed so far to open the future GSI plans in one way or another for HIF beam experiments.

REFERENCES

1. K. Blasche *et al.*, The SIS heavy ion synchrotron project, in *Proceedings of the 1985 Particle Accelerator Conference.*, Vancouver, IEEE Trans. Nucl. Sci. **NS-32**, (5) 2657–2661.
2. D. Böhne *et al.*, Status report on the SIS/ESR project, in *Proceedings of the 13th International Conference on High Energy Accelerators*, edited by A. N. Skrinsky (Novosibirsk, 1986), 204–208.
3. D. Böhne, Status report on the SIS/ESR project, in *Proceedings of the 1988 International Symposium on Heavy Ion Fusion, Nucl. Instrum. Meth.* **A278** 19–21 (1989).
4. K. Blasche *et al.*, Status report on the GSI synchrotron facility and first beam results in Proc. of the IEEE 1989 Particle Accelerator Conference (Chicago, USA) pp. 27–28.
5. K. Blasche *et al.*, Status of the SIS/ESR facility at GSI Darmstadt, in Proceedings of the 14th International Conference on High Energy Accelerators (Tokyo, Japan, 1989), in *Part. Accel* **32**, 83–90 (1990).

6. D. Böhne *et al.*, The performance of the SIS and developments at GSI, in *Proceedings of the European Particle Accelerator Conference*, (Nice, France, 1990).
7. B. Francszak, Report on the first year of SIS operation, in *Proceedings of the European Particle Accelerator Conference* (Nice, France, 1990).
8. D. Böhne, Plans for HIF accelerator studies at GSI, in *Proceedings of the 1984 INS International Symposium on Heavy Ion Accelerators and their Application to Inertial Fusion*, edited by Institute for Nuclear Study (Tokyo, Japan, 1984).
9. I. Hofmann, in Proceedings of the International Symposium on Heavy-Ion Fusion (Washington, DC, USA, 1986), AIP Conference Proceedings **152** 74 (1986).