THE COOLER SYNCHROTRON COSY FACILITY

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Abstract

The cooler synchrotron COSY Jülich is now running continuously with its experimental programs. The machine covers the whole momentum range from 600 MeV/c up to 3.3 GeV/c and delivers up to $3 \cdot 10^{10}$ protons. Electron cooling is applied up to 645 MeV/c. Stochastic cooling will enhance the beam quality in the range from 1.5 to 3.3 GeV/c. Substantial progress in developing the machine was made to increase the intensity and quality of the beam for internal as well as external experiments. In addition, a polarized proton beam could be successfully accelerated up to 2 GeV/c.

1 THE COSY FACILITY

The COSY accelerator complex [1] comprises several ion sources, the refurbished isochronous cyclotron, a 100 m long injection beam line, the COSY-ring and extraction beam lines to the external experiments. The ion sources are a H_2^+, H^-, D^- and a H^- polarized ion source. The injector cyclotron (JULIC) is now running continuously with H^- beams with a momentum of 296 MeV/c. Currents of approximately 10 μA are fed into the accelerator ring via stripping injection. This injection technique has proven to be very reliable when the H_2^+ ion source was used. The well-tried injection scheme is also applied for polarized H^- beams.

The ring has a circumference of 183.47 m and stands out for its great flexibility in tuning the lattice optics to the needs of the internal as well as external experiments. Sixteen quadrupoles in each 40 m long straight section of COSY grouped as four triplets allow the ion optics to be tuned such that the sections act as telescopes with a 1:1 imaging giving either a π or a 2π phase advance. At the same time optimized beam conditions for the two internal experimental stations located in the target telescope can be adjusted. The other one (cooler telescope) contains the accelerating rf-cavity, the electron cooler, scrapers, Schottky pick-ups, and current monitors.

The arc sections have a length of 52 meters each. They are composed of three identical elements that have in themselves a mirror symmetry. A half-cell has a QF-bend-QD-bend structure with the option to interchange focusing-defocusing for added flexibility in adjusting the tune. This structure leads to a six fold symmetry for the total magnetic lattice of the ring. Stripping target and bumper magnets for injection and electrostatic and magnetic septum for extraction are located in one arc-section. Besides the diagnostic kickers and the elements for the ultra slow extraction the other arc-section contains the internal target station where the COSY-11 experiment has been installed. At the connecting points where the arc sections meet the target telescope the stochastic cooling pick-ups are built in. The corresponding kickers are located in the cooler telescope section.

In total 18 sextupoles are installed. They can be grouped into 11 families. Three of them are placed in the arcs and eight are in the telescopes.

At present three internal experiments are in operation, the COSY-11, COSY-13 and the EDDA-experiment. The latter two are located in the target telescope.

Extraction beam lines guide the beam to three external experiments. One site being the large magnetic spectrometer BIG KARL, the other the Time of Flight facility (TOF), and the third (NEM) is foreseen for experiments with low proton momenta (800 MeV/c). A fourth beam line is under discussion for experiments requiring longitudinal polarization.

A typical machine cycle lasts between 5 seconds and one hour. At injection the ring is filled up with $2 \cdot 10^{11}$ protons corresponding to the space charge limit. At maximum momentum, 3.5 GeV/c, up to $3 \cdot 10^{10}$ protons have been measured.

2 INTERNAL EXPERIMENTS

There is a very intimate relation between internal experiments and the accelerator as they affect each other in a direct way. EDDA [2] is an internal experiment at TP2 that has been set up to measure excitation functions with high precision. The basic design is a thin horizontally oriented fiber target that intercepts the beam combined with a cylindrical detector system surrounding the thin walled beam pipe. Due to its construction the EDDA experiment is not only a tool for medium energy physics but also an excellent probe for investigating and verifying beam properties of COSY with high precision [3]. This experiment has special requirements on the beam to achieve optimal measurement conditions. This concerns the lateral stability and the orientation of the phase space ellipses. It is the latter point where the flexibility of the target telescopes proved invaluable [3]. Moreover, it was proven that the lattice allows to shift transition energy upwards during acceleration so that no transition jump is needed [3]. This property allows to take excitation data even when ramping up the machine to flat top energy.

Different conditions have to be satisfied for the COSY-11 and COSY-13 experiments. Both take data in flat top of the machine [2].

To enhance the machine flexibility the control system has been updated to allow to run COSY with supercycles. At present each supercycle consists of three different machine settings which can be combined independently as shown in figure 1. The set up has been made for the COSY-13 experiment and allows a quick comparison of measurements close to the threshold of the reaction.

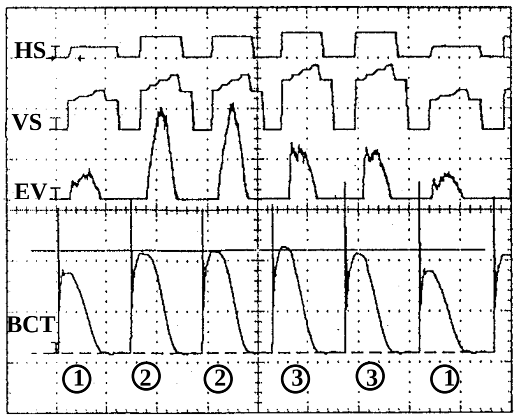

Figure 1: Beam current transformer signals (BCT) for a supercycle in COSY. Each cycle, labelled by one, two and three corresponds to momenta 1.7, 2.25 and 2.68 GeV/c, respectively. The event rate (EV) has its maximum value within cycle two. The upper two traces are the currents of the horizontal (HS) and vertical (VS) steerer magnets which optimize the event rate.

The machine starts with cycle one delivering protons with momentum 1.7 GeV/c at flat top. In the next two cycles, labelled with two, a momentum of 2.25 GeV/c is available. They are followed by two cycles, labelled by three, at 2.68 GeV/c flat top momentum finishing the supercycle. Besides the beam current transformer signal (BCT) the figure shows the event rate (EV) as well as the currents of the horizontal (HS) and vertical steerer magnets (VS) to optimize the event rate.

Since the installation of electron cooling in 1993 [4] it has been shown the an electron cooled beam could be successfully accelerated to flat top energy. Recently several experiments with the electron cooler have been carried out to increase the injection efficiency by stacking. Figure 2 shows the beam current as a function of time during stacking.

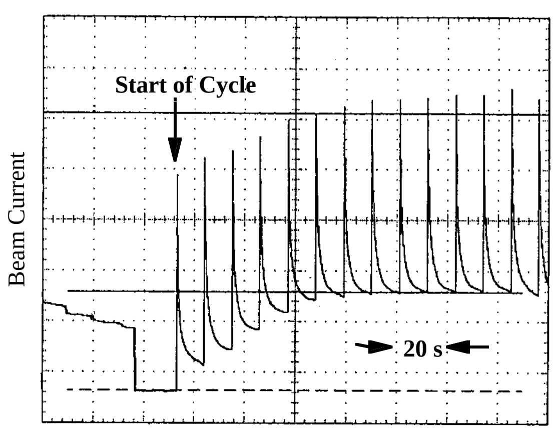

Figure 2: Increasing beam current during stacking

Each spike corresponds to a new injection into COSY. During injection the beam is electron cooled decreasing the transverse as well as the longitudinal emittance. By properly adjustment of the dipole field the beam is slightly slowed down to move on an inner orbit. This prevents that the already circulating beam hits the stripping target when the next injection process begins. As proposed by [5] it can be seen that the number of stacked protons increases until an equilibrium limit of the cooled beam is reached after nearly 50 s. Each injection is accompanied by a sudden beam loss which results from the fast cooling of the injected beam to the space charge limit. This limit increases during stacking so that the number of stored particles increases. Since the space charge limit is proportional to the emittance [4] the number of stored particles can be enlarged if the cooling force is properly counterbalanced by transverse heating. Further experiments will be carried out to study the stacking mechanism in detail.

During 1996 polarized protons were injected and successfully accelerated to 2 GeV/c [1]. The polarization was measured continuously during acceleration with the internal experiment EDDA. Further progress is expected if the already installed tune jump system to overcome depolarizing resonances [1] will be used.

3 EXTERNAL EXPERIMENTS

Resonant extraction and stochastic extraction [6] are applied to serve external experiments. Beams with momenta up to 2.75 GeV/c have been delivered to three experimental collaborations.

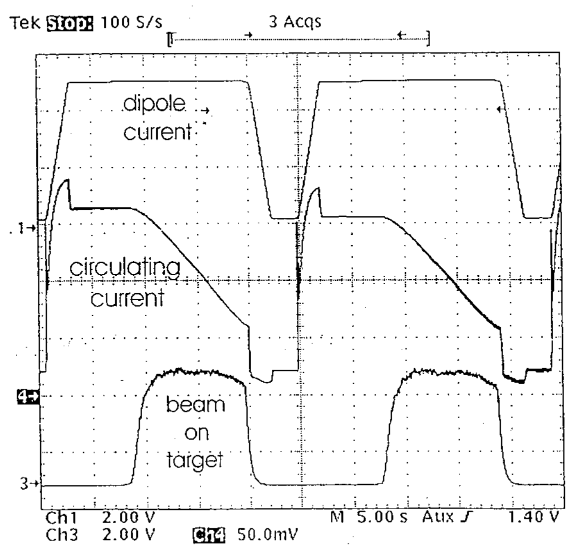

Figure 3: Two cycles show the extracted beam (beam on target) together with dipole current and the circulating beam. The spill length is approximately 14 s.

Conventional extraction at COSY is made by creating a third order resonant condition by sextupole excitation and sweeping the horizontal tune through the resonance by quadrupole ramping. At present typical spill lengths of the order of 10 s are requested with $2 \cdot 10^{10}$ protons per spill. The extraction efficiency of nearly 85% was reached. Further progress was made in stochastic extraction (figure 3). First experiments were carried out at 2.75 GeV/c. Instead of moving the horizontal tune by quadrupoles the optic was kept fixed and a rectangular shaped noise was swept over the beam distribution. Because of the finite horizontal chromaticity the protons will then diffuse towards the resonance where they are extracted. A precalculated sweep frequency program was applied to prepare a rather flat spill without prior beam shaping [6].

4 STOCHASTIC COOLING

The COSY stochastic cooling system [1] operates in the frequency range from 1 GHz to 3 GHz divided into two bands (1 - 1.8) GHz and (1.8 - 3) GHz. At present the horizontal pickup (4 m length) is installed in the ring consisting of two tanks each 2 m long. Also, one of the two vertical pickup tanks is now placed in the ring. The other one completing the system will be installed in May, 1997. The pickups are cryogenically cooled down to nearly 60 K. Uncooled preamplifiers with a noise temperature below 50 K are mounted outside the vacuum tanks. The rest gas pressure can be kept on 10^{-10} hPa. The position of the electrode bars are independently adjustable and thus allow for closed orbit suppression. Programmable delays permit an energy adjustment from 1.5 GeV/c up to the maximum momentum 3.3 GeV/c. Two kicker tanks of length 2 m are installed for the horizontal and vertical plane, respectively. Similar to the pickups the electrode bars are independently movable. Measurements of transverse and longitudinal Schottky spectra of an unbunched beam with $3 \cdot 10^{10}$ protons have been carried out with good signal-to-noise ratio [1].

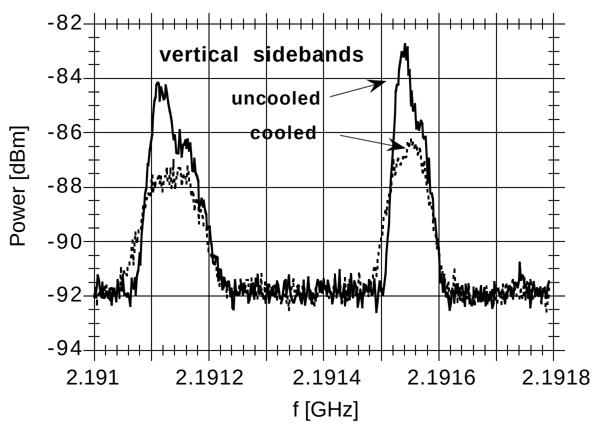

Figure 4: First stochastic cooling of the vertical beam emittance. The emittance is cooled by a factor of two.

Hardware transfer function measurements (HTF), i.e. sending an excitation around 0 dBm to the kicker and measuring the response from the pickup without beam, have proved that the mounted ferrite material is sufficient to damp propagating modes in the vacuum chamber [7]. In recent experiments vertical beam transfer function measurements (BTF) have been carried out to gain experience in adjusting gain and phase of the vertical cooling system in band I. In addition open/closed loop measurements were done to optimize the system gain. A first result is shown in figure 4 indicating vertical stochastic cooling of a debunched beam with $1.5 \cdot 10^{10}$ protons at pc = 3.39 GeV. The figure shows a lower and upper sideband in the frequency range of band II near the 1392th revolution harmonic of the beam. The vertical emittance before cooling (thick curve) is reduced by approximately a factor of two within 5 minutes (dotted curve). The long cooling time reflects the large number of stored protons but is also partly due to a yet not optimized lattice resulting in a large mixing factor in this case. Future measurements will include the EDDA experiment which is an excellent tool to probe beam profiles.

5 SUMMARY AND OUTLOOK

In 1996 in total 6520 hours were scheduled. From this the machine was in operation for 6174 hours. In total 4248 hours were available for the user of COSY. Proton numbers up to $3 \cdot 10^{10}$ are accelerated to the design momentum of 3.3 GeV/c. A polarized proton beam could be successfully accelerated. To ensure polarization during acceleration a tune jump system has been installed at the beginning of 1997. Measurements of the fast quadrupoles and the corresponding power supply have shown that their design specifications are very well fulfilled. Machine runs with polarized protons using the jump system will be carried out. In addition, improvements of the stochastic extraction as well as increasing the beam intensity are given high priority to further exploit the machine's potential for medium energy physics. In first investigations of the stochastic cooling system a reduction of the vertical emittance was observed. The work on transverse and longitudinal (filter method) stochastic cooling is still continuing.

Considerable work is done for a new device for experiments at internal targets, the 0^0 facility ANKE [2], to study nuclear medium effects. The realization of the facility, for which three additional large dipole magnets will be installed in the COSY ring, made progress in the completion of the concept studies and in construction. The 0^0 facility will be located between two triplets of the cooler telescope.

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