THE PERFORMANCE OF COSY

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Abstract

At the cooler synchrotron COSY the stochastic cooling system for both transverse and longitudinal cooling came into operation and was successfully applied to an internal target experiment. Further developments to accelerate polarized protons to the maximum momentum 3.3 GeV/c of COSY were carried out. Stacking with the electron cooler was applied to increase the injected proton intensity. In the beginning of 1998 successful experiments with the new internal ANKE spectrometer were done. The stochastic extraction is now established with spill lengths in the order of several minutes.

1 INTRODUCTION

The cooler synchrotron COSY Jülich [1, 2] delivers up to $3 \cdot 10^{10}$ protons in the momentum range from 600 MeV/c to 3.3 GeV/c. The machine is equipped with an electron cooler operating up to 645 MeV/c. Stochastic cooling [3] enhances the beam quality in the range from 1.5 to 3.3 GeV/c. The stochastic extraction [4] has been established and serves the external users at different momenta with the desired spill lengths in the order of minutes. Polarized protons are available up to 3.3 GeV/c. A special tune jump system has been incorporated to overcome depolarizing resonances [5].

At present four internal experiments are in operation. The COSY-11 [6] experiment uses one arc dipole as spectrometer. The COSY-13 [7] and the EDDA-experiment [8] are located in the target telescope whereas the ANKE spectrometer [9] is installed in the cooler telescope section.

The extracted beam is fed to three external experiment devices, the large magnetic spectrometer BIG KARL, the Time of Flight facility (TOF) and the third (NEMP) is foreseen for experiments with low proton momenta (800 MeV/c).

A 'supercycle' was implemented in the control software for the machine setup and for internal experiments which allows to run the machine automatically with three different machine settings. This software extension was extremely helpful for the internal experiments COSY 11 and COSY 13 which carry out measurements near the threshold of nuclear reactions. Three different machine settings allow to take data below, close at and far above the threshold in one supercycle.

The scheduled beam time for COSY in the year 1997 has amounted 7080 hours. With an up-time of 6635 hours the accelerator complex has proven an extreme good reliability of nearly 94%.

2 INTERNAL EXPERIMENTS

In general COSY serves two types of internal experiments. One type, the EDDA experiment, takes data during ramping up the machine to flat top energy. This experiment is set up to measure excitation functions with high precision. Optimal conditions concerning the lateral stability and the orientation of the phase space ellipses are accomplished by the flexibility of the target telescopes and the possibility to shift transition energy upwards during acceleration so that no transition jump is needed. The latter property permits to take excitation data even when ramping up the machine to flat top energy. The second type, as the COSY11, COSY13 and the ANKE experiment, require different optical conditions at a fixed flat top energy.

2.1 Stochastic Cooling

Longitudinal stochastic cooling by the filter method and transverse cooling [10] were successfully applied during a COSY-11 experiment run at momentum 2.6 GeV/c with about $1 \cdot 10^{10}$ stored protons. This experiment located with a cluster target in one of the arcs of COSY demands besides a high luminosity a small diameter in the reaction zone in order to reconstruct the mass spectrum with high resolution. Without cooling a special optic of the COSY ring was necessary to create a small beam spot size at the target location.

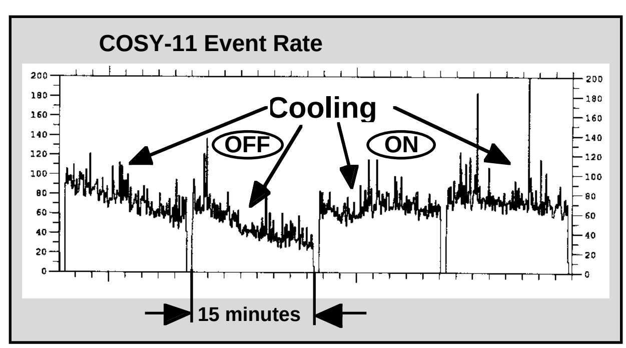

Figure 1: The COSY-11 event rate is constant over 15 minutes if the cooling system is on.

Furthermore, during the experiment the optical conditions had to be continuously adjusted in order to prevent the beam spot from moving away from the target due to energy loss. This becomes especially important during long time runs. Using stochastic cooling the optic is adjusted to optimum cooling conditions. The great advantage of the cooling system is evident from figure 1.

It shows the event rate of the COSY-11 experiment for four cycles each of 15 minutes length. Stochastic cooling increases the cycle length and thereby the duty factor significantly. Moreover, cooling of the horizontal as well as the vertical beam size simultaneously keeps a high beam quality during the whole time of the experiment. COSY had only to be refilled for a next spill due to losses coming from reactions between the target and the proton beam. Cycle lengths of more than one hour are now possible [3].

2.2 Polarized Protons

In a strong focusing synchrotron imperfection and intrinsic resonances cause depolarization during acceleration. In the energy range of COSY five imperfection resonances are crossed. The number of intrinsic resonances depends on the superperiodicity of the lattice given by the number of identical periods in the accelerator. The betatron phase advance in the two straight sections of COSY is matched to 2π so that only the arcs contribute to the strength of intrinsic resonances.

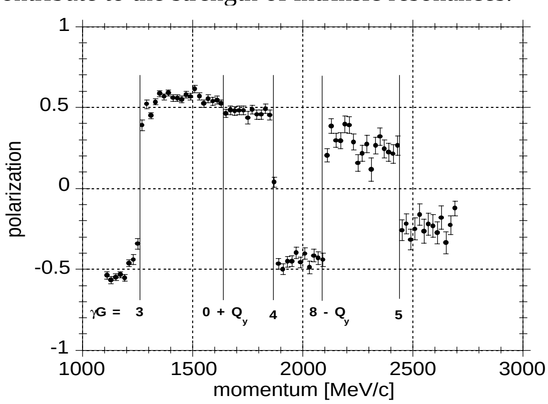

Figure 2: Polarization recorded during acceleration with the EDDA detector.

Figure 2 shows the successful acceleration of a polarized beam to 2.7 GeV/c. Correction dipoles or the solenoids of the electron cooler acting as partial snake have been successfully used to conserve the polarization at the imperfection resonances by exciting total spin flips (γG = 2,3,4,5). The magnetic structure allows to adjust superperiodicity P = 6. Then only one resonance ($\gamma G = 8 - Q_y$) is excited which flips the spin with polarization losses. To conserve polarization at this resonance a tune jumping system was developed. To accelerate the beam to maximum energy the transition energy is shifted upwards with the horizontally foccussing quadrupoles in the arcs which leads to a reduced superperiodicity. Additional intrinsic resonances are excited (e.g. $\gamma G = 0 + Q_y$) which can be suppressed by tuning the vertically focussing quadrupoles in the arcs.

2.3 Stacking

To increase the intensity of the polarized proton beam in COSY tests with the electron cooler and a repetitive injection were carried out. The orbit bump in COSY for the stripping injection was deformed so that the incoming beam is not injected on the closed orbit. The resulting betatron oscillations as well as the emittance and momentum spread of the injected beam is cooled by the electron cooler. After five seconds of cooling the next stack is injected and cooled. Due to the deformed orbit bump the injected and cooled stacks do not hit the stripping target and survive the next bumper action. In figure 3 the repetitive injection and cooling for an unpolarized proton beam is shown. The intensity of the beam was reduced in front of the cyclotron to an intensity which is comparable to the polarized beam intensity. The result was an accumulated beam of $4 \cdot 10^9$ protons after about 180 seconds. The single injection leads to an intensity of $1 \cdot 10^9$ protons.

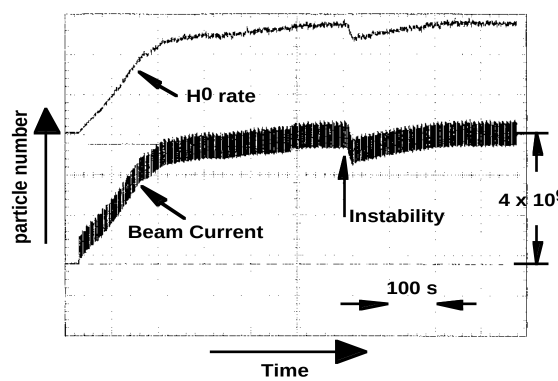

Figure 3: Stacking of protons with electron cooling. The beam is injected every 5 seconds. The stored intensity increases until an equilibrium is reached after about 180 seconds. As marked by the arrow an instability due to space charge prevents a further increase in intensity.

2.4 Commissioning of ANKE

In May 98 the spectrometer ANKE has been implemented into the COSY ring and is presently being commissioned. It is a universal facility for the studies of ejectiles which are emitted in forward direction in collisions of the proton beam with nuclear targets (strip targets, gas, pellet or atomic beam target). The separation of the ejectiles from the circulating beam and the identification of their momenta and emission angles is achieved with the central large aperture dipole magnet (D2, 60 tons) of 20 cm gap width. The two other dipole magnets (D1 and D3, 15 tons each) serve for guiding the circulating beam but also for studying reaction products which are emitted at 180 degrees with respect to the beam. The physics program at ANKE will concentrate on studies of the influence of the nuclear medium on elementary processes. In a first beam time the accelerating procedure of COSY has been adapted to the new situation with ANKE, i.e. altered orbit length, multipole components of the separator magnets during ramping. A demanding detector setup to identify K^+ mesons has been successfully tested. Figure 4 shows the test installation of the 6 m long ANKE facility.

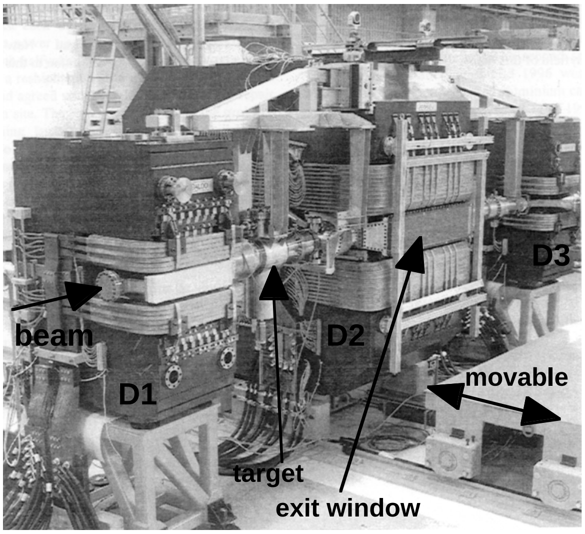

Figure 4: View of the ANKE facility. The reaction products penetrate the large exit window in the gap of D2 and are analyzed by detectors on the right hand side of D2. The bending angle can be varied between zero and 10.6 degrees.

3 EXTERNAL EXPERIMENTS

At COSY stochastic extraction is now used in the wide momentum range from 800 MeV/c to 3.3 GeV/c. A digital noise generator developed at COSY is used for stochastic extraction and beam shaping. An extraction efficiency of 80% to 30% is realized. The requested spill duration is up to several minutes. Figure 5 gives an example for the stochastic extraction at 2.6 GeV/c.

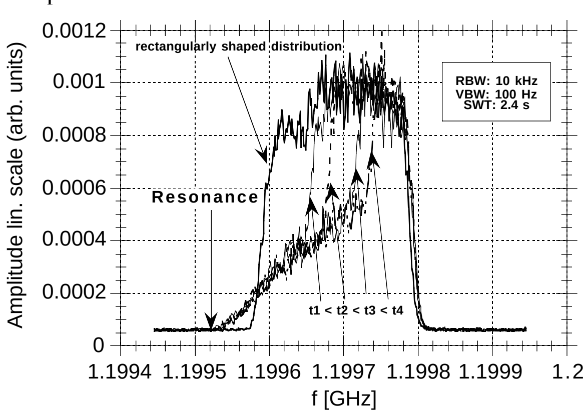

Figure 5: Stochastic extraction at 2.6 GeV/c. The noise is swept from the left over the shaped distribution.

The figure shows longitudinal Schottky spectra in a linear scale taken with the pickup of the stochastic cooling system at the 780th revolution harmonic. Prior to extraction the beam was shaped for about 500 ms by noise to a rectangular form. During extraction (30 s) band limited rectangular noise is swept from the left over the shaped distribution and consecutive spectra are taken at times t1 to t4. As expected [11] the density decreases linearly in the region of the resonance. The sharp edge in the distribution corresponds to the upper edge of the swept noise at the given instant t1 to t4. The shape of distribution of particles which are not yet extracted is not altered. The pattern shows the typical diffusion into the resonance which appears to the left of the distribution due to the positive horizontal chromaticity and the negative frequency slip factor.

4 SUMMARY AND OUTLOOK

With the help of stochastic cooling the experimental conditions could be significantly increased. However finite dispersion and signal attenuation in the cables constituting the notch filter deteriorate the cooling time. First promizing results using optical fiber transmission lines will be followed up. The great advantage is based also on the fact that the cooling system can then be incorporated in supercycles. Stochastic extraction is now possible in a wide momentum range. Further studies will be carried out in order to increase the extraction efficiency especially at larger momenta of the machine where unknown sextupole components of the dipoles complicate the determination of the optimum sextupole setting. Also, extraction studies using an additional electrostatic septum will be continued. The beam quality and intensity of polarized protons including stacking will be a major topic in the near future as well as experiments with the ANKE facility.

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