Status of COSY

R. Maier, U. Bechstedt, J. Dietrich, U. Hacker, S. Martin, D. Prasuhn, P. v. Rossen, H. Stockhorst, R. Tölle

Institut für Kernphysik, Forschungszentrum Jülich GmbH
Postfach 1913, D-52425 Germany

Abstract

COSY Jülich is a cooler synchrotron and storage ring with a proton momentum range from 270 to 3300 MeV/c. It has been conceived to deliver high precision beams for medium energy physics. To accomplish this goal two cooling systems are used. An electron-cooling system that reaches up to a momentum of 645 MeV/c and a stochastic cooling system that covers the upper momentum range from 1500 to 3300 MeV/c. Since its inauguration in April 1993 substantial progress in developing beams for the experiments has been achieved and the physics program has started with first measurements. Proton beams in a wide energy range have been delivered to internal as well as external experiments. Important design features of the machine and results of the commissioning process are presented.

1. Description of the Facility

1.1 General Layout

The COSY accelerator complex comprises several ion sources, the refurbished isochronous cyclotron, a new 100 m long injection beam line, the COSY-ring with a circumference of 184 m, and extraction beam lines to the external experiments [1]. The ion sources are a H_2^+, H^-, and a H^- polarized ion source.

At present the injector cyclotron runs continuously with H_2^+ beams with an energy of 76 MeV. Currents around 10 μA are readily obtained and fed into the accelerator ring via stripping injection. This injection technique has proven to be very reliable. It was, therefore, decided to use the same injection scheme for polarized H^- beams as well. Preparations have been made already for the necessary changes in the injection region of the ring.

At present 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 is a medical area which is intended for pre-therapeutical studies and radiation therapy [2]. A fourth beam line is foreseen for experiments needing longitudinal polarization. An overview of the facility is given in the floor plan in fig. 1.

The COSY-ring has a race track design with 40 m long straight sections [3]. Sixteen quadrupoles in each of these sections 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 internal experimental stations TP1 and TP2 can be adjusted. Meanwhile, the EDDA-experiment went into operation at target point TP2 [4]. While one straight section has been designated to serve the experiments the other one contains accelerator specific components like the accelerating rf-cavity, the electron cooler, scrapers, Schottky pick-ups, and current monitors.

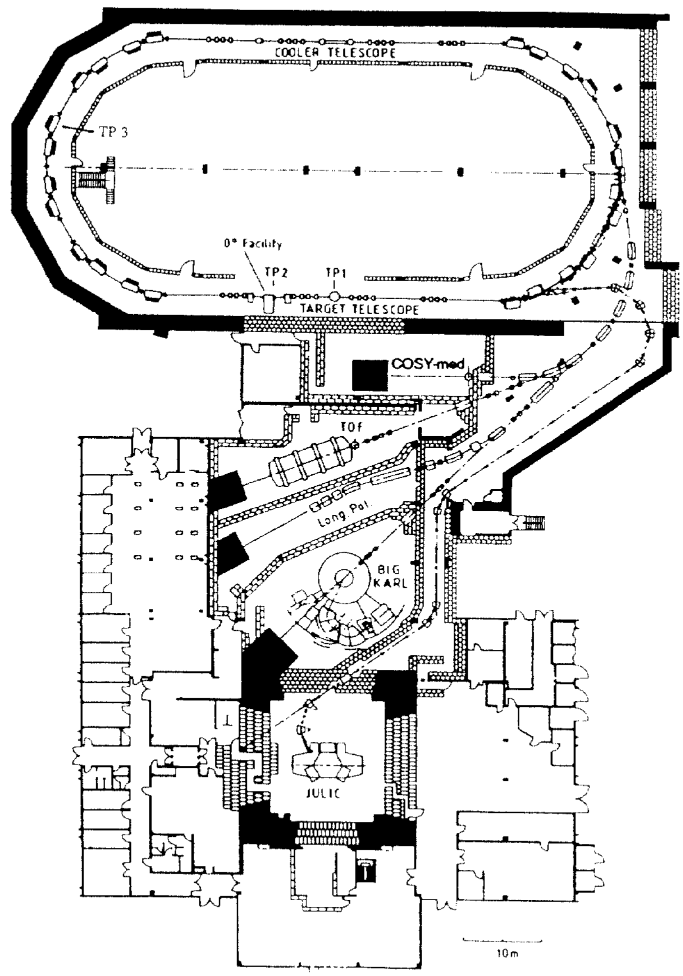

Fig. 1 Floor plan of the COSY accelerator facility

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 kicker and the elements for the ultra slow extraction the other arc section contains the internal target station TP3 where the COSY-11 experiment is being set up [5]. This target station uses one of the ring's bending magnets to separate ejectiles around zero degree from the circulating beam and is thus well suited to study physics close to particle thresholds. At the connecting points where the arc sections meet the straight sections the stochastic cooling pick-ups and corresponding kickers will be installed.

1.1 Control System

The control system uses autonomously operating units for each accelerator component. They are organized in a hierarchical order with a distributed real time operating system [6]. Data communication runs over a local area network using TCP/IP and a field bus. The field controllers use a modular real time kernel RT/OS developed in Jülich while the host systems operate under UNIX. The computer hardware consists of RISC mini-computers from Hewlett Packard and VME-computers. G64 Crates and modules are used as an expansion of the VME-bus for tasks where fast response is not imperative. The graphical man-machine interface uses object oriented programming techniques on top of an X-window shell. System behavior and reliability of the system have been very good with only negligible downtime which is remarkable for a complex system with new design concept. The object oriented approach has fully paid off because especially in the initial phase changes were frequent due to new hardware and/or new requests from the operators. Changes and modifications could be done in a fast and efficient way taking advantage of the already running software.

1.2 Beam Diagnostics

Nearly all the foreseen diagnostic tools are now available for monitoring the beam during injection, acceleration and extraction (see separate contribution to this conference). The tools were developed and perfected according to the needs of the operators.

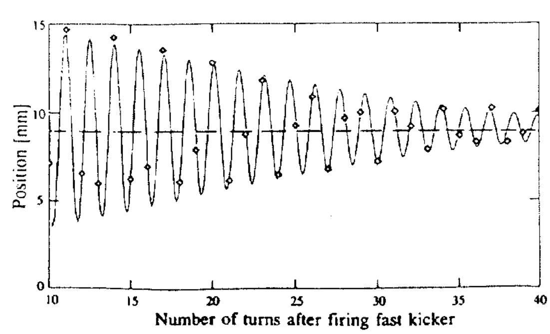

Fig. 2 Horizontal betatron oscillation initiated with fast kicker

As an example fig. 2 shows the betatron oscillation after firing the fast diagnostic kicker element. By repeated measurements of the amplitude from turn to turn with one beam position monitor the uncorrected closed orbit value and the fractional betatron tune can be deduced. The uncorrected orbit is given by the dashed line. The open diamonds are the measured position values. The solid line is the fitted damped betatron oscillation ($q_x \approx 0{,}66$).

1.4 Ion Sources

At present the H_2^+ source is being used with stripping injection into COSY [7]. It has demonstrated reliable operation together with the injecting cyclotron. As there is a strong demand for polarized beams a polarized source has been developed. The stripping injection will be kept for its high efficiency and ease in operation. Therefore, the decision fell towards a H^- polarized source after successful tests had been performed accelerating H^- with the cyclotron. Meanwhile a separate H^- unpolarized ion source has been installed and beam currents up to 10 μA have been extracted from the cyclotron. In future operation when the stripping area has been modified only H^- will be used for unpolarized and polarized beams. This will allow for fast switching between polarized and unpolarized beams without changes to the cyclotron, the injection beam line, or the stripping region of COSY. The polarized ion source has been mounted at the injection beam line to the cyclotron and went through its first testing stage [8]. Performance thus far obtained resulted in beam currents of about 1 μA H^- in the injection beam line to the cyclotron with polarization values estimated to be larger than 75%.

1.5 Cyclotron Injector

For higher system performance and reliability major components of the JULIC cyclotron had been replaced like the RF-Generator and the trim coils. Since its recommissioning the cyclotron had been operating with very high reliability as an injector [9].

1.6 Stochastic cooling

The stochastic cooling is using a two band RF-system (1 -1.8 GHz; 1.8 - 3 GHz). The gap width of the ultra cold pickup electrodes as well as of the kicker electrodes can be adjusted according to the beam size to get maximum sensitivity [7]. All active components of the RF signal path are available meanwhile. A programmable delay is used that will allow to cool over an energy range from 0.8 to 2.5 GeV. Prototypes of critical components inside the cooling tank have already been tested and optimized. Detailed information concerning this cooling component is given in a dedicated article at this conference.

2. Commissioning of the Accelerator

Putting a complex accelerator into service is always a challenging task. This holds especially for COSY with its unique ion optical design. The high flexibility inherent in the layout using telescopic straight sections has to be paid with a high complexity that puts enormous demands on the control system and the operators. Especially in the start up phase the confrontation with the vast parameter space that had to be searched magnified the efforts needed to understand and handle the system. For example to raise the beams's energy fifteen principal magnetic ramps and the rf-cavity's frequency and amplitude have to be matched with minute tolerances.

Although all magnetic components had been precisely measured at a test site, it was apparent from the beginning that the tight mounting conditions inside the ring would change in some way their magnetic properties. This uncertainty, in connection with the large number of elements involved augmented the problems.

Table 1 Milestones during commissioning

- Jul 8th 1993 p at TOF and med. areas
- Jul 9th 1993 270 MeV/c p in the focal plane of BIG KARL
- Aug. 24th 1993 Events from EDDA at 1.2 GeV/c
- Sep. 1st 1993 acceleration to 1.4 GeV/c, $3*10^{10}$ protons
- Sep. 9th 1993 Hydrogen data of cooled protons
- Nov. 5th 1993 res. extraction at 270 MeV/c
- Nov. 24th 1993 res. extraction at 660 MeV/c
- Dec. 13th 1993 res. extraction at 1.4 GeV/c

Despite of these handicaps the commissioning crew succeeded in steadily improving the quality of the beam. Table 1 lists some relevant milestones that were passed during the commissioning procedure.

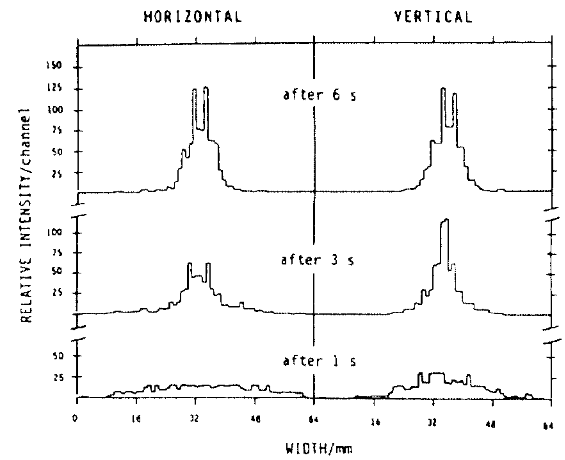

Fig. 3 Horizontal and vertical profiles of H° 25 m behind the electron cooler

3. Cooling the Beam with Electrons

In Feburary 1993 the electron cooler was moved from its test site into the ring [11]. For the first time cooled protons circulated on May 25th 1993 in the COSY-ring [12]. The voltage of the e-cooler was set at 20660 V corresponding to an injection energy of about 38 MeV. The electron current was 0.25 A and the ring contained about 10^9 protons with the rf running at the corresponding frequency and an amplitude of 500 V. The shrinking of the longitudinal phase space was clearly seen in the sum signal of the beam position monitors (BPM) where the width was reduced by a factor of four after ca. 3 s. In a second test run the Schottky noise of the coasting beam was picked up and using a spectrum analyzer with a FFT one could deduce the momentum spread of the beam. It shrunk through electron cooling by a factor of ten from 10^{-3} to 10^{-4} $\Delta p/p$. In a run in September we had in addition the neutral H^0s as a diagnostic tool. H^0 atoms are formed in small quantity inside the electron cooler and fly forward undisturbed by magnetic fields. These particles are detected with wire chambers 25 m downstream of the e-cooler behind the first ring dipole. This tool made for the first time also the transverse cooling process in COSY visible and allowed to study the dynamic behavior. The distributions obtained as a function of time can be seen in fig. 3. A detailed description of the operational characteristics of the e-cooler is given in a separate contribution to this conference.

4. Start up of Internal Experiments

There is a very intimate relation between internal experiments and the accelerator as they affect each other in a direct way. As mentioned before EDDA is an internal experiment at TP2 that has been set up to measure excitation functions with high precision. Minute anomalies found could give new insight into hadron-hadron interaction. 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. The detector system consists of several scintillator layers with high granularity to extract position and angle of the emerging reaction products. The beam on target is besides others monitored via secondary electron emission. A low noise signal is obtained from the secondary electron monitor electronics (SEM). 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.

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. Fig. 4 shows relevant parameters of an early run. Four parameters versus time are combined in this picture. One horizontal division corresponds to 200 ms. The vertical scale shows the parameters under measurement converted to a voltage with an arbitrary scaling and offset. Trace 2 gives the vertical position of the fiber target. It rests underneath the beam and is moved into the beam at a fixed time. Trace 1 shows the secondary electron current which steeply rises the moment the fiber dives into the beam. The current then gradually fades away proportional to the diminishing beam as particles get scattered outside the ring's acceptance. The circulating particles are monitored with a beam current transformer (BCT) as shown in the lowest curve. This is an immediate signal for the number of particles circulating in the ring. Its decline after the fiber target is moved in coincides with the fading seen in the SEM signal. The curve labeled momentum is derived from the dipole current. As depicted the target was moved into the beam shortly after the flat top of the beam momentum had been reached with 1.4 GeV/c. A beam life time of 160 ms can be deduced from the curves. Although this value was

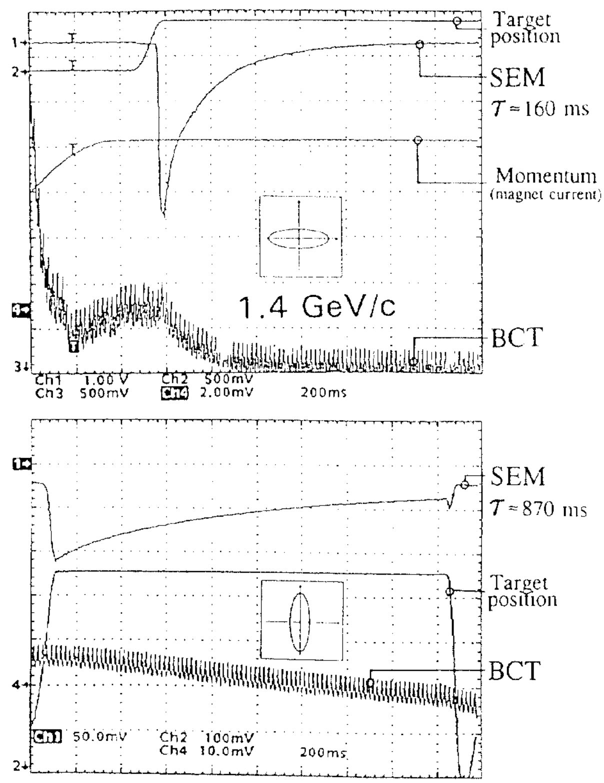

Fig. 4 Beam current on the internal target measured with SEM

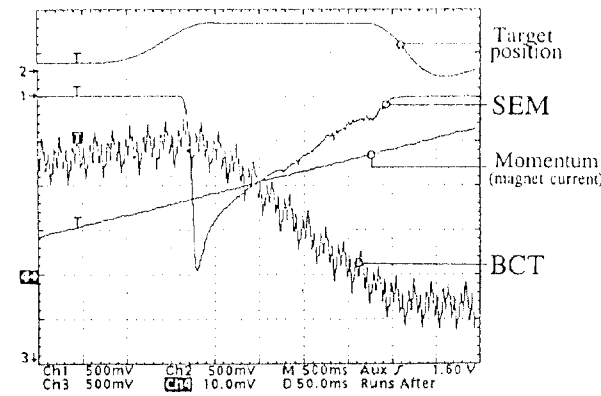

Fig. 5 Beam on the internal fiber target during acceleration

fine for the first data taking, the rush of data was hard to handle by the computers. Therefore, the experimenters liked to see a much longer life time.

The key to this goal is found in the small ellipse found in this picture. This ellipse shows schematically a beam cross section at the target position. The large horizontal extent was not optimal for the horizontally stretched 5 μm carbon fiber. By changing the settings of the straight section the ellipse was rotated by 90 degree shown in the picture underneath yielding a significantly better behavior. The time scales are identical. Keep in mind that this change was virtually transparent to the rest of the ring's ion optic. At the top the SEM signal is seen, the bottom curve is the BCT signal. The target position is shown in the middle. The important figure to note is the beam life time which has been extended by more than a factor of five to 870 ms. This dramatic increase in beam life time meant a real breakthrough for the experiment, relieving the data acquisition from the high peak count rate it had to deal with before. The carbon fiber that was used during these plots was needed to estimate background reactions produced when using a polyethylene (PE) fiber to investigate p-p interaction. Meanwhile, with a somewhat thinner PE-fiber beam life times of 2.7 s have been reached.

In the plots shown before the target had been moved into the beam after the momentum had reached the flat top. But this experiment's goal is to measure excitation functions which means that it needs to take data while the machine is ramping up the energy. This requirement puts high demands on the machine's parameter stability during the time these parameters are synchronously changed to reach the flat top. This critical behavior was investigated a few days before the new setting of the straight section was established. One finds the result plotted in figure 5 with the horizontal scale being 50 ms/div. The important difference compared with the upper plot in figure 4 is, that the target was moved into the beam while the machine was ramping up, thus covering a momentum range from 786 to 1131 MeV/c. During data acquisition in the ramp no variations were found that did hint a temporary instability on the side of the machine. This stability fulfills an important prerequisite for the upcoming precision investigations of EDDA. Additionally, the longer life time available now will certainly ease the task of scanning a broader momentum range.

5. External Beams

External experiments hinge on the quality of the extracted beam. Getting the beam past the extraction elements was a nontrivial and time consuming task as the experiments demanded a long spill time in the order of seconds. Because at the moment the elements for the ultra slow extraction are not available for operation the resonance extraction had to be developed in a way to get close to this aim. Figure 6 shows a plot demonstrating the behavior of the machine's principal parameters during resonance extraction with a time scale of 1 s/div. The upper trace shows the extracted current measured with scintillator paddles in the external beam line. An overall spill time of about 2 s was reached in this example. Below this is the sextupole ramp under which is shown the extraction bump in the closed orbit with a similar shape but starting a little earlier. The trapezoidal structure with points down is the RF-signal. The RF is adiabatically switched off shortly before extraction to avoid any residual time structure that would otherwise reduce the overall duty factor of the external beam. The trace with the needle like peak at the beginning is the current measured with the BCT. At this peak the machine is filled with protons at injection energy. Catching the particles

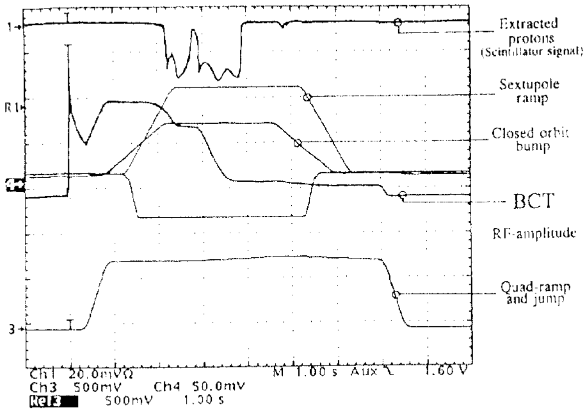

Fig. 6 Machine parameters during extraction cf. text

with the RF reduces the current as is seen in the first minimum. Accelerating the beam cranks the current up due to the higher revolution frequency until the plateau is reached. Shortly after, the ramps to initiate the extraction start. The bottom curve shows the current in the ring's arc quadrupoles. Opposed to ordinary storage operation the current in the plateau is not kept constant but raised with a mild slope to force the circulating particles into resonance.

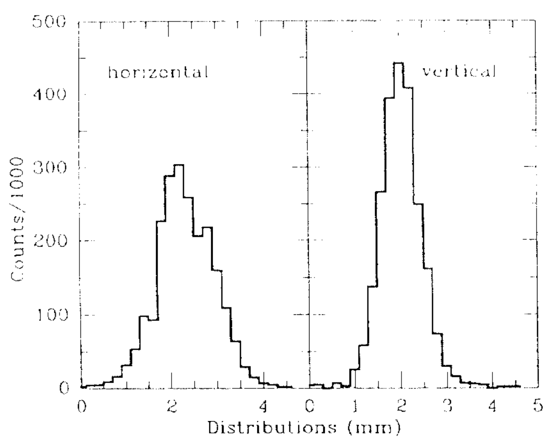

Fig. 7 Horizontal and vertical beam spot size at the TOF target position

Beams with momenta ranging from 270 to 1030 MeV/c have been delivered to three experimental collaborations. In particular for experiments that measure close to threshold precisely defined energies have been extracted as in the case of the $p+p \rightarrow d+\pi^+$ reaction. External experimental stations have also been used for pre-therapeutical studies. Fig. 7 shows histograms of the horizontal and vertical beam spot at the TOF target station at 1030 MeV/c taken with a silicon micro-strip detector. Strip width was 200 μm. Although no cooling had been applied in this case we found a machine setting giving a FWHM close to 1 mm in both directions which was very advantageous for the experiment.

6. Summary and Outlook

The cooler synchrotron COSY has shown reliable operation and a steady growth in beam quality, energy and intensity. It has reached now a point where the experimental program can progress with its intended measurements. The future will be marked by bringing components like the ultra slow extraction into operation and installing systems like the elements for stochastic cooling that are close to completion. This.holds also for experiment specific parts like the addition of the internal experiment COSY-11 at TP3 which is due to be installed in November this year. A machine development program is underway that will continue to improve our handling and understanding of the machine. On this path the raise of the extraction efficiency and duty factor and the move to higher energies have been given high priority to further exploit the machine's potential for medium energy physics.

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