STATUS OF THE COOLER SYNCHROTRON COSY JUELICH

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Abstract

The Cooler Synchrotron COSY delivers proton and deuteron beams in the momentum range from 300 MeV/c to 3400 MeV/c. The different modes of operation – internal experiments with thin or thick targets, external target experiments with slow extraction or with very short extraction pulses – require different ion optical conditions. Polarisation experiments are of increasing interest in the COSY community. Results of the polarisation conservation during acceleration and the beam preparation for the different experimental requirements will be presented.

1 INTRODUCTION

The COSY accelerator facility, shown in figure 1, is depicted in detail in [1,2,4,5]. Briefly, it consists of two sources for unpolarized H^-/D^-- ions and one for polarized H^-- ions, the injector cyclotron JULIC that accelerates the H^-- ions up to 300 MeV/c and D^--ions up to 600 MeV/c and the cooler ring COSY with a circumference of 184 m accelerating the protons and deuterons up to 3.3 GeV/c. Injection into COSY takes place via charge exchange of the negative ions over 20 ms with a linearly decreasing closed orbit bump at the position of the stripper foil. The polarized source presently delivers 10 µA of polarized H^-- ions. Four internal target areas [1,2] are available for experiments with the circulating beam. The beam can also be extracted via the stochastic extraction mechanism and is guided to three external experiment areas [1,2]. Recently, fast kicker extraction [3] has been tested, which is essential for the new experiment JESSICA. The phase space density of the protons in COSY is improved by electron and stochastic cooling [4]. The zero-degree-facility ANKE is now routinely in operation [2].

2 MODES OF OPERATION

COSY is working in different modes of operation: Internal experiments with solid targets and short cycle times (20 s), internal experiments with gas cluster or atomic beam targets and long cycle times (up to 1h flat top time) and slow extraction with extraction times between 20 s and 5 minutes. In 1999 the single turn extraction was studied at COSY for the first time with the aim to deliver 10^7 requested protons with a 1 µs pulse length to the JESSICA experiment. To accomplish this goal the diagnostic kicker, which is normally used to excite betatron oscillations for tune measurements, was fired fast enough so that the beam could be extracted within one single turn. Particle detection was carried out with the wall current monitor placed in front of the JESSICA experimental setup. A significant intensity increase was achieved when the transverse and longitudinal beam emittances at injection were reduced with the electron cooler. In the latest beam time 10^9 protons per pulse could be extracted within one pulse of 200 ns length.

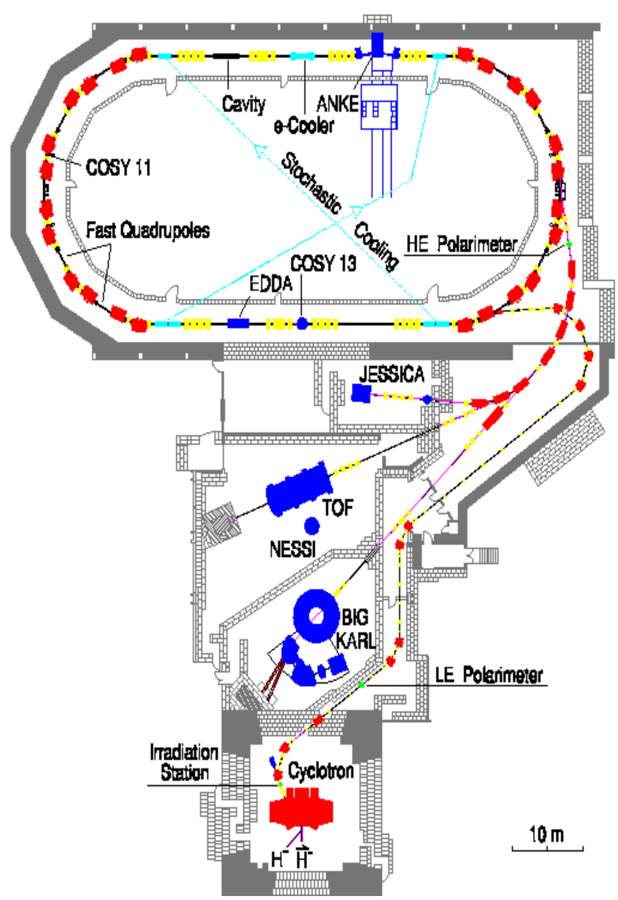

Figure 1: Floor plan of the COSY accelerator facility.

3 POLARIZED PROTON BEAMS

3.1 General

Vertically polarized protons in COSY encounter two types of depolarizing resonances during acceleration [5]. Imperfection resonances occure at equally spaced energies if the number of spin precessions per turn equals

$$\gamma \cdot G = k \qquad (1)$$

Here γ is the relativistic Lorentz factor, G = 1.792846 (anomalous magnetic moment of the proton), and k is an integer. A loss of polarization at these resonances is avoided by artificially increasing the resonance strength, such that the polarization direction is completely reversed (adiabatic spin flip) when protons are accelerated across the resonance. A vertical correction dipole located at a position with a large vertical beta-function is used to increase the orbit distortion that enhances the resonance strength.

The vertical betatron motion excites the second type of resonances. The necessary horizontal fields for vertical focussing tend to turn the spin around a horizontal axis and consequently, vertical polarization is lost. If the two long straight sections of COSY are matched to a 2π phase advance only the arcs contribute to the resonance strength. Then, spin resonance occurs for the condition

$$\gamma \cdot G = k \cdot P \pm (Q_y - 2), \qquad (2)$$

where P denotes the supersymmetry of the machine and Q_y is the vertical tune. According to equation (2), accelerating a polarized beam requires the highest possible supersymmetry of the lattice in order to minimize the number of depolarizing intrinsic resonances. The highest supersymmetry P equals 6 if the quadrupoles in the 6 unit cells of the COSY arcs are supplied with the same current. However, the standard lattice to accelerate the beam to maximum momentum has the reduced supersymmetry P equal to 2 since the harmful transition energy is shifted upwards during the acceleration. Due to symmetry breaking installations (ANKE etc.) in most cases P is only equal to 1 so that all resonances compiled in figure 2 have to be crossed during acceleration up to the maximum momentum.

3.2 Acceleration of a Polarized Proton Beam

In 1996, polarized protons were first injected and accelerated in COSY. One method to conserve polarization at the intrinsic resonances is a rapid vertical tune change. However, due to the non-adiabatic nature of this tune jump the beam emittance is increased. Theoretical and experimental studies showed that the flexibility of the COSY lattice and its control system offer the possibility to suppress certain intrinsic resonances. In this procedure the acceleration starts with the highest possible supersymmetry P equal to 6 to avoid polarization losses at the first intrinsic resonance $(6 - Q_y)$. At about 900 MeV/c the optics is then switched to P equal to 2 in order to shift the transition energy upwards.

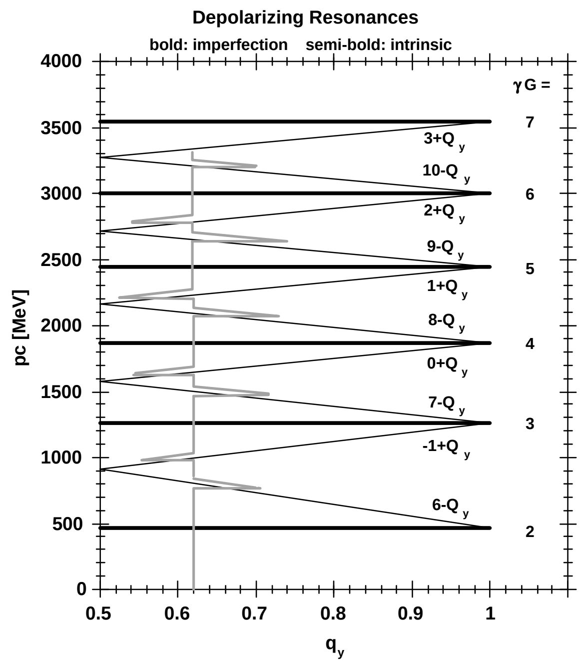

Figure 2: Depolarizing resonances during acceleration of protons in COSY as a function of the vertical fractional tune. The shaded zig zag line q_y = 0.62 symbolizes the change in working point (not in scale) during acceleration of the beam. All resonances in the range up to 3.3 GeV/c are crossed. The last resonance being crossed is 10 - Q_y.

The high reliability of the tune jump system consisting of two pulsed air core quadrupoles however allowed fast tune jumps, which preserved the polarization at all nine resonances. Tune changes of at most 0.06 within 10 µs are possible and double crossing of resonances is avoided by a fall time of 40 ms. Polarization and particle losses due to an emittance increase can be kept low during acceleration if the beam position is carefully aligned during the acceleration ramp. The vertical tune is fixed close to 3.62 during acceleration in order to have enough time for consecutive tune jumps (figure 2). The dynamic tune measurement [6] allows adjusting the tune during acceleration as well as the time and amplitude of the tune jumps. Figure 3 shows online measurements of the vertical steerer and fast quadrupole currents in comparison with the beam current (BCT). In this case one fast quadrupole was used. The beam is accelerated in 2.6 s from injection, 0.294 GeV/c, up to 3.1 GeV/c. Particle losses due to the steerer and fast quadrupole actions are less than 10%. About $1.5 \cdot 10^{10}$ polarized protons are accelerated into the flat top.

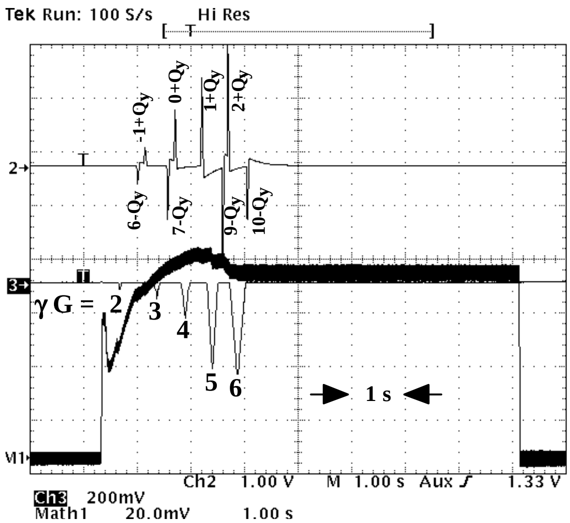

Figure 3: Trace M1 shows the beam current versus time measured with a beam current transformer (BCT). Trace 3 represents the current of the vertical steerer magnet that excites a total spin flip at the imperfection resonances. The current of the fast quadrupole is given by trace 2.

The natural strength of the $8 - Q_y$ resonance is strong enough to excite an almost total spin flip. This is visible in figure 4, which shows the polarization during acceleration in the range 1.3 GeV/c and 3.1 GeV/c. The initial polarization is 80 % and drops to 75 % at flat top momentum. The loss of about 6 % can be assigned to the $8 - Q_y$ resonance. On-line polarization measurements are carried out during acceleration with the high precision detector EDDA, designed to measure pp-elastic scattering excitation functions and spin correlation coefficients during the acceleration of the COSY beam [7]. This detector is a double layered scintillation hodoscope and in conjunction with a CH_2 or C fiber target well suited to function as a polarimeter. The great advantage of this on-line measurement is that the behavior of the polarization at every resonance is clearly visible in only a few ten minutes, depending on the desired measurement statistics. The time for the whole procedure to conserve polarization up to 3.3 GeV/c can thus be restricted to some hours. A fast change of the flat top momentum or a change in the ramping speed becomes thus possible.

4 HARDWARE DEVELOPMENT

A new broadband cavity based on the material VitroPerm came into operation, which allows the simultaneous application of the fundamental frequency and higher harmonics. The frequency range of the fundamental 400 kHz to 1.6 MHz covers the operation range of COSY. One great advantage of the new cavity is that no tuning loop is necessary [8].

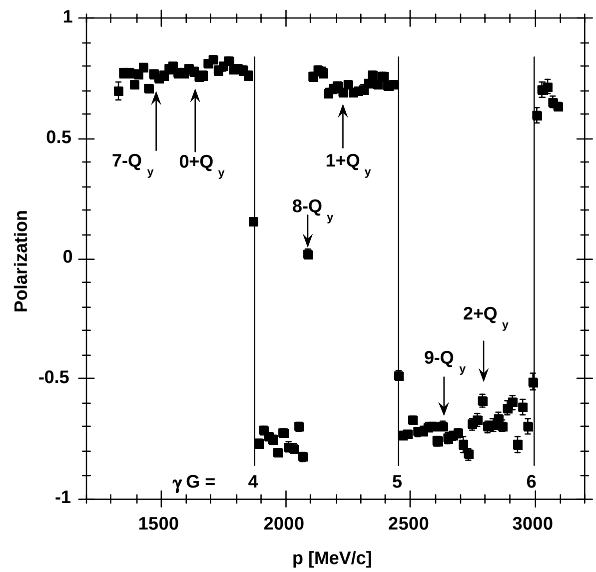

Figure 4: On-line polarization measurements, starting in this case at 1.3 GeV/c, with the EDDA detector during acceleration of the proton beam to 3.1 GeV/c. The vertical lines indicate the position of the imperfection resonances. The $8 - Q_y$ resonance at 2.1 GeV/c is strong enough to excite an almost total spin flip. All other intrinsic resonances (arrows) were crossed with a fast tune jump. A total spin flip is created with a vertical steerer for all imperfection resonances.

5 ACKNOWLEDGEMENT

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