THE MEDIUM ENERGY PROTON SYNCHROTRON COSY

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Abstract

At the cooler synchrotron COSY the year 1999 was predominantly determined by the development of vertically polarized proton beams in the whole momentum range from 300 MeV/c up to 3300 MeV/c. Starting with an initial polarization of 80 %, the beam could be accelerated up to maximum momentum with $4 \cdot 10^9$ protons at a polarization level of 75 %. The polarized beam has been used for an internal experiment as well as, after stochastic extraction, at an external target station. Beyond that the following developments were carried out: Electron cooler studies have been performed to increase the proton intensity with a combined cooling stacking injection. The now routinely operating stochastic cooling was upgraded by a fast frequency variable optical notchfilter. It will be employed in supercycles of COSY that allow varying flat top energies from cycle to cycle. Fast kicker beam extraction was investigated for the new experiment JESSICA. Finally, a new broadband cavity came into operation, which allows the simultaneous application of the fundamental frequency and higher harmonics. This report mainly deals with the development of polarized proton beams. At the end a summary of the other important activities is given together with references to contributions to this conference.

1 INTRODUCTION

The COSY accelerator facility is depicted in detail in [1,2,4,5]. Briefly, it consists of two sources for unpolarized H^- - ions and one for polarized H^- - ions, the injector cyclotron JULIC that accelerates the H^- - ions up to 300 MeV/c and the cooler ring COSY with a circumference of 184 m delivering protons up to 3.3 GeV/c. Injection into COSY takes place via charge exchange of the H^- - ions over 20 ms with a linearly decreasing closed orbit bump at the position of the stripper foil. The polarized source presently delivers 8.5 μA of polarized H^- - ions. Four internal target areas [1,2] are available for experiments with a 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 ANKE facility is now routinely in operation [2].

2 POLARIZED PROTON BEAMS

2.1 General

Vertically polarized protons in COSY encounter mainly two types of depolarizing resonances during acceleration [5]. Imperfection resonances belong to the first type. Their strengths are proportional to vertical closed orbit distortions. Any field and positioning error of the magnets then leads to depolarization 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 telescopes are matched to a phase advance 2π 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. The strength of these resonances is determined by the particle position in vertical phase space as well as by the vertical focussing strength and depends on the square root of the emittance. 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 all quadrupoles in the 6 unit cells of COSY 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 acceleration [1,2]. This procedure is necessary for internal experiments to take data in the whole acceleration ramp. In addition, several installations in the ring (e.g. ANKE facility [2], e-cooler) may reduce the symmetry. For most cases P is only equal to 1 so that all resonances compiled in Fig. 1 have to be crossed during acceleration up to 3.3 GeV/c.

2.2 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. In the case the telescopes of COSY are matched to a phase advance of 2π, a special optics was found that keeps P equal to 2 with a special ramping procedure for the vertical focussing quadrupoles in the inner unit cells of the arcs. Two intrinsic resonances ($10 - Q_y$, $0 + Q_y$) could be successfully suppressed [5].

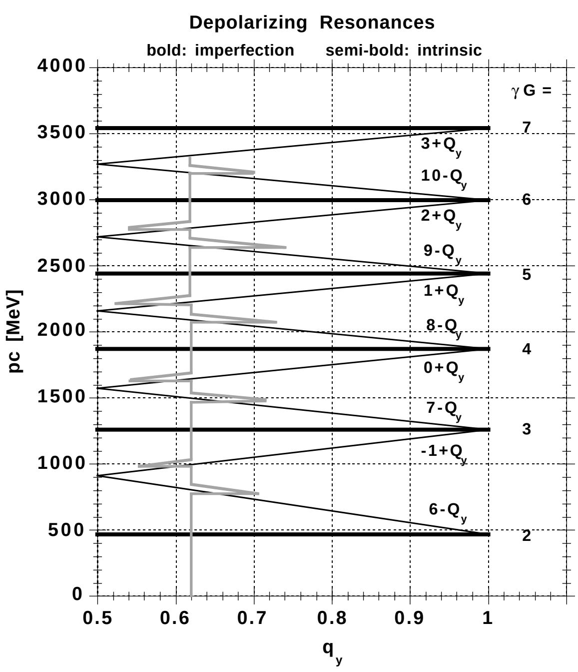

Figure 1: Depolarizing resonances during acceleration of protons in COSY as a function of the vertical fractional tune. The shaded zigzag line at $q_y = 0.62$ symbolizes the change in working point (not in scale) during acceleration of the beam. All resonances in the range up to 3.3 GeV/c are crossed. The last resonance being crossed is $10 - Q_y$.

The described method needs a careful and time-consuming adjustment of the telescopes and of the arc optics. In addition, several new installations in the ring meanwhile may lead to a decrease of the supersymmetry of P equal 1. In this case at most nine intrinsic and five imperfection resonances must be crossed in the momentum range up 3.3 GeV/c. 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 in the acceleration ramp. At injection the vertical tune is below 3.66. Therefore it is fixed close to 3.62 during acceleration in order to have enough time for consecutive tune jumps (figure 1). The dynamic tune measurement allows adjusting the tune during acceleration as well as the time and amplitude of the tune jumps. Figure 2 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 $4 \cdot 10^9$ polarized protons are accelerated to flat top.

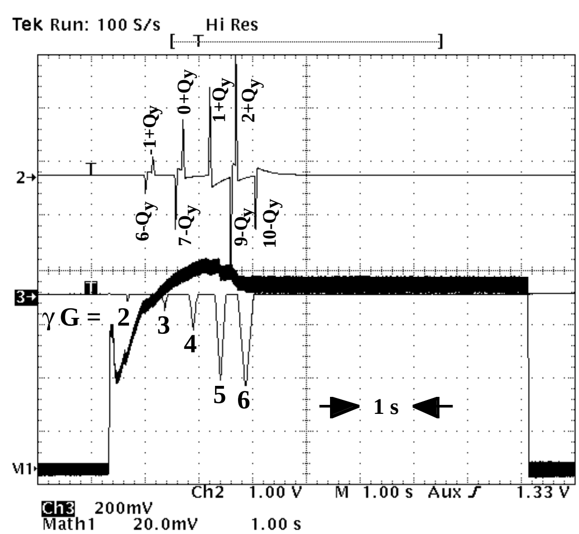

Figure 2: Trace M1 shows the beam current versus time measured with a beam current transformer (BCT). Trace 3 represents the current of the vertical steerer magnet that excites a total spin flip at the imperfection resonances. The current of the fast quadrupole is given by trace 2.

The natural strength of the $8 - Q_y$ resonance is strong enough to excite an almost total spin flip. This is visible in figure 3, 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-scattering excitation functions during the acceleration of the COSY beam [6]. 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.

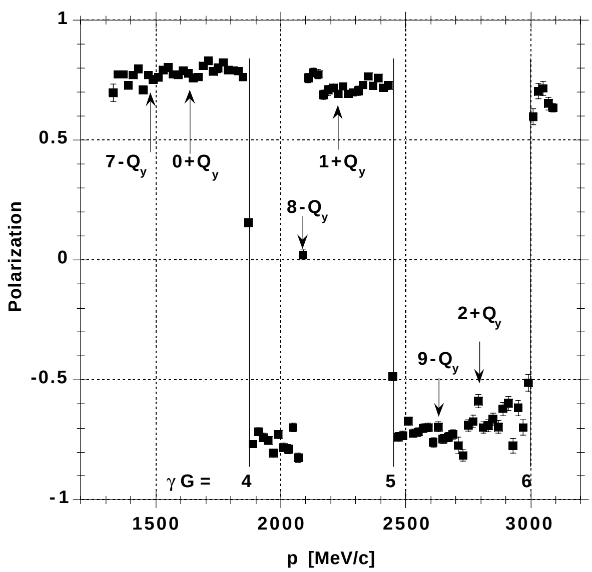

Figure 3: On-line polarization measurements, starting in this case at 1.3 GeV/c, with the EDDA detector [6] during acceleration of the proton beam to 3.1 GeV/c. The vertical lines indicate the position of the imperfection resonances. The $8 - Q_y$ resonance at 2.1 GeV/c is strong enough to excite an 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 the imperfection resonances.

2.3 Stochastic Extraction of a Polarized Beam

The method of stochastic extraction [2] has been used to extract a polarized beam at 0.8 GeV/c with a spill length of 10 s. The extraction resonance is excited with sextupoles at the horizontal tune 11/3. The polarization measured by the TOF collaboration [7] dropped gradually from about 60 % down to about 30 %. The loss in polarization was possibly due to the fact that third order depolarization resonances are crossed when the horizontal tune is moved from below towards the extraction resonance. Further investigations are still in progress.

3 BEAM AND HARDWARE DEVELOPMENT

To increase the intensity of the polarized proton beam in COSY further combined cooling stacking experiments [4] with the electron cooler at injection energy have been done. After about three minutes of stacking the flat top intensity of the beam was $4 \cdot 10^9$ unpolarized protons as compared to 10^9 protons without stacking. Here, the intensity from the cyclotron was reduced to that of a polarized beam.

The implementation of an optical notch filter for longitudinal stochastic cooling [8] has proven to be good. The notch depth could be increased by 10 dB while signal dispersion is reduced as compared to the old filter built out of solid air-filled coaxial lines. An energy change can be handled within one hour with ready-made optical fibers. First promising tests with a continuously changeable optical signal path have been carried out. This system comes into operation in future and will allow fast energy changes from cycle to cycle.

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, was fired fast enough so that the beam could be extracted within a single turn. Particle detection was carried out with the wall current monitor placed at the low energy target place. A significant intensity increase was achieved when the transverse and longitudinal beam emittances at injection were reduced with the electron cooler. Measurements sustain that the requirements of the JESSICA experiment could be fulfilled [3].

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 [9].

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