PROGRESS AND DEVELOPMENTS AT THE COOLER SYNCHROTRON COSY

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Abstract

The cooler synchrotron COSY delivers unpolarized and polarized protons in the momentum range 300 MeV/c up to 3.65 GeV/c. Electron cooling at injection level and stochastic cooling covering the range from 1.5 GeV/c up to maximum momentum are available to prepare high precision beams for internal as well as external experiments in hadron physics. The beam is fed to external experiments by a fast kicker extraction or by stochastic extraction. The beam development has been continued to increase the number of stored protons and also to deliver deuterons.

1 GENERAL OVERVIEW

In 2001 the operation of the COSY accelerator facility [1] could be successfully continued for internal as well as external experiments in hadron physics. Comprehensive studies were carried out to preserve the polarization of stored protons up to maximum momentum, resulting in an enlarged particle number at a high degree of polarization for the internal experiments EDDA and COSY 11, as well as for the external experiment TOF. In addition, the beam current of the polarized ion source could be increased further and the beam transmission in the external beamlines and cyclotron was improved. As a result, the number of accelerated protons reached up to $2 \cdot 10^{10}$ with a degree of polarization of 75% at 3.4 GeV/c. The experience gained in acceleration could also be used successfully to decelerate a polarized beam down to 1 GeV/c. Consequently, the EDDA experiment could take data not only in the upward but also in the downward ramp, which improved the statistics by nearly a factor of two. Further machine studies led to an increase in beam lifetime of more than one hour even without stochastic cooling. This result is very important for the internal experiments TRI and ANKE.

It was shown that the original COSY design momentum of 3.3 GeV/c could be extended to 3.65 GeV/c by carefully adjusting the machine parameters.

A series of machine experiments was specifically dedicated to electron cooling experiments in order to study the performance of electron cooling in COSY in more detail. The experiments were carried out together with research visitors from Dubna and Novosibirsk. Focal points were the precise alignment of proton and electron beam, longitudinal cooling force measurements, limits for the proton current as function of the achievable emittances, proton beam instabilities during and after the cooling process, and further studies to increase the proton intensity by stacking. In all experiments the fast real time vectoranalyser developed in 1997 turned out to be an outstanding device to observe the time evolution of beam distributions with great precision.

Adiabatic capture studies of an electron-cooled beam have been carried out. It turned out that the capture efficiency depends strongly on the instant at that the higher harmonic cavity is turned on and how fast the voltage is increased. Also, the ratio of the amplitudes of the first and third harmonic are expected to influence the capture efficiency. Here, further investigations are neccessary.

A beam profile monitor using a position sensitive micro channel plate (MCP) detector has been developed and was tested extensively [2].

A wall current monitor (WCM) that was formerly located in the ring, was installed in the experimental area of JESSICA for non-beam disturbing diagnostics of intensity and time structure of a fast extracted beam. Details of this broadband pick-up are presented in [3]. To investigate the beam position stability a round beam position monitor (BPM inner radius 150 mm) from the same type of the COSY-ring monitors has been installed in the extraction beamline upstream to the JESSICA-target [4].

The work to realize a new injector for COSY was continued with high priority. This new injector [5] aims to fill COSY with polarized and unpolarized protons or deuterons up to the space charge limit. A project study was carried out to establish the specifications of the new injector (superconducting linear accelerator with final energies between 50 and 60 MeV). The results were compiled in a conceptual design report describing the machine as well as all necessary sub-systems including diagnostics, computer control and infra-structure.

2 ACCELERATION OF A STACKED PROTON BEAM

Figure 1 shows the proton stacking process, starting with $1 \cdot 10^{10}$ protons, over a period of about 30 s in which the beam current is increasing. Acceleration to the flat top momentum 1.57 GeV/c starts after 30 s. Such a stacked beam with about $5 \cdot 10^{10}$ protons with emittances of about 3 μm is not stable [6]. However, its lifetime of about 2 s is sufficient for acceleration without losses in the beginning of the ramp if injection is stopped. This achievement will smoothen the way to the planned storage cell experiments that need low initial emittances and high proton currents, much more than the standard stripping injection at COSY can provide.

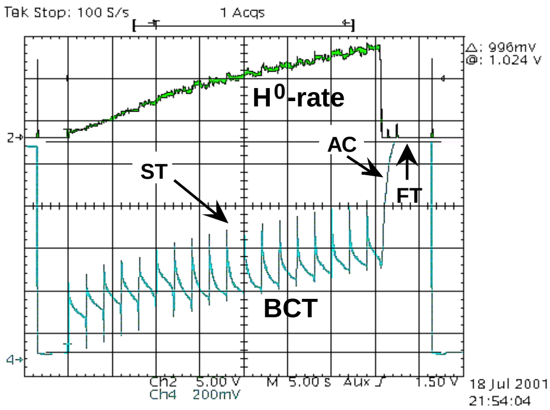

Figure 1: Increasing beam current (BCT) during stacking (ST) of protons and acceleration (AC) to flat top (FT) with $5 \cdot 10^{10}$ protons. During cooling the H^0 - rate is increasing. Horizontal scale: 5s/div.

3 FAST EXTRACTION OF AN ELECTRON COOLED PROTON BEAM

Fast kicker extraction is applied to deliver a short high intensity beam pulse to the JESSICA experiment that carries out studies for the ESS high power target. The successful fast kicker extraction [3] of an electron cooled beam for JESSICA since the year 1999 has demonstrated that the preparation of the proton beam at injection, i.e. reducing the beam size connected with an increase of phase space density can open new experimental possibilities at COSY.

The investigation of the fast kicker extraction was continued and a result is shown in figure 2. After nearly 18 s of cooling the beam is accelerated to 1.57 GeV/c.

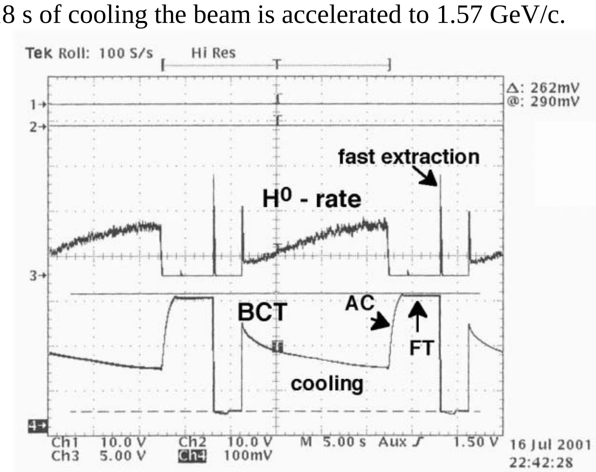

Figure 2: Electron Cooling, acceleration (AC) to flat top (FT) and fast extraction after 5 s flat top. Horizontal scale: 5s/div.

A fast kick is applied after 5 s flat top so that the beam bunch is kicked into the electrostatic septum within one turn. It was proven that the required beam intensity of $2 \cdot 10^9$ protons in a pulse of 200 ns length could be reached.

4 SLOW EXTRACTION OF AN ELECTRON COOLED PROTON BEAM

In contrast to the fast kicker extraction method, stochastic extraction is capable for extracting the beam slowly over a long period of time. The beam particles are driven by swept noise into the 11/3 order resonance in the horizontal plane created by sextupoles. In this extraction process the horizontal beam emittance is determined by the extraction mechanism, whereas the vertical emittance is determined solely by the optics of the COSY ring. Stochastic extraction is now applied routinely with an efficiency of more than 80% at proton momenta up to 3.4 GeV/c. This was achieved by theoretical as well as experimental studies of the extraction mechanism and improved diagnostic methods. In addition, careful optimizing the transmission of the external beamlines, tune and chromaticity adjustments as well as a careful positioning of the septa have significantly reduced beam losses to the external experiments. As a result, extraction rates up to 10^9 protons/s were measured. As requested by experiments, the proton beam was also slowly extracted over up to ten minutes.

Further, these improvements helped to extract a polarized beam of particular high quality to TOF.

By applying electron cooling at injection, it was possible to reduce the size of the extracted beam further, which significantly reduced the halo and thus the counting rates measured with the veto detectors at the experiment. This yielded a beam quality at the experiment BIG KRAL, which was never achieved before.

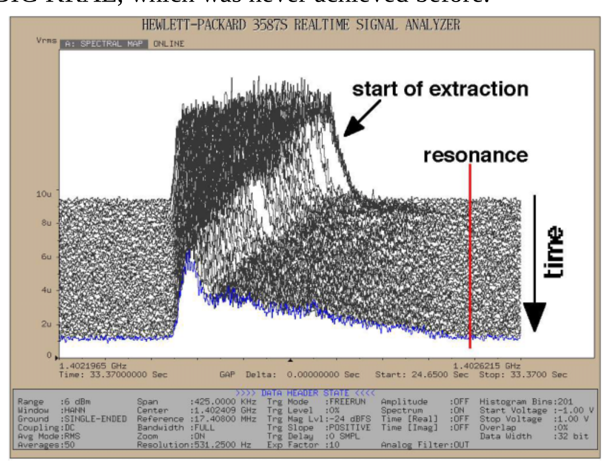

Figure 3: Time evolution of the beam distribution (linear scale) over app. ten seconds of stochastic extraction observed at the 1000th harmonic of the beam. The line marks the resonance where the beam density is zero.

Figure 3 displays longitudinal spectra in a linear scale versus time of a beam with momentum 1.57 GeV/c observed at harmonic number 1000. The sweeping noise is moved with constant velocity from the higher frequency side into the waiting rectangularly shaped beam. The figure makes visible that the protons diffuse along a straight line into the resonance where they are extracted. During extraction the sharp low frequency edge moves through the stack. Note that the left-hand side of the stack is not affected. In figure 4 a snap shot shows a complete cycle in COSY. The beam is injected and electron-cooled for 10 s as is visible in the increasing H^0 - rate. After loss-less acceleration to 1.57 GeV/c slow extraction starts after 5 s. The rectangularly shaped beam distribution and the constant sweep velocity of the extraction noise result in linear drop of the beam current. Hence, the mean spill is constant with 10^9 protons/s during extraction over nearly 10 s. Averaged over the whole 20 s cycle the intensity is $5 \cdot 10^8$ protons/s.

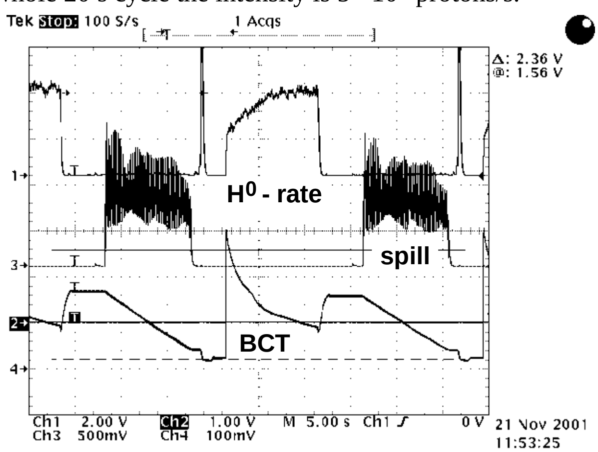

Figure 4: At injection level the proton beam is electron-cooled as is visible in the increasing H^0- rate. After acceleration to 1.57 GeV/c the beam is slowly extracted. Horizontal scale: 5s/div.

The resulting beam spots on a viewer placed in the scattering chamber of the experiment had a radius of 2 mm. The halo ratio for a 3 mm veto hole could be reduced from $2.5 \cdot 10^{-2}$ to $4.0 \cdot 10^{-4}$ for a cooled beam. Thus the primary beam intensity can be increased by a factor of 60 for the same veto counting rate.

5 ACCELERATION OF COOLED DEUTERONS

During nearly ten years of operation of COSY the request on deuterons increased more and more. The successful replacement of the extraction septum in the cyclotron by a new one capable to hold the voltage necessary for 540 MeV/c deuterons now offers the possibility to satisfy the increasing demands of the experimentalists for deuteron beams in COSY. After installation the preparation of D^- beams in the ion source and acceleration in the cyclotron started. A deuteron beam could be successfully injected and accelerated in COSY to 2 GeV/c. For the external experiment MOMO $1 \cdot 10^{11}$ deuterons could be accelerated to 2 GeV/c which were then extracted over 20 s by the method of stochastic extraction.

Electron cooling tests at injection have been carried out to cool $2 \cdot 10^{11}$ deuterons prior to acceleration to 2 GeV/c. Figure 5 shows the cooling process over 14 s and the loss less acceleration. Due to instabilities during cooling the final deuteron number at flat top is $5 \cdot 10^{10}$.

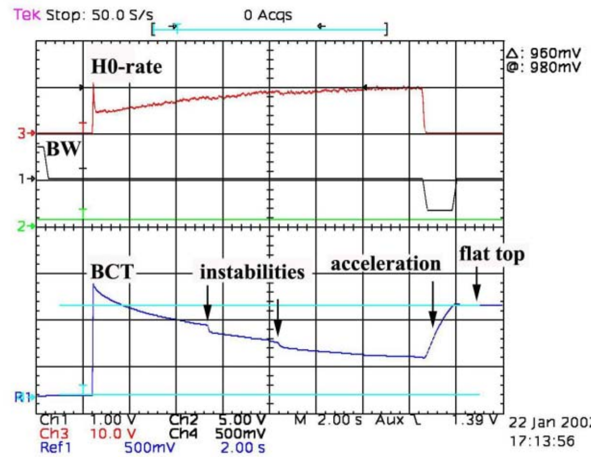

Figure 5: Beam current (BCT) versus time during cooling and acceleration. At injection level the proton beam is electron-cooled as is visible in the increasing H^0- rate. The beam is then loss less accelerated to flat top.

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