RECENT GAINS IN POLARIZED BEAM INTENSITIES FOR THE COOLER SYNCHROTRON COSY AT JÜLICH*

R. Gebel#, O. Felden, R. Maier, P. von Rossen,
IKP, Forschungszentrum Jülich GmbH, 52425 Jülich, Germany.

Abstract

Since January 1999 routinely about 1 μA of polarized H^- ions are delivered for charge-exchange injection into COSY. For protons a polarization of 85 % was routinely achieved. Deuterons with polarizations of 75 % were delivered to experiments offering the choice to receive sequences consisting of eight out of fifteen available different states. By advancing the components of the polarized ion source the number of polarized particles for injection into the cyclotron has been increased by a factor of three to a new record value of $5{,}5 \cdot 10^{12}$ H^- ions, delivered in a 20 ms pulse with a repetition rate of 2 seconds. This report sums up the characteristics of the polarized ion source in its present mode of operation and describes the achievements towards higher beam intensities as well as for providing polarized H^- and D^- beams with high reliability.

INTRODUCTION

Since January 1996, the cyclotron JULIC [1,2] operates as the injector of H^- or D^- beams for the cooler synchrotron COSY [3-5] at the IKP of the Forschungszentrum Jülich. Since 1999 routinely 1 μA of polarized H^- ions are delivered for charge-exchange injection into COSY. Additionally, polarized D^- ions have been delivered to experiments [6,7]. A sequence of up to fifteen different polarization states for deuterons has been provided for experiments. For unpolarized operation about 10 μA of unpolarized H^- or D^- is available for injection into the synchrotron. The colliding beams source itself provides polarized negatively charged protons or deuterons. The original design value with respect to the achievable polarized beam intensity for protons and deuterons had been 30 μA [8-10]. For several years that value had been as distant goal for routine operation and in retrospect would have been unachievable with the original components of the source. It had been, therefore, decided to systematically identify any weak point, replace components accordingly, and add systems needed to analyse problems. The objective was to obtain a system that would stand up to routine operation over many weeks. A record value surpassing by a great margin the original design value was achieved by the source for polarized negatively charged light ions in 2005.

DESCRIPTION OF THE POLARIZED ION SOURCE

The principle of operation is to collide a polarized hydrogen beam or deuterium beam with a neutral Caesium-beam [11] having an energy of about 45 keV. In a charge exchange reaction, taking place in a solenoidal magnetic field, negatively charged hydrogen, or deuteron, ions are created and accelerated toward the extraction elements. The ions are then bend by 90°, pass a Wien-filter and enter the transporting source beam line that guides them into the cyclotron. Figure 1 shows schematically the colliding beams source (CBS) with the systems that have been replaced or added to the source during this improvement program.

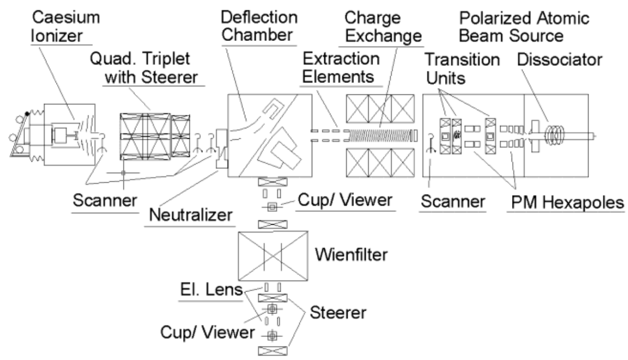

Figure 1: Layout of the COSY CBS. Being underlined indicates added or replaced parts.

RECENT DEVELOPMENTS

Caesium Ionizer

A breakthrough decision was to develop a pulsed caesium beam matched to the short injection period of up to 20 ms for COSY, virtually eliminating by this the severe sputtering damage that had been an obstruction for reliable operation [12-14]. The Caesium emitters, a porous tungsten button on a heated Molybdenum construction, formerly bought from an external supplier, had also been a weak link and have been replaced by a part that had been completely constructed at the research centre, outperforming the original part by a wide margin. The pulsed operation of the Caesium gun is controlled via a high voltage electrode. The parameter space for the operation of the gun was carefully mapped to find a setting that delivered a nearly rectangular pulse shape. This was an important prerequisite for the precise transport of this beam, which is strongly governed by space charge effects in the initial phase. The compact but complex design of this pulsed caesium gun is exhibited in Fig. 2. Beam diagnostics, like beam scanner, faraday cups and viewer, for the caesium beam was added to successfully shape the transversal phase space for optimal overlap with the atomic hydrogen or deuterium beam.

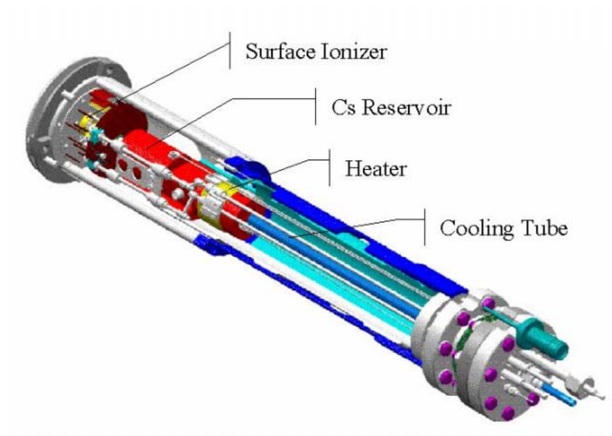

Figure 2: Pulsed Caesium ionizer. Only the main parts are shown.

Charge Exchange Region

In order to provide high polarization the charge exchange region is exposed to a solenoidal field of up to 2 kG. The polarization of protons is expected to saturate with field magnitudes of three times the critical magnetic field of 0,51 kG. The emittance is expected to increase in parallel with the magnitude and the beam size. The measured behaviour is depicted in Fig. 3.

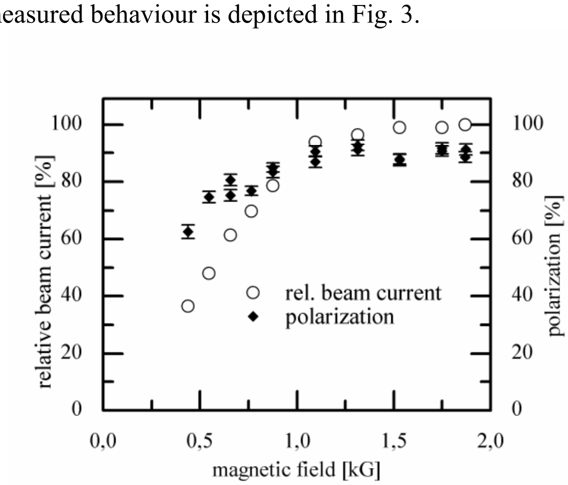

Figure 3: Beam intensity as a function of the magnetic field magnitude in the charge exchange solenoid.

To extract the beam after formation of H^- or D^- a gradient voltage is applied over the charge exchange region. A set-up with eight electrodes using independent power supplies showed limitations in reliability due to sparking in this region. A solution with single resistive coils served well for years and provided in pulsed operation voltages up to 20 Volts. Replacing this standard set-up by 18 electrodes in mid 2005 connected to a matched passive voltage divider allowed to apply voltages up to 100 V.

Dissociator

The pulsing concept was further developed to include the atomic beam part as well. This was also crucial to increase the uptime of the ion source. The dissociator producing atomic hydrogen or deuterium beams is a prime component of the source. In a Pyrex-tube containing the gas, a high frequency discharge breaks the molecular bond. A stream of atomic gas leaves this tube through a nozzle cooled down to 36 K. The pulsing encompasses the dissociator rf-discharge as well as the gas supply. The latter one comprises three gases. The main gas hydrogen respectively deuterium and small additions of nitrogen and oxygen. For each the exact flow and timing was investigated to obtain optimal performance. Alone for this component 14 parameters have to be adjusted. Difficulties are amplified by the necessity to condition the components for longer time periods as surfaces and vacuum change during the tuning process.

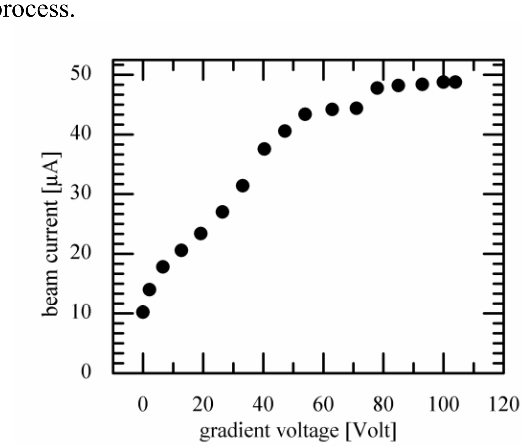

Figure 4: Beam intensity as a function of the magnitude of the gradient voltage applied over the charge exchange region.

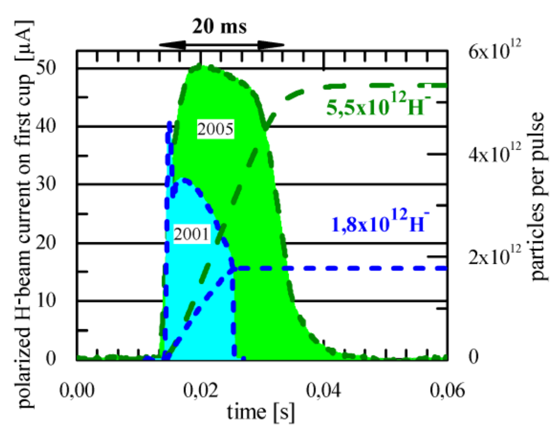

Figure 5: Record beam pulses from the polarized ion source and integrated particle number per pulse.

This number was of course even higher during the design phase when nozzle length, nozzle temperature, discharge tube, and geometry of the skimmer section had to be optimized. All of the above give some insight into the complexity of the source although many crucial refinements cannot be mentioned here. This is ample evidence that achieving maximum beam intensity and quality requires a detailed insight into the system. Minute variations in vacuum and surface conditions can significantly alter the overall behaviour and require very often a lengthy search of the large parameter space for a new optimum.

The dissociator with its cooled nozzle is now available in a version optimized for higher repetition rate and low gas consumption. Using the parameters close to the approved ones a comparable performance has been found.

RECENT GAINS

The new record value of 50 µA polarized proton beam, reached during a routine beam time in 2005, which nearly doubled the original design value of 30 µA is not the result of the optimization of a single component but the result of an optimization process that did not spare any component. Fig. 5 shows the pulse extracted from the source during a December run compared to a quite good pulse of a former setting used in 2001. The transport of such a pulse to the exit of the cyclotron is inevitably associated with significant losses. A bar graph in Fig. 6 reveals the situation that was present during this December run. Despite rather high losses inside the cyclotron, which were due to a temporary bad vacuum inside the main chamber, to which negative ions are very sensitive because of electron stripping, the pulse still contained $1.9 \cdot 10^{11}$ protons.

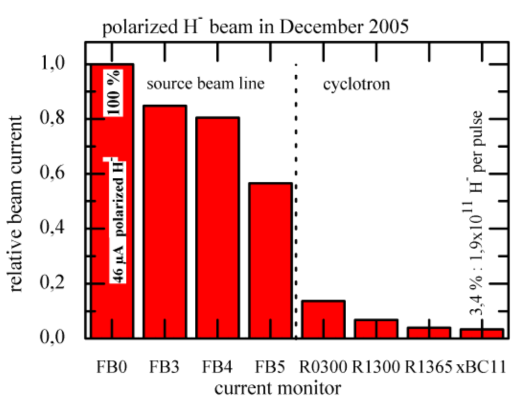

Figure 6: Record beam transport from the polarized ion source and ions per pulse for injection into COSY.

CONCLUSION

To reach peak performance inside COSY not only each component of the polarized ion source has to be optimal but also any other component on its way to the experiment like the source beam line, the cyclotron, the low energy beam line, the injection process into COSY, and the following acceleration process. Of course those systems vary in the challenge they pose to the optimization process.

The improvement program that has been started years ago is still a work in progress and holds great promise. It can be expected that it will significantly contribute to the quality of the ongoing physics program also in the future.

ACKNOWLEDGEMENTS

The authors like to thank the injector staff members Ronald Brings, Armin Kieven and Norbert Rotert, as well as Wolfgang Derissen from the IKP construction and Helmut Hadamek and his staff of the IKP workshop for their effective support of our endeavours in keeping the ion sources and JULIC operating reliably and to raising their performance.

The European community under contract number HPRI-CT-2001-50021 has supported this work.

REFERENCES

[1] W. Bräutigam et al; "H- operation of the cyclotron JULIC as injector for the cooler synchrotron COSY-Jülich; Proc. of Cyclotrons 1998, Caen, IOP (1999) 654.

[2] W. Bräutigam et al.; "Extraction of D- beams from the cyclotron JULIC for injection into the cooler synchrotron COSY". Proc. of Cyclotrons 2001, East Lansing, AIP 600 (2001) 123.

[3] R. Maier, Cooler Synchrotron "COSY – performance and perspectives", NIM A 390 (1997) 1.

[4] H. Stockhorst et al., "Progress and developments at the cooler synchrotron COSY", 8th EPAC (2002) 629.

[5] B. Lorentz et al., "Status of the cooler synchrotron COSY-Juelich", 9th EPAC, Lucerne (2004) 1246.

[6] R. Gebel et al.; "Polarized negative light ions at the cooler synchrotron COSY/ Jülich"; 10th Symp. on PNNIB, Kiev, Ukraine, AIP Conf. Proc. Vol 763, New York (2005) 282.

[7] R. Gebel et al.; "Negative ion sources at the injector cyclotron JULIC for the cooler synchrotron COSY". Proc. of Cyclotrons 2004, Tokyo, Particle Accelerator Society of Japan (2005) 287.

[8] P.D. Eversheim et al, Proc. of the workshop PST1995, Köln, (1995), 224.

[9] P.D. Eversheim et al., The Polarized Ion-Source for COSY, Proc. SPIN 1996 Symposium, Amsterdam.

[10] R. Weidmann et al., Rev. Sci. Instrum.,67 p.II, (1996), 1357.

[11] W. Haeberli, Nucl. Instrum. Methods, 62 (1968) 355

[12] M. Eggert et al., NIM A vol. 453 ; (2000), 514.

[13] O. Felden et al., Proc. of the workshop PST2001, World Scientific, Singapore, (2002), 200.

[14] O. Felden et al., in Proc. of the workshop PST 2003, Novosibirsk, NIM A 536 Issue 3, (2005), 278.