

OPERATION OF THE INJECTOR CYCLOTRON JULIC FOR THE COOLER SYNCHROTRON COSY/JÜLICH

R. Gebel*, R. Brings, O. Felden, R. Maier, Forschungszentrum Jülich GmbH, Germany

Abstract

Since January 1996, the cyclotron JULIC operates as the injector of H⁻ or D⁻ beams for the cooler synchrotron COSY at the Institut für Kernphysik (IKP) of the Forschungszentrum Jülich. After more than a decade of reliable operation some cyclotron subsystems showed wear-out symptoms and a process has been started in order to assure the availability for the challenging scientific program at COSY. E.g. the vacuum system and main components of the radio frequency system of the cyclotron have been partly replaced. The performance of the operation with polarized negative ions has been continuously improved by applying results of detail studies.

INTRODUCTION

Since January 1996, the cyclotron JULIC has operated as the injector of H⁻ or D⁻ beams for the cooler synchrotron COSY at the IKP of the Forschungszentrum Jülich [1,2,3]. For unpolarized operation an intensity of about 10 μ A of H⁻ and D⁻ is available for injection, giving the high margin for the desired performance of the polarized ion source. That unpolarized beam current is sufficient to obtain in 20 ms about $2 \cdot 10^{11}$ stored particles in the synchrotron. This value is assumed to be close to the space charge limit at this working point of COSY. Since 1999 routinely 1 μ A of polarized H ions are delivered for charge exchange injection into COSY. Since 2001 also polarized D⁻ has been delivered to experiments. A sequence of up to fifteen different polarization states has been provided. This report sums up the characteristics of the cyclotron and the ion sources in its present mode of operation and describes the efforts for higher beam intensities as well as for providing unpolarized and polarized H⁻/D⁻ beams with high availability.

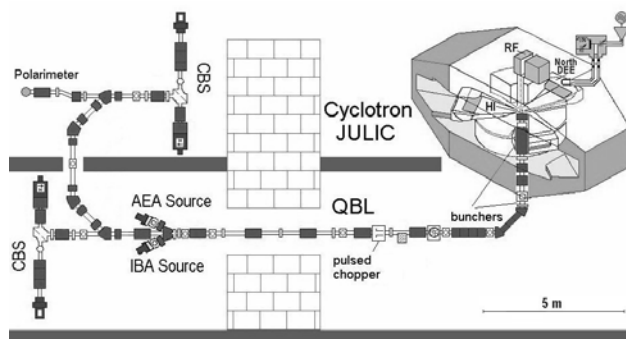


Figure 1: Layout of the COSY injector with ion sources and transfer beam line.

Besides serving COSY as injector the cyclotron was used in providing irradiations at the internal and external target stations for external users.

CYCLOTRON OPERATION

The cyclotron is in use since the mid 60s of the last century. Most of the systems were refurbished between 1980 and 1989. But again 20 years later wear-out of tubing, the loss of elasticity of vacuum and water seals becomes more prevalent. In mid 2007 the injector cyclotron JULIC passed 112000 hours of operation since it started delivering beams as COSY injector in 1989 after a major refurbishment. The time distribution over the years since 2000 is shown in fig. 2. In 2005 and 2006 the installation of a new large detector was prepared and successfully finished. Water leakages of internal and external magnet systems had interrupted the operation for about 400 hours in 2004. The operation was interrupted for about 500 hours in 2006 due to a failure of the adjustable air line tube of the central conductor of the rf system. That causes an additional reduction of available beam time in these years. During the last years several components of the cyclotron have been replaced successfully. The efforts are briefly summarized and depicted. It can be expected that the ongoing improvement program will significantly contribute to the quality of the ongoing physics program for the study of hadron structure and dynamics also in the future.

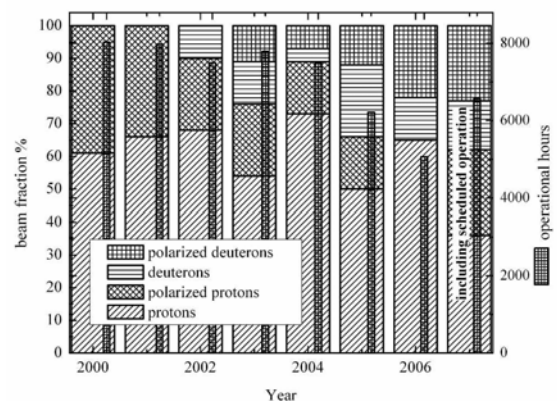


Figure 2: Operation of the cyclotron as the injector for COSY. The delivered beam species as well as the operational hours from 2000 to 2006 are displayed.

NEW POWER SUPPLIES

Since 2004 several magnet power supplies have been replaced. The main magnet, the compensated channel as well as the correcting coils are operated with new power converters. In summer 2007 the transfer beam line

*r.gebel@fz-juelich.de

between the sources and the injection into the cyclotron has been equipped with new power supplies.

The improved beam transmission through the cyclotron is given in fig. 4 for the case of unpolarized deuterons.

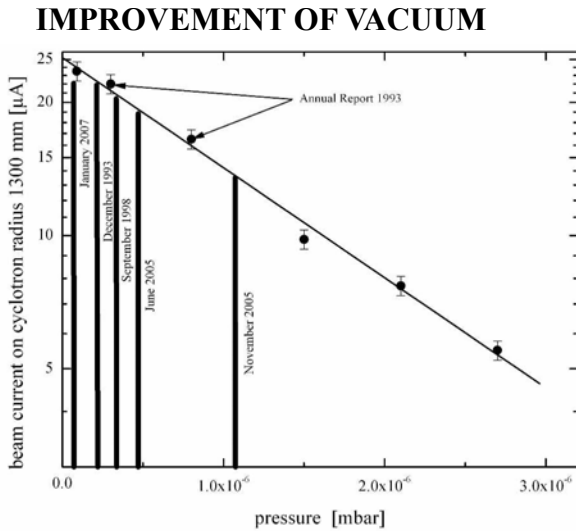


Figure 3: A semi-log plot of the beam intensity close to the extraction radius as a function of the measured pressure. The exponential fit includes all points and shows the limit for unrestricted pumping speed.

The upgrade of the vacuum system has proceeded. The replacement of the main turbo molecular pumps has been completed after the implementation of a new control system.

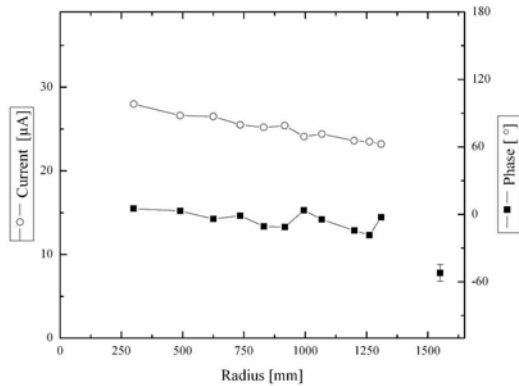


Figure 4: Beam transmission through the cyclotron, demonstrating the improved vacuum situation in 2006.

A vacuum leak at a welded flange was finally found and successfully fixed in the beginning of 2006. The polishing of critical surfaces, the installation of new vulcanized vacuum seals, where accessible, resulted in the recovery of the intolerable state of the vacuum system, which has reduced the performance for beam delivery of the injector in the second half of 2005. The pressure dependence of the intensity close to the extraction radius is depicted in fig. 3. The beam losses reached a critical level of over 50 % in November 2005. Shortly after the recovery from the shutdown the system has reached a pressure in the low 10^{-7} mbar regime. After some weeks the average pressure in the chamber decreased to values below $1 \cdot 10^{-7}$ mbar.

ADJUSTABLE AIR LINE

During the summer shutdown the damages at the linear tuning element of the central tuner became obvious during maintenance. Severe burn-out, scratches and broken contact springs made it necessary to overhaul the linear tuner completely. After refurbishment of the parts the operation has been continued delayed and with reduced working range for the frequency. The needed operational modes for COSY have been realized without problems. In summer 2007 the complete functionality has been recovered by an exchange of the support structure of the tuning element. The water cooled condensators with their motor driven positioning unit has been replaced successfully by a new construction.

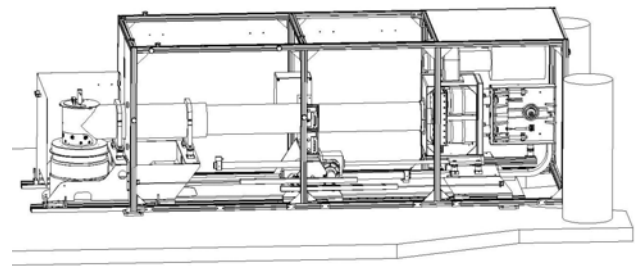


Figure 5: The new construction for the matching hardware on the top of the cyclotron magnet's yoke. The air line has been improved in summer 2006. The tuning condensators have been replaced in winter 2006.

SEPTUM OPERATION

A long term activity is the improvement of the extraction septum for the operation with deuteron beams at high momentum. Due to depositions on the isolator the usability of the septum is limited in case of operation at high voltages above 30 kV. The differential pumping system of the linear actuators has been replaced, providing improved leak rates in the vicinity of the septum. Two spare septa are manufactured to allow fast replacement.

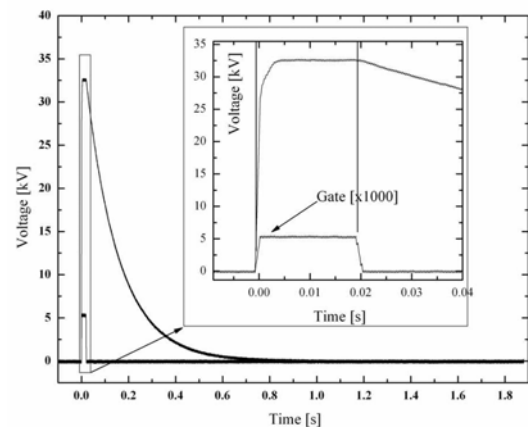


Figure 6: Performance of the pulsed extraction septum.

The availability of D^- operation of the COSY injector is dependent on a reliable septum operation. To allow uninterrupted service the power supply for the septum has been pulsed for operation above 25 kV with rise times of around 100 ms. This mode of operation allowed the usage of an otherwise inoperable septum due to increasing loss of isolation. Over two years of operation between exchanges has been reached. Benefiting from the good experience with transistor switches for pulsed operation of the ion sources a switching circuit for the voltage of the septum has been realized for voltages up to 65 kV. With this switch rise times of about 2 ms are realized. The pulse width has been reduced to a fraction of the former set-up. The quality of the pulsing scheme is depicted in fig. 6. After reaching the desired deflecting voltage the voltage is kept constant until the end of the gating pulse. The slow decay in the unloaded test condition decreases under real test conditions due to the resistive load of the coated isolators of the septum deflector.

GAINS IN POLARIZED INTENSITIES

The colliding beams source itself provides polarized negatively charged protons or deuterons [6-7]. The original design value with respect to the attainable intensity had been 30 μA at the exit of the source. For several years that value had been a distant goal for routine operation [8-11].

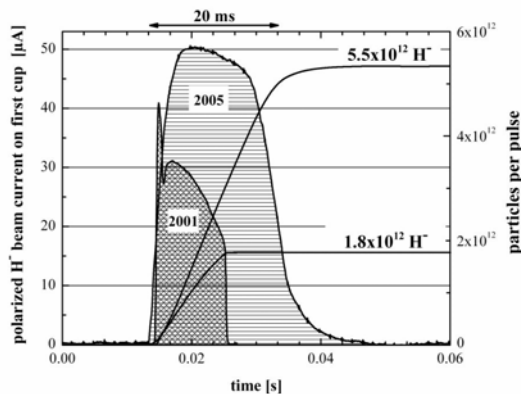


Figure 7: The gain in charged particles per pulse compared to the best result achieved in 2001.

A record value of 50 μA , surpassing the original design value, was achieved during a routine beam time in 2005 [12]. This was not the result of the optimization of a single component but the outcome of an optimization process that did not spare any component. Fig. 5 shows the pulse extracted from the source during that experimental run compared to a quite good pulse of a former setting used in 2001. The intensities of polarized beams extracted from the cyclotron exceeded 1.9 μA for deuterons and 2.0 μA for protons. With intensities of this magnitude it was possible to provide $2.6 \cdot 10^{10}$ polarized deuterons at maximum beam momentum in COSY for experiments. The time dependence of the unpolarized and polarized deuteron beam current during a cycle in the synchrotron is shown in fig. 8. The circulating beam

current reaches 35.4 mA for unpolarized and 6.3 mA for polarized deuterons. The analysis of the signal from the beam current transformer demonstrates the capability to inject, to capture and to accelerate the beams with high efficiencies.

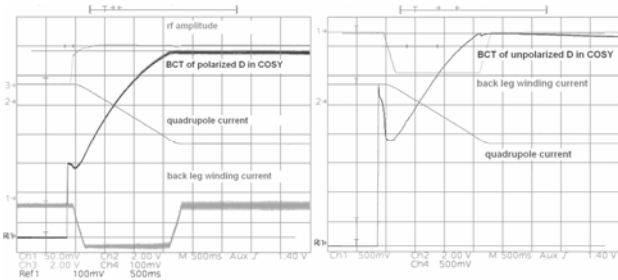


Figure 8: Deuteron beams in COSY.

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