PREPARATION OF AN ION SOURCE FOR AN EXTRA LOW ENERGY SYNCHROTRON

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Abstract

ELENA is a compact ring for cooling and further deceleration of 5.3 MeV antiprotons delivered by the CERN Antiproton Decelerator (AD) down to 100 keV. Because of the long AD cycle of 100 s, it is foreseen to use a source for protons and H^- with a kinetic energy of 100 keV for commissioning and start-ups. The source, designed to provide 0.2 to 2.0 μs pulses with 3×10^7 ions, is based on a proven multicusp volume source used at the COSY/Jülich injector cyclotron. The source and its auxiliaries were refurbished, upgraded to $+/-100$ keV operation at the Forschungszentrum Jülich and have been set in operation at CERN in April 2015 for first tests of new equipments.

INTRODUCTION

CERN has approved in 2011 the construction of the Extremely Low ENergy Antiproton ring ELENA [1] due to the growing scientific demand for low-energy antiprotons. ELENA is a small synchrotron with an electron cooler for further deceleration of 5.3 MeV antiprotons delivered by the antiproton decelerator AD [2]. Electron-cooling of antiprotons of about 100 keV energy will produce a beam quality that allows delivery of pulses in electrostatic beam lines to experiments in the AD hall. The ELENA Feasibility Study [1] constitutes the scientific and technical basis of the project. ELENA is also an accelerator test platform for developing new generation sources for antiprotons which may start with FLAIR [3], an addition to FAIR at the GSI in Darmstadt [4]. CERN's AD with ELENA is going to be the world's sole source for low-energy antiproton physics for the near future. The Institute for Nuclear Physics (IKP-4) of Forschungszentrum Jülich [5] has committed, like other parties, to contribute significantly to ELENA with manpower and equipment. Setting-up ELENA and experiments is foreseen with a dedicated H^- and proton source. This enables making part of the commissioning independent of the CERN schedule. A 100 keV source can be installed in a section of the transfer beam line between AD, experiments and ELENA. The ion source provides higher intensity and more frequent injections than possible with AD, about one bunch every 100 seconds, and improves efficiency.

SYSTEM LAYOUT AND STATUS

The 100 keV H^-/proton ion source with auxiliaries has been prepared in Jülich for delivery in an early stage of ELENA installation. The source is one of the first components installed in the AD hall at CERN in April 2015. All systems are operational and the source can be useful for validation of equipment prior and during their installation.

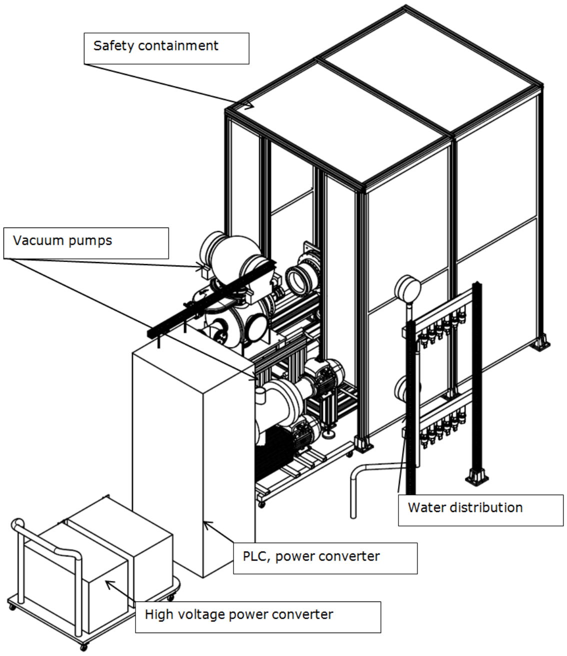

Figure 1: ELENA source set-up for commissioning, with its auxiliaries.

It is planned to test e.g. ion switch yard elements and diagnostic devices. In order to enable these activities the source has been delivered equipped with vacuum system, power converters, a local control computer and diagnostic tools. The ion source was successfully operated at 100 keV with both polarities in Jülich. Table 2 provides parameters first operation with 100 μA H^- and 150 μA proton ion beams. The first installation at CERN is very close to the opertional configuration used at Jülich. In a second step, after installation of the beam line elements between source to the ion switch after June 2015, the source is going to be installed at its final position. The faraday cage is already at its final position. The ion source system has been installed within the AD machine circumference and inside shielded areas. The position is fixed by the requirements of the switch yard for serving both ions and antiprotons to the ELENA ring and the experiments. The layout of the equipment integrates the HV cabinet which is enclosed inside a grounded safety cabinet of Faraday type and the ion source components. The ion source power supply is composed of four power supplies, filament driver to heat the filaments, arc power supply to create a discharge, two extraction power supplies for pulling out, or suppressing, ion beam and auxiliary power converters and high voltage solid state switches for pulsed operation.

Together with supplies for PLC, mass flow controller and controller unit, these parts are located inside a 19 inch HV cabinet on insulators. All devices are enclosed inside a safety cabinet which prevent accidental access to these components. Using a 400 Hertz transformer enabled compact foot print and reduces the power ripple significantly. The ion source is equipped with a vacuum system comprised of a 2200 l/s vacuum pump, a 250 m^3/h roots pump and mechanical fore pumps. Siemens Local Control System is connected to the PLC on HV with fiber links and and provides an Ethernet interface for local area communication. This complete system used for tests at Jülich is shown in Figure 1.

ION SOURCE DESCRIPTION

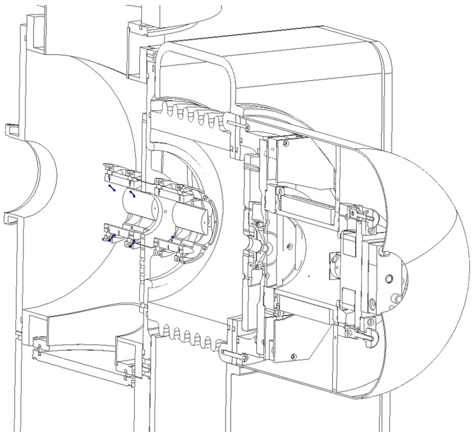

Figure 2: ELENA ion source with electrostatic screen, safety box and the first vacuum section with a quadrupole doublet.

The ion source is a specialized source of negative ions for cyclotrons [7], which is also capable of producing protons without mechanical modifications. For this only the polarity of beam potential and extraction have to be reversed. Figure 2 displays the main components of the ion source and the first section of beam transport. It comprises of an arc discharge chamber and a triode accelerator with an integrated ion trap. Permanent magnets are included in the ion source body and the accelerator, forming the magnetic cusp and filter fields. The discharge is allowed to run continuously in order reach the most stable conditions for ion production. The extraction system is pulsed between negative and positive voltages according to the production of positive or negative ions. The accelerating structure forms a series of electrostatic lenses and, in addition, beams are launched from the surface of a plasma which acts also as a lens. Depending on the plasma conditions the source produces a converging or diverging beam. Low beam intensities, as required for ELENA, are correlated to low plasma densities and the routine operation is going to be below the condition for a perveance matched extraction. The source is therefore equipped with an additional electrostatic quadrupole doublet close to the isolator exit. This doublet provides in addition steering capabilities in order to compensate for unwanted residual deflection by the magnetic filter elements, the electron suppressor in the extraction electrode or misalignment. The extraction elements have been optimized by combination of numerical simulation and experimental verification.

SIMULATION OF BEAM EXTRACTION

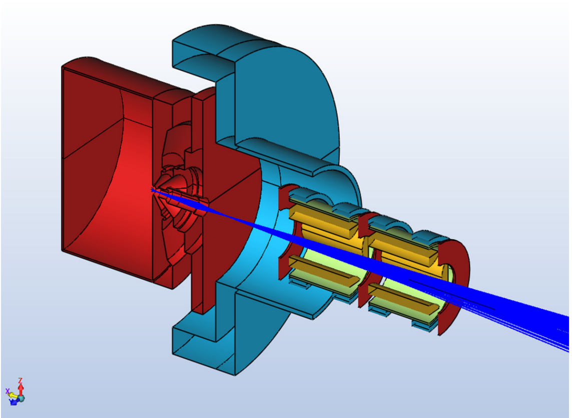

Figure 3: 3D ion source model for beam simulation.

The source and handling of the beam is still under investigation. Simulation tools have been used to optimize several components of the source, and possible beam line elements have been tested for usability and optimum position. Constructional data has been imported to program suites for field calculations and particle tracking. The upgrade to +/− 100 keV operation required special care. With dedicated models for extraction, available ion optical elements and isolation structures calculations have been essential to reach the current level of performance. Results for calculated beam properties are briefly summarized in table 1.

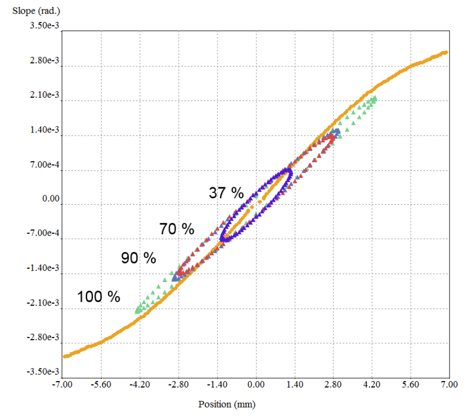

Figure 4: Emittance plot for 250 μA H^- at 100 keV extraction voltage, with ellipses for the given beam fractions.

By simulation e.g. the electron trap has been investigated during the course of refurbishment of all source systems. The electron trap in the extraction electrode, connected to the extraction HV supply, has to remove the the co-extracted electrons from the beam prior to full acceleration. The setup has been improved by adding a second set of permanent

Table 1: Simulation Results

Parameter	unit	I_0	90%	37%
current	mA	0.25	0.22	0.09
Emittance				
$\epsilon_{RMS,norm}$	μm rad	0.11	0.09	0.05
TWISS				
α		-11.5	-6.8	-2.6
β	m/rad	23.0	13.5	4.9
γ	m/rad	5.8	3.5	1.6

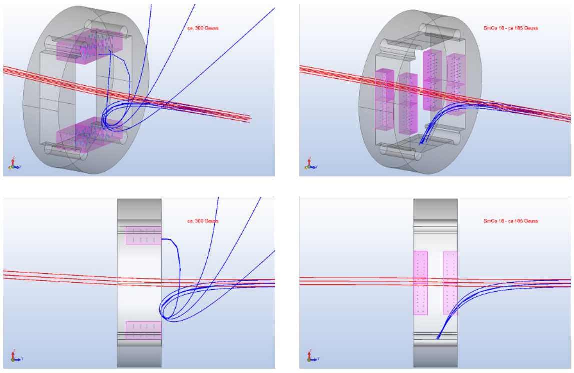

Figure 5: Extraction trap improvement. (protons: red, electrons: blue)

magnets with opposing magnetic field direction. The first one bends the electrons into the side of the electrode, the second dipole prevents secondary electrons from exiting and corrects the deflection angle of the much heavier ions. Figure 5 compares the functionality of the old and the new system. Electron suppression and reduced ion beam deflection have positive impact on source performance. The extraction elements have been modeled with a 2D-Rs and 3D dimensional field solvers ELECTRO, COULOMB and AMPERES, which are part of the Lorentz program suite [8]. Figure 3 depicts one iteration towards optimized position of the elements behind the extraction electrode. This calculation includes space charge and provides a solution for a sample of 1000 beams, representing 250 μA, started from the meniscus of the plasma. Distances and settings of the quadrupole lenses are adjusted for acceptable beam transport conditions. Figure 4 shows the according phase space plot of this model situation. The calculated RMS emittance, the half axis product, for 90% of the beam is about 0.7 mm mrad and in accordance with the required specification. The source should deliver maximum intensity within the acceptance of the synchrotron to allow one pass position measurements and in pulses with a steep rising edge. The normalized RMS emittance from the source needs to be around 0.1 mm mrad. The first estimates of the measured emittance indicate that collimation of the beam in order to fit the phase space requirements might be needed. Parameter optimization and additional measurements are going to be continued at CERN before relocating the source to its final position.

Table 2: Preliminary Results for +/−100 kV Beams

Parameter		100 μA H^-	150 μA p
Arc Current	[A]	3.0	1.0
Arc Voltage	[A]	75	75
Extraction Voltage	[kV]	-3.0	+2.9
Suppression Voltage	[kV]	+.2	-0.2
Filament Current	[A]	76.0	73.4
Gas Flow	[sccm]	0.90	0.60
TWISS			
$\epsilon_{RMS,norm}$	[μm rad]	0.26	0.37
α		-0.11	-0.14
β	[m/rad]	0.37	0.27
γ	[m/rad]	2.76	3.74

CONCLUSION

The H^- and proton source and auxiliaries provided by the IKP-4/Forschungszentrum Jülich as an in-kind contribution for the ELENA project have been installed at CERN, after refurbishing and upgrading the system to +/−100 keV extraction energy, as one of the very first ELENA equipments. The source itself is since April 2015 at a preliminary location and is going to be connected to the beam lines after June 2015. The Faraday cage containing source auxiliaries on high voltage is already at the final position. This source can be used to test special equipment later in 2015 and for ELENA ring commissioning in 2016.

ACKNOWLEDGMENT

The work has been supported within the framework of the Helmholtz Association's Accelerator Research and Development (ARD) [9] program.

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