DESIGN OF A VERSATILE INJECTOR FOR A LOW-ENERGY EXPERIMENTAL PLATFORM AT KACST

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Abstract

At the National Centre for Mathematics and Physics (NCMP), at the King Abdulaziz City for Science and Technology (KACST), Saudi Arabia, a multi-purpose low-energy experimental platform is presently being developed in collaboration with the QUASAR group at the University of Heidelberg, Germany. The aim of this project is to enable a multitude of low-energy experiments with most different kinds of ions both in single pass setups, but also with ions stored in a low-energy electrostatic storage ring. In this contribution, the injector of this complex is presented. It was designed to provide beams with energies up to 30 kV/q and will allow for switching between different ion sources from e.g. duoplasmatron to electrospray ion sources and to thus provide the users with a wide range of different beams. We present the overall layout of the injector with a focus on the optical design and the foreseen diagnostic elements.

INTRODUCTION

Electrostatic storage rings have proven to be invaluable tools for studies in atomic physics and biophysics, i.e. for life sciences in general. Around some tens of keV, they allow avoiding problems related to hysteresis effects and remanence of magnetic fields.

Today only three such machines exist, all of them having a comparable, compact racetrack-shape layout and working at a fixed energy of 20 keV [1, 2] or 30 keV [3] with a continuous beam. Two of the rings [1, 3] can be operated at liquid nitrogen temperature and only one of them [2] is equipped with an electron merged beam device, which works at the required low energies but with a rather limited resolution.

The aim of the Pro-ESR project is to design, construct and operate a state-of-the-art fixed energy storage ring that will allow for precision experiments with most different kinds of ions in the energy range of up to 30 keV at the King Abdulaziz City for Science and Technology (KACST) in Riyadh, Saudi Arabia [4]. This machine will serve as a multi-user, multi-purpose facility for different scientific communities and will be used at the same time as an experimental and a training facility.

In order to benefit most from the mass-independence of the electrostatic rigidity, a highly flexible injector complex is a necessity and its design is presently being carried out in collaboration between the experts from KACST, King Khaled University, the University of Heidelberg, Germany, and the Joint Institute for Nuclear Research (JINR).

This paper describes the optics design of the injector complex. While the mid- and long-term planning foresees already the possibility to inject ions from different ion source, e.g. a Duoplasmatron ion source and an Electrospray ion source, an additional focus was put on a quick realization of the injector in a simplified layout, which will allow for early testing of all components, and thus provide an excellent base for future extensions.

INJECTOR DESIGN

The assembly of the injector complex is planned in a staged approach:

First, a commercial ion source will be used with a beam transport system consisting of a first Einzellens and a beam matching section containing four electrostatic quadrupoles and a set of steerer electrodes.

Second, an 90° analyzing spectrometer magnet with +26.6° pole faces and a high mass resolution will be added to this setup and allow for a direct comparison of the output beam intensity and quality in both cases.

Third, additional ion sources and a beam switching element (chopper) will complete the injector. Optional elements for the beam switching are either a 30° switching magnet or an electrostatic quadrupole used not as a focusing device, but as a beam selector.

This staged approach guarantees the fastest possible availability of beam.

The aim of the low-energy beam transport section is to efficiently capture the beam from the ion source and to transport it to the analyzing magnet, where the particles of interest will be filtered out from the main beam. The tasks of the different sections of the here-described injection system can be summarized as follows:

- Production of ions, pre-acceleration of the ions and formation of ion beams with requested beam quality and beam current is realized in the *ion source* and the *ion source extraction system*.
- Separation of charge states to be injected into the Storage Ring from all the other ion species extracted simultaneously from the ion source in the *spectrometer line*.
- Switching between the selected ion species from different ion source branches, beam intensity

control, matching of beam parameters to the requirements of the subsequent synchrotron operation and formation of the beam pulses (macropulse chopping) are done in the *beam transport line.*

The design goals for the injection beam line as a whole are:

- Efficient beam extraction from the ion source;
- Minimization of the beam distortion due to space charge forces;
- Separation of the charge states isotopes in the range of masses between A=1…100 by a high resolution (commercially available analyzing magnet). The resolution may be increased at a later stage by adding further mass filters;
- Modification of the DC beam from the ion source to short bunches (τ ≈30 µs with a repetition rate of 0.1…10 Hz) to provide single turn injection into the ring as well as in-ring experiments;
- Operation of several ion sources in parallel is foreseen as a future option and design of the injection line accommodates already at least three ion sources;
- Beam delivery to the injection point in the storage ring.

It should be noted that the distance from the last focusing element of the injection line to the injection point of storage ring, the so-called *matching point,* is determined by the final layout of the storage ring and is expected to be between around 2 and 2.5 m. Furthermore the matching of the injected beam to the storage ring lattice has to be highly flexible to allow for different lattice settings during ring operation. In other terms, the injection line optics should allow the independent variation of all transverse coordinates in x-x' and y-y' phase planes.

BEAM EXTRACTION FROM THE ION SOURCE

In order to estimate the beam characteristics to be expected from the commercial ion source, numerical studies with the computer code POISSON [5] were done. This program allows for the 2-dimensional computation of the electric field distribution and consequently for an estimation of the extraction regions' impact on the particle beam to finally be injected into the low-energy storage ring.

Detailed information on the potential distribution was extracted from the data and is shown in the following Figures. Figure 1 shows the potential distribution along the beam axis starting from the ion source. This gives a (rough) idea about the fringe fields originating from the source region and thus about potential disturbances of the extracted ion beam. It should be pointed out that in the future real setup, the voltages will be inversed, i.e. the ion source put on a potential of U=30 kV and the external extraction electrode put on ground.

Figure 2 plots the axial field distribution for four different starting points. While the red curve corresponds to the case when the simulation starts at the edge of the anode (0), the other curves correspond to the start positions: -1, -2 and -5mm before the anode. In later simulations only the red curve was used.

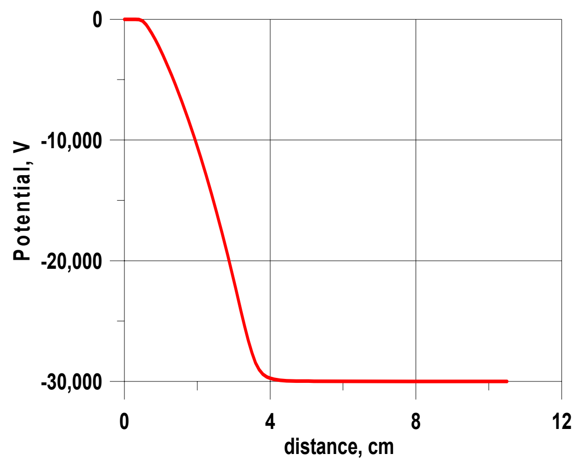

Figure 1: Potential distribution from ion source along beam axis

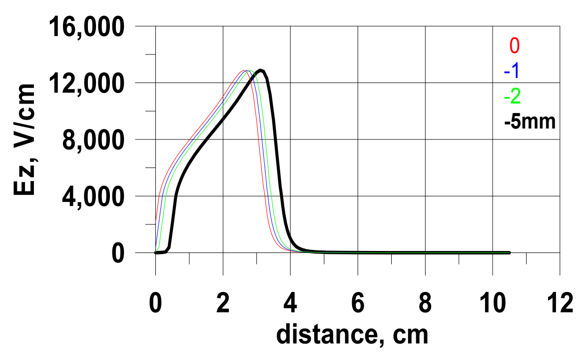

Figure 2: Axial field distribution for four possible starting points.

Right after the ion source, an electrostatic Einzellens with two grounded electrodes and a central cylindrical electrode at voltage *V* will be used to radially focus the ion beam. The Einzellens forms an integral part of the beam extraction system. It should be pointed out that An important feature to optimize the extraction from the ion source is the possibility to laterally move the first grounded electrode towards and away from the ion source (with an accuracy in the order of 100 □m).

The particle motion through this section was simulated with the codes SIMION [6], MAD [7] and Trace3D [8] to cross-check all results and allow for an in-detail analysis. The beam tracking in Trace3D is performed by multiplication of the full transfer matrixes up to third order elements. Some non-linear effects are included as well as the motion in the longitudinal direction. The code outputs the beam envelopes and the phase space ellipses in x–x′ and y–y′ phase planes at any desired point of the injection line. For all calculation the use of a commercial Duoplasmatron ion source was assumed.

With the given parameters of the Duoplasmotron ion source, a reasonable first focal point should be placed ~1m from the source. This position will then serve in a second step as the base for a point to point imaging with an analyzing magnet. By using a three-tube Einzellens geometry, where the two outer electrodes are on ground potential with a central electrode on roughly +15.6 kV, the focus is reached after 873 mm, see fig. 3. The present parameters of the injector are summarized in Table 1.

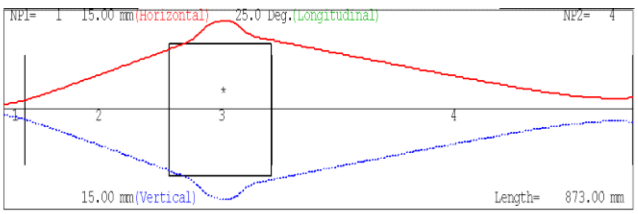

Figure 3: Overview of the extraction system and the first Einzellens, focusing voltage U_f=15.6 kV.

Table 1: Parameters of Einzellens and first part of injector.

Distance from ion source to intermediate image point of electrostatic quadrupoles	380 mm
Distance from ion source extraction hole to extraction electrode	30 mm
Distance from ion source to potential electrode of Einzellens	130 mm
Acceptance of Einzellens	$A_{x,Y}^{norm}$ = 120 π mm·mrad
Voltage on Einzellens potential electrode	+15.6 kV
Inner diameter of Einzellens electrodes	30 mm
Length of potential electrode	50 mm
Gap between potential and ground electrodes	5 mm
Maximum beam divergence through Einzellens	40 mrad
Distance from Einzellens to intermediate focus	50 cm
Beam diameter in the intermediate focus point (not including space charge effects)	3 mm
Beam diameter in the intermediate focus point (including space charge effects)	5…8 mm (beam current 200 … 500mkA)

90° ANALYSING MAGNET

The performance of the injector will be improved at a later stage by adding a high resolution analyzing magnet to the injection beam line. During the design of the injector, the beam was already tracked through a 90° analyzing magnet to estimate the final performance of the overall injector. A magnet with a central radius of 400 mm with 26.6° pole faces provides a double focusing of the beam at a focal distance of 800 mm from the magnet pole edge. The required magnetic field to bend a beam of 30 keV ions is 626 G. Such a magnet is commercially available.

After the analyzing magnet, the beam needs to be matched to the twiss parameters of the storage ring. These last are not fully known at this stage but the matching with the set of four quadrupoles is feasible. Figure 4 gives an illustration of the matching considering a beam with an emittance of 40π mm·mrad focused into a spot of 6 mm diameter.

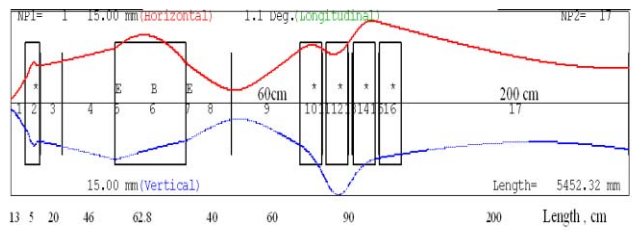

Figure 4: Overview of the injection beam line including the set of four quadrupoles.

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