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Development of a High Resolution Analyzing Magnet System for Heavy Molecular Ions

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Abstract

At the King Abdulaziz City for Science and Technology (KACST, Saudi Arabia), a versatile ion-beam injector was constructed to provide the electrostatic storage ring with the required high-quality ion beams. In order to remove the ambiguity over the ion mass due to the exclusive application of electric fields in the set-up, the injector is being equipped with a high resolution mass analyzing magnet. A high resolution Analyzing Magnet System has been designed to provide a singly-charged ion beam of kinetic energy up to 50 keV, mass up to 1500 Amu, and with the mass resolution fixed to $\Delta m/m = 1:1500$. The system includes specific entrance and exit slits, designed to sustain the required mass resolution. Furthermore, specific focusing and shaping optics have been added upstream and downstream the system, in order to monitor and adapt the shape of the ion beam at the entrance and exit of the system, respectively. The present paper gives an overview on the design of this mass analyzing magnet system together with the upstream/downstream adapting optics.

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Keywords: Ion-beam injector, magnetic fields, electrostatic storage rings, atomic and molecular physics

1. Introduction

Electrostatic storage rings [1] have gained significant attention during the last years due to their valuable use in atomic and molecular collisions. They have indeed, allowed ground-breaking advances to be made in the interdisciplinary fields of e.g. biophysics, biochemistry, and radiobiology, as well. An up-to-date complete

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electrostatic storage ring facility for atomic and molecular physics is being built at the King Abdulaziz City for Science and Technology (KACST), in Riyadh, Saudi Arabia [2]. The ELectrostAtic Storage Ring (ELASR) [2] of this facility is designed to store beams at fixed-energy up to 30 keVq. The facility is presently equipped with a simplified version of the ion injector, which consists of inline ion-optics for steering and focusing the beam. This in-line version of the injector has already been built and is operating, as well. Moreover, the initial the design of this ion injector includes a 90° electrostatic deflection set-up, which foresees the possibility to inject ions from two different sources [3].

This injector is expected to guarantee flexibility of the whole experimental infrastructure and to provide high quality beams of various ion species. At present, the injector is an exclusively electrostatic in-line optical scheme, which consists of two main parts, (1) the extraction and focusing system, and (2) the beam matching system, which relies on a set of two doublets of quadrupoles. In spite of the considerable interest of such an experimental facility, the electrostatic nature of this device does not allow the mass identity of the stored ions to be determined. Thus, the injector is being equipped with a high resolution mass analyzing magnet, which in addition, should ensure the transmission of a high quality macromolecular ion beam to be injected and stored in the ring. Such analyzing magnet is equipped with equidistant entrance and exit slits, which have been specifically designed to sustain the required mass resolution. To integrate the magnet into the injector beam-line, the optical lattice of the later was appropriately adapted. Quadrupole-based optics located upstream and downstream the analyzing magnet system, guarantee the full control of the shape of the ion beam at the entrance and exit of the system, respectively. In the present paper, we briefly describe the design of this high resolution analyzing magnet system as well as the specific optical schemes which are required by the insertion of a high resolution magnetic selector.

2. Design of the high resolution mass selector

The analyzing magnet is intended for use in an electrostatic storage ring experiment in particular, the ELASR storage ring facility that is being built in Riyadh. The analyzing magnet system is intended to fulfill the specific experimental requirement of a high resolution in the mass of macromolecular ionic species. It features a dipole magnet that is designed to provide singly-charged macromolecular ion beams of kinetic energy up to 50 keV, for ion mass up to 1500 amu, and with the mass resolution fixed to $\Delta m/m = 1:1500$, without degrading the required high quality beam to be injected and stored in the ring. The system includes specific entrance and exit slits, which are designed to sustain the required mass resolution. Figure 1 shows a 3D illustration of this high resolution mass analyzing magnet, including the slits, as drawn by SolidWork software.

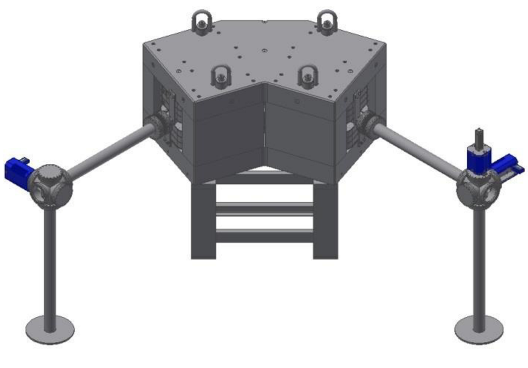

Fig. 1. Overview of the mass analyzing magnet, including the slits, as drawn by SolidWork software.

As the starting point, the main parameters of the system were set as 1m for the radius of the central trajectory, 90° for the bend angle and 50 mm for the magnet gap. The choice of these parameters leads to the maximum magnetic field as large as 1.25 T, which is slightly below saturation of iron (around 1.5 T). Then, four successive stages of simulations and calculations were necessary to define the details of the whole system.

(1) Ion optical calculations were performed to determine the position of both the entrance and exit slit, which correspond to the conjugate object and image. A particular attention is devoted to the double focusing (horizontal and vertical) action of the uniform magnetic fields, which determines, at first order, (i) the resolution of the magnet, according to the slit width and (ii) the beam profile at the exit of the system. These parameters are essential, as they define the limiting specifications of the system. To this end, two different ion-optics simulation packages have seen used to track ions and simulate the beam envelope through the whole analyzing magnet system; the Beam-line Simulator software, which is a magnet based ion-optical code and the Particle Beam Optics Laboratory (PBO Lab™), which represents an excellent approach to providing software for particle beam optics modelling [4]. Figure 2 shows the beam envelope tracked through the Analyzing magnet system from the entrance slit to the exit one.

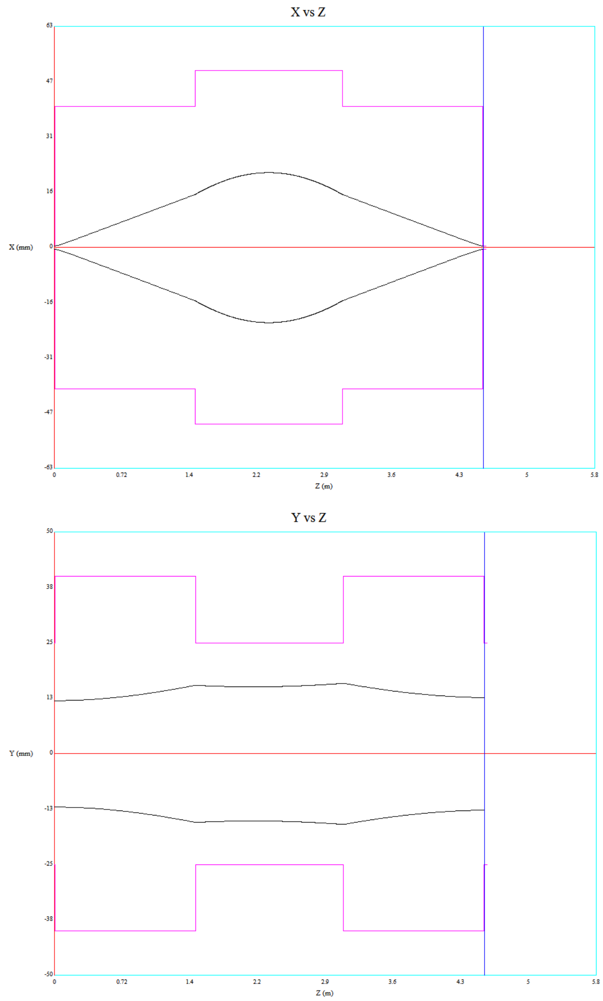

Fig. 2.: Beam envelope tracked through the Analyzing Magnet System. Upper figure: the Analyzing Magnet System as drawn by SolidWork. Central figure or upper plot: the most divergent beam that the system can analyze in the horizontal plane at a resolution of 1:1500. Input is (x = 0.5 mm, x' = 0.01 radians) at entrance slit. Lower plot or lower figure: The largest beam specifications that the system can transport in the vertical plane; input is (y = 12 mm, y' = 0.0065 radians) at entrance slit.

(2) 2D-modeling of the magnetic field through a cross section of the magnet allows both the shape and dimensions of the magnet and of the coils, their mass, current intensity, as well as well as the general field distribution to be determined; it also allows checking for possible iron saturation. Gemini software from Infolytica has been used in this purpose, yielding the 2D simulations in figure 3, below.

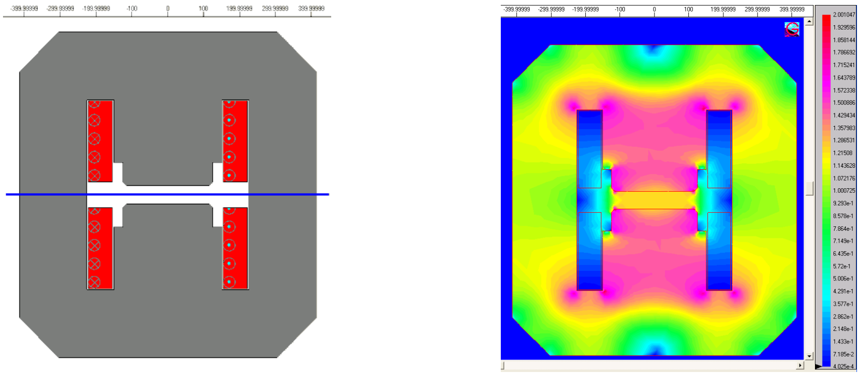

Fig. 3. **Left**: Analyzer Magnet 2D Magnetic Model. **Right**: Magnetic Field as a Function of Colour. **B_{Max}(0,0,0) = 1.24685 T, I_{Max}2D = 187.065 Amps**. The central pole is just entering into saturation at ~1.5 Tesla.

(3) 3D-modeling was used to check for field flatness errors and for the required necessary peak power;

(4) Finally, a **particle trajectory calculation** was performed to ensure that the magnet design exhibits the required mass resolution. Figure 4 shows the result from Opera code, from Vector Fields.

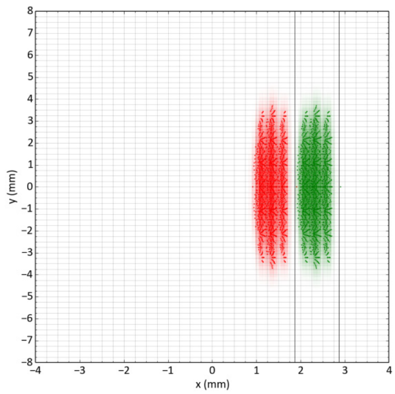

Fig. 4. 50 keV Ion trajectory calculation showing the complete separation between adjacent mass ion spots at the Exit Slit, 1500 mm downstream of the effective edge of the magnet. The right spot corresponds to mass **1500 AMU** and the left one to mas **1499 AMU**. Specification at Entrance Slit are: x = ± 0.5 mm, x' = ±10.5 mrad, y = ± 15 mm, y' = ±6.8 mrad.

3. Insertion of the Analyzing Magnet System - Quadrupole-based adapting optics

As shown in figure 5, the high resolution mass Analyzing Magnet System is being mounted downstream the second part of the injector beam line (i.e. part 2), taking advantage of the upstream set of two quadrupole doublets. This upstream Quadrupole-based optics is intended to provide full control of the shape and divergence of the ion beam at entrance slit, that is, the object point of the magnet. Likewise, a qudrupole triplet is added downstream of the Analyzing Magnet System, along with sets of electrostatic steerers from the Quadrupole-based optics by which the beam is adapted to match the characteristics of the storage ring. The qudrupole triplet allows in principle for matching all transverse phase space parameters independently, while the sets of steerers allow the beam to be steered in both horizontal and vertical planes. Comprehensive investigations were performed by specific simulation codes including Beam-line Simulator and PBO Lab™ codes, to optimize the optical lattice of the entire injector set-up, to maintain the quality of the beam. This is however will be described in a future publication.

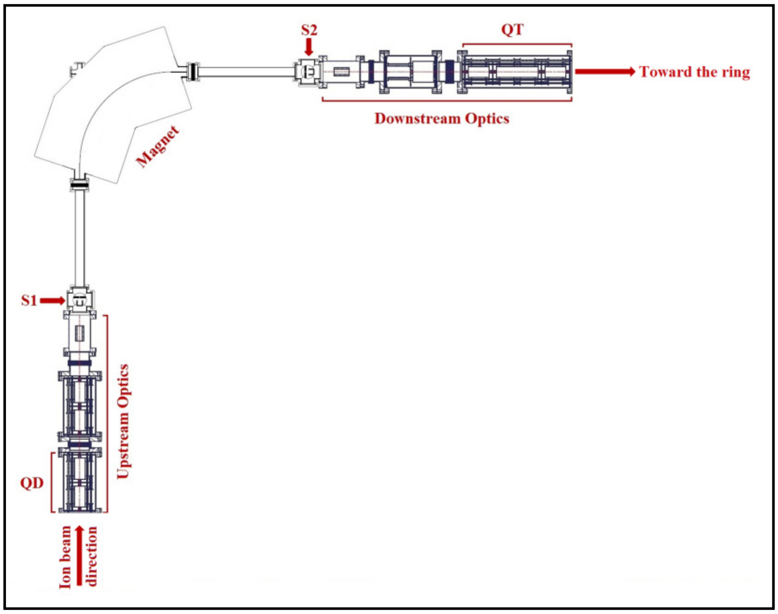

Fig. 5. Overview of the high resolution Analyzing Magnet System together with the upstream and downstream quadrupole-based optics. QD: Quadrupole Doublet, S1: Entrance Slit, S2: Exit Slit, QT: Quadrupole Triplet

Conclusion

In this paper, we briefly describe the design of the high resolution mass Analyzing Magnet System, which has been specially developed for insertion in the ion-beam injector of the storage ring ELASR in Riyadh. The injector including the mass Analyzing Magnet System was constructed to provide the ELASR storage ring with the required high-quality ion beams. Indeed, this analyzing magnet acts to remove the ambiguity over the mass of the ions to be stored. The design features a dipole magnet that is intended to provide a singly-charged ion beam of kinetic energy up to 50 keV, mass up to 1500 Amu, and with the mass resolution fixed to $\Delta m/m$ =1:1500. The system includes specific entrance and exit slits, designed to sustain the required mass resolution.

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