Proposal of an RF-only double-funnel system for ions extraction from a cryogenic stopping cell for the Super-FRS at FAIR

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In 2001 we proposed [1] an idea to replace a radio-frequency quadrupole (RFQ) or sextupole (SPIG) rod structure, which are conventionally used for an ion beam extraction from stopping gas cells into vacuum, by an RF-only ion funnel. Later we suggested [2] the using this technique for production of focused ion beams. Recently this RF-only ion funnel concept has been successfully checked [3] at Stanford University, USA in measurements of ions extraction into vacuum from a high-pressure (10 bar) noble-gas environment.

Here we propose the RF-only double-funnel system for ions extraction from a cryogenic stopping cell for the Super-FRS at FAIR, which prototype device is described in details in [4]. A schematic representation of this double-funnel system is shown in Fig. 1.

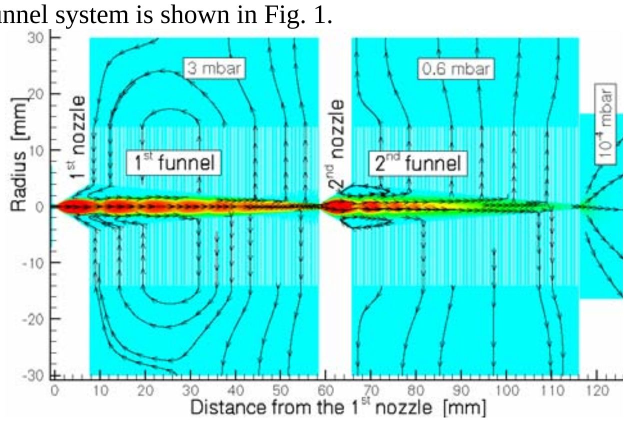

Figure 1: (color online) Schematic design of the RF-only double-funnel system for ions extraction from a cryogenic stopping cell for the Super-FRS at FAIR. The simulated velocity field for helium buffer gas at the stagnation pressure of 2 bar and temperature of 75 K in the gas cell is shown in addition. See text for explanation.

The ions are extracted from gas cell (not shown in the Fig.1) via supersonic He buffer gas flow through the 1st converging-diverging nozzle that has the following dimensions: the subsonic converging cone has the entrance diameter of 1.3 mm, the length of 1 mm; nozzle throat diameter is 0.3 mm; the supersonic diverging cone has the length of 7.7 mm and the exit diameter of 8.0 mm. The funnels are connected through the 2nd diverging nozzle having the throat diameter of 0.8 mm, the length of 7.2 mm and the exit diameter of 8.0 mm. The both funnels have the same following geometry: the number of ring electrodes is 144, they have the same outer diameter of 28 mm and the inner diameter decreasing from 8.0 mm at the funnel entrance to 0.8 mm at the funnel exit; ring electrodes made from 0.1 mm thick stainless steel sheets; the gap between electrodes is 0.25 mm. It should be notice, that the design of these funnels is identical (except of the length and the number of ring electrodes) to funnel that has been used in the Stanford's apparatus [3].

RF-voltages applied to the funnels (in such a way that phase shift between adjacent ring electrodes is 180^{o}) confine the ions inside the funnels while the most part of the buffer gas flow out through the gaps between funnel rings and pumped. No any DC field is applied to the funnel electrodes and the ions are transported through this double funnel system only under a combined action of RF field and the buffer gas flow. The both nozzles have a ground potential.

The operation of this double-funnel system we have explored by means of detailed computer simulations. First, we made gas dynamic simulations for the buffer gas flow. Then the results of these simulations (flow fields of gas density, temperature and velocity) we used as input for ion-trajectory Monte-Carlo simulations. A detailed description of the similar computer simulations one can find elsewhere ([2, 3] and references inside). Notice that the measurements in [3] are in a good agreement with these computer simulations.

The results of gas dynamic simulation for the helium buffer gas velocity field at the stagnation pressure of 2 bar and temperature of 75 K in the gas cell is shown in the Fig. 1 for illustration. A complex gas flow barrel shock-wave structures inside the funnels are clear visible. The gas flow rate through the 1st nozzle is 123.7 mbar l/s (at the room temperature of the vacuum pumps). At the background gas pressures in the 1st and the 2nd vacuum chamber, which are maintained by pumping, of 3.0 mbar and 0.6 mbar, the gas flow rates through these chamber are 99.5 mbar l/s and 24 mbar l/s, correspondingly. The gas flow rate into the next vacuum chamber (downstream the 2nd funnel exit) is only 0.19 mbar l/s that allows extracting ions into the high-vacuum conditions ($2 \cdot 10^{-4}$ mbar) with the use of 1000 l/s turbo molecular pump.

Some results of the ion-trajectory simulations are shown in next figures. Fig. 2 shows the ion transmission as function of ion mass at fixed RF frequency and funnel RF voltages. The influence of the 1st funnel RF voltage on the ion transmission for ion masses m = 20 and m = 100 at fixed RF frequency and the 2nd funnel RF voltage is shown in the Fig. 3. The effect of the 2nd funnel RF voltage on the ion transmission for ion masses m = 20 and m = 100 at fixed RF frequency and the 1st funnel RF voltage is shown in the Fig. 4. The influence of the RF frequency on the ion transmission for ion masses m = 20 and m = 100 at fixed 1st funnel RF voltage 20 V_{pp} and 2nd funnel RF voltage 10 V_{pp} is shown in the Fig. 5.

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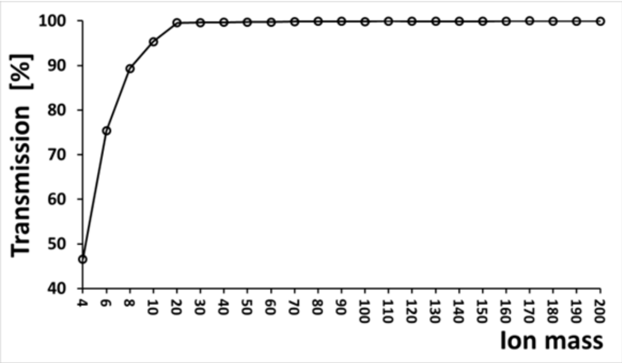

Figure 2: Ion transmission as function of ion mass at fixed 1st funnel RF voltage 20 V_{pp} and 2nd funnel RF voltage 10 V_{pp} and RF frequency 5 MHz.

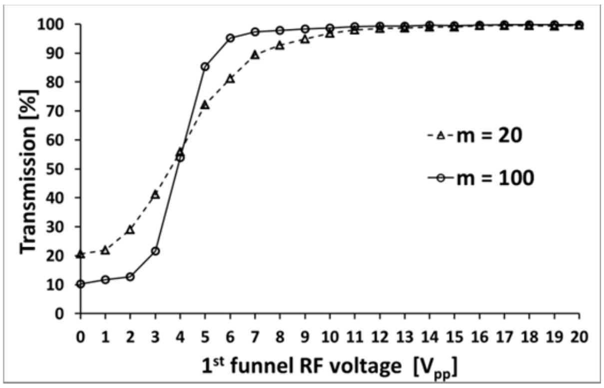

Figure 3: Ion transmission for ion masses m = 20 and m = 100 as function of the 1st funnel RF voltage at fixed 2nd funnel RF voltage 10 V_{pp} and RF frequency 5 MHz.

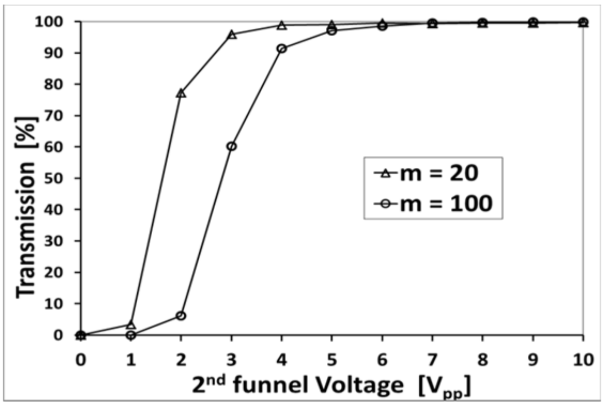

Figure 4: Ion transmission for ion masses m = 20 and m = 100 as function of the 2nd funnel RF voltage at fixed 1st funnel RF voltage 20 V_{pp} and RF frequency 5 MHz.

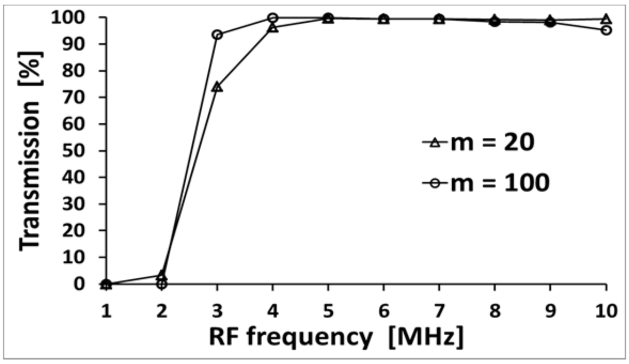

Figure 5: Ion transmission for ion masses m = 20 and m = 100 as function of RF frequency at fixed 1st funnel RF voltage 20 V_{pp} and 2nd funnel RF voltage 10 V_{pp}

The presented results make it apparent that our proposal of the RF-only double-funnel system looks very promising and can be used for ions extraction from a cryogenic stopping cell for the Super-FRS at FAIR. It has the extraction efficiencies of more than 99% for ions in a wide range of masses, it is compact, has relatively simple design and do not require big vacuum pumps for the buffer gas evacuation. Moreover, it has big advantage over the present prototype device [4] because it allows the gas cell operation at much higher stagnation pressure (2 bar). The design pressure in [4] is only 0.3 bar that corresponds to a stopping cell length of 100 cm for the required gas thickness of 20 mg/cm^2. It means that the gas cell can be made much shorter (15 cm) and will allow, in addition, for a smaller time of ions transportation through the stopping gas cell by applying a higher longitudinal DC potential gradient.

References

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