MODELING OF THE BEAM TRANSMISSION EFFICIENCY DEPENDENT ON THE CHARGE EXCHANGE WITH THE RESIDUAL GAS FOR THE CI-100 CYCLOTRON

A. Tikhomirov, G. Gulbekian, R. Oganessian, and M. El-Shazly
FLNR, JINR, 141980 Dubna, Russia

Abstract

The numerical simulation of the beam transmission efficiency dependent on the charge exchange of accelerated ions with the residual gas has been carried out for the CI-100 cyclotron and its subsystems: the axial injection system and the extracted beam channel. The CI-100 cyclotron, used for applied physics researches, will be equipped with an ECR ion source. Produced modeling calculations allow determining the main requirements for the basic parameters of the vacuum system in order to provide the necessary transmission efficiency of accelerated heavy ions.

1 INTRODUCTION

The upgrade project of the CI-100 cyclotron-implanter is now under consideration. The cyclotron will be equipped with the ECR ion source and the axial injection system instead of the internal PIG-source in order to provide heavy ions beams for an irradiation of films and samples in purposes of solid-state physics researches and applications. Modeling of the beam transmission efficiency dependent on the charge exchange with the residual gas directs to set the main requirements for the basic parameters of the cyclotron vacuum system. Basic parameters of the cyclotron and ion beams are presented in Tables 1 and 2.

Table 1: Basic Parameters of the Cyclotron

Diameter of cyclotron magnet pole (cm)	105
Radius of accelerated beams extraction (cm)	46.5
The number of periodic elements of vacuum chamber's sector structure	4
Azimuth length of hill	56°
Average magnetic field in cyclotron center (T)	1.903
Magnet pole hill gap (cm)	2.0÷2.2
Valley gap (cm)	11
The number of dees	2
Voltage on the dee (kV)	50
Vacuum chamber's volume (m^3)	1.5
Vacuum pump's limiting residual pressure (10^{-7} Torr)	1÷2

Table 2: Ion Beams of the CI-100

Accelerated ion	Harmonic mode	Extraction energy (MeV/u)
$^{40}Ar^{10+}$	4	2.4
$^{84}Kr^{10+}$	6	0.5
$^{84}Kr^{13+}$	4	0.9
$^{84}Kr^{15+}$	4	1.2
$^{84}Kr^{17+}$	4	1.5
$^{84}Kr^{20+}$	4	2.2
$^{132}Xe^{16+}$	6	0.5
$^{132}Xe^{20+}$	4	0.9
$^{132}Xe^{26+}$	4	1.5
$^{132}Xe^{31+}$	4	2.1

The loss of the intensity of the ion beam due to its charge-changing collisions with the residual gas molecules is determined by the cross sections for the loss process over a wide range of energy and depends on the pressure distribution in a cyclotron. The average pressure inside the cyclotron is a function of the vacuum chamber's conductivity, the pumping speed of the pumps, the gas loading (first of all, the gas flow from the internal ion source such as a PIG source and the outgassing from vacuum chamber surfaces).

The computer simulation program VACLOS[1] using Microsoft EXCEL has been developed to determine the beam loss caused by the charge-changing collisions between various heavy ions and residual gas molecules during acceleration in a cyclotron. This program includes the following main parts:

- the determination of the pressure distribution inside the cyclotron;
- the evaluation of the ion charge changing cross section;
- the calculation of the transmission factor for different ion beams.

The computer simulation program code GENAP[1] carries out analogous procedures for an oblong vacuum chamber, such as ion beam transport line, linear accelerators etc., and for the fixed ion energy.

Both VACLOS and GENAP codes are based on the experience of FLNR cyclotrons[1,2,3] and have good accordance to experimental data of theirs and other vacuum facilities[4].

2 BEAM TRANSMISSION IN AXIAL INJECTION SYSTEM OF CI-100 CYCLOTRON

The transmission efficiency of the beam due to the charge exchange is shown in Fig. 1. As one can see, it is necessary to have the average pressure in a working range of lower than $3{\cdot}10^{-7}$ Torr to provide the transmission efficiency of better then 82% for $^{132}Xe^{31+}$ and 92% for $^{84}Kr^{15+}$ ions. The results of the numerical simulation of the pressure distribution under different vacuum conditions corresponding to transmission efficiency requirements are illustrated in Figures 2 and 3. Figure 4 shows that the diameter D=10 cm is optimal for the ion guide pipe of the axial injection system.

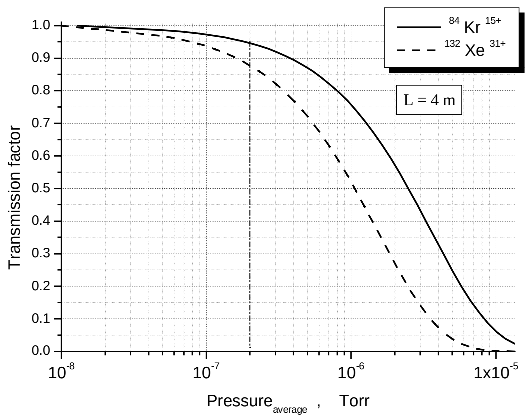

Figure 1: The transmission efficiency in the channel of axial injection system.

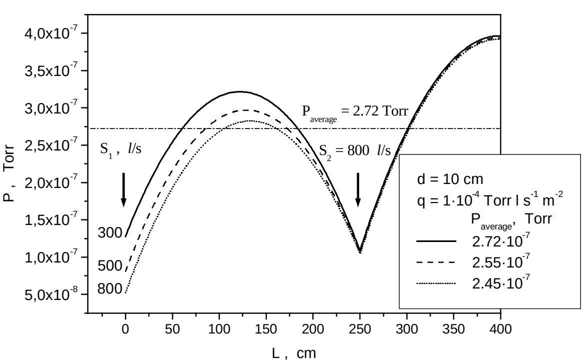

Figure 2: The pressure distribution along the ion guide pipe of the axial injection system for three variants of the pumping speed of the first vacuum pump: 300, 500 and 800 l/s.

3 BEAM TRANSMISSION IN CI-100 CYCLOTRON'S VACUUM CHAMBER

The results of VACLOS simulation of the beam transmission efficiency are presented in Fig. 5. It shows that it is necessary to have the average pressure in a working range of lower than $2{\cdot}10^{-7}$ Torr to provide the transmission efficiency of better then 85% for $^{132}Xe^{31+}$ and 97% for $^{84}Kr^{15+}$ ions. The results of the simulation of

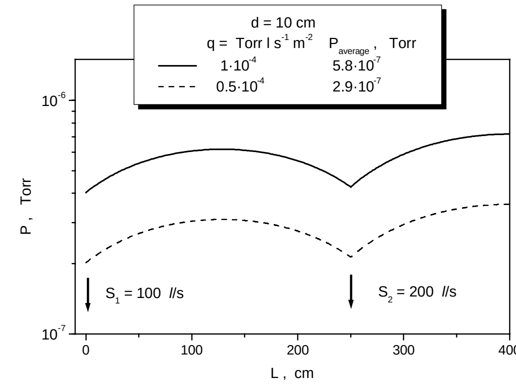

Figure 3: The pressure distribution in the ion guide pipe (∅ 10 cm) of the axial injection system for pumping speeds S_1=100 l/s, S_2=200 l/s, under two values of the gas loading: $q_1=0.5{\cdot}10^{-4}$ $Torr{\cdot}l{\cdot}s^{-1}{\cdot}m^{-2}$ and $q_2=1{\cdot}10^{-4}$ $Torr{\cdot}l{\cdot}s^{-1}{\cdot}m^{-2}$.

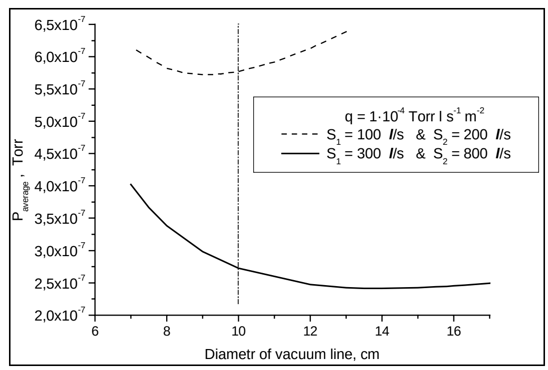

Figure 4: The dependence of the average pressure in the ion guide pipe on the diameter under following pumping conditions: 1) S_1=100 l/s and S_2=200 l/s, 2) S_1=300 l/s and S_2=800 l/s.

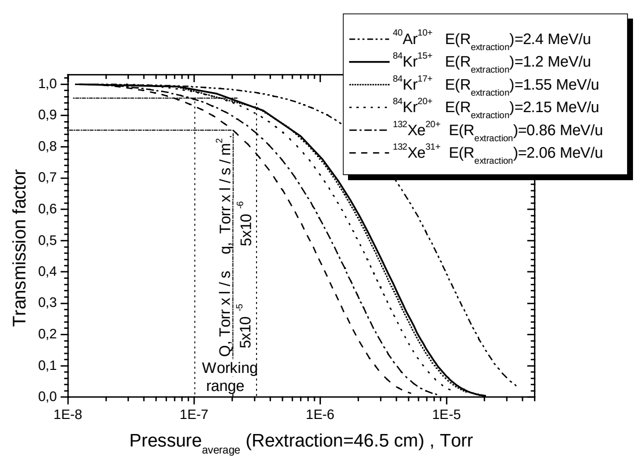

Figure 5: The transmission efficiency of $^{40}Ar^{10+}$, $^{84}Kr^{15+}$, $^{84}Kr^{17+}$, $^{84}Kr^{20+}$, $^{132}Xe^{20+}$ and $^{132}Xe^{31+}$ ions in the CI-100 cyclotron up to the extraction radius R_{extr}= 46.5 cm.

the pressure distribution under different vacuum conditions according to requirements of the transmission efficiency are presented in Fig. 6.

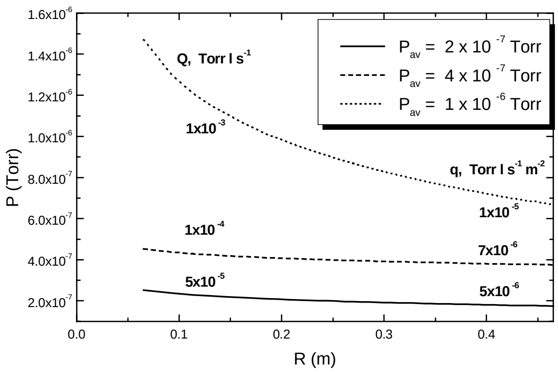

Figure 6: The radial pressure distribution in the cyclotron vacuum chamber under different gas loading conditions for the gas flow in the cyclotron central region Q, Torr·l/s and specific outgassing rate q, $\mathrm{Torr{\cdot}l{\cdot}s^{-1}{\cdot}cm^{-2}}$: 1) $Q=5{\cdot}10^{-5}$, $q_1=5{\cdot}10^{-6}$ and $P_{average}=2{\cdot}10^{-7}$ Torr; 2) $Q=1{\cdot}10^{-4}$, $q_1=7{\cdot}10^{-6}$ and $P_{average}=4{\cdot}10^{-7}$ Torr; 3) $Q=1{\cdot}10^{-3}$, $q_1=1{\cdot}10^{-5}$ and $P_{average}=1{\cdot}10^{-6}$ Torr.

4 BEAM TRANSMISSION IN EXTRACTED BEAM CHANNEL

Transmission efficiencies of accelerated and extracted ion beams are shown in Figures 7 and 8. The average pressure of $5{\cdot}10^{-6}$ Torr ensures the transmission efficiency of all range of ions about 95%. Corresponding vacuum requirements are provided by pumping conditions as shown in Fig. 9.

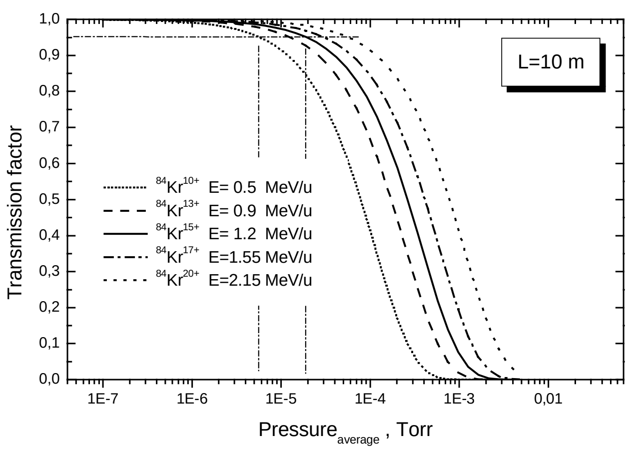

Figure 7: The transmission efficiency of $^{84}Kr^{10+}$, $^{84}Kr^{13+}$, $^{84}Kr^{15+}$, $^{84}Kr^{17+}$ and $^{84}Kr^{20+}$ ions in the extracted beam channel (of length L=10 m) of the CI-100 cyclotron.

5 CONCLUSIONS

The results of ion transmission simulation for the CI-100 cyclotron have allowed to determine the main requirements for the vacuum system parameters in order to provide the necessary efficiency of the ion beam injection, acceleration and transport to an experimental facility after extraction from the cyclotron.

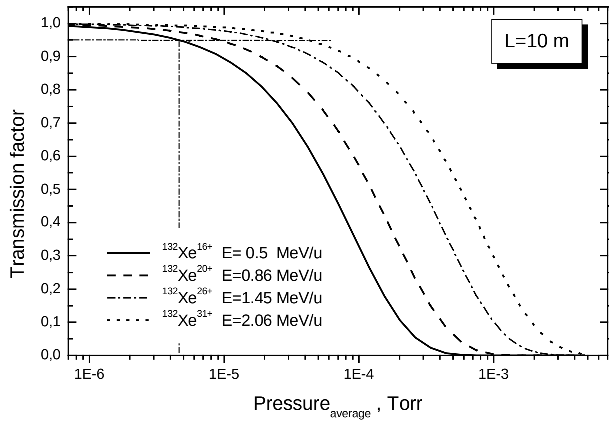

Figure 8: The transmission efficiency of $^{132}Xe^{16+}$, $^{132}Xe^{20+}$, $^{132}Xe^{26+}$, and $^{132}Xe^{31+}$ ions in the extracted beam channel.

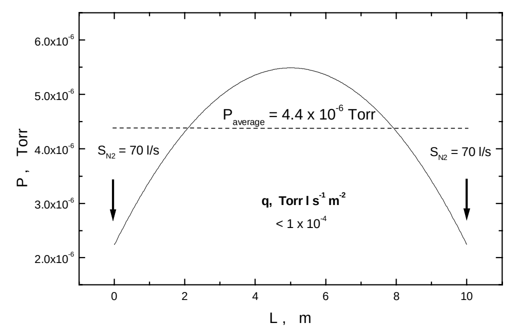

Figure 9: The pressure distribution over the extracted beam channel (of length L=10 m) that is pumped by two pumps with effective speed of N_2 pumping S1=S2=70 l/s.

Due to the flexibility of the input parameters allowing the changing diameter of vacuum chamber, free location of different pumping units and gas sources, the GENAP code turned out to be a very valuable tool for the checking of the existing long vacuum systems (ion beam transport lines, linear accelerator etc.) as well as the design of new ones.

The vacuum loss simulation program VACLOS allows one to estimate quite satisfactorily the transmission factors of any accelerated ions in a wide range of energy and gas loading in different operation regimes both with an ECR and with a PIG ion source, that is important for analyzing and forecasting the efficiency of a cyclotron with the definite vacuum system.

6 REFERENCES

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