SIMULATION OF THE TRANSMISSION EFFICIENCY OF THE DRIBS TRANSPORT LINES

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Abstract

Computer simulation of the beam loss caused by the charge exchange with a residual gas and a transmission efficiency investigation of the ion optic system have been carried out for the DRIBs transport lines. The DRIBs accelerator complex will include two main ion guide lines for transport of low energy radioactive ion beams (with injection energy E_inj ~ 15 keV): the line from the RIB - separator of the U400M cyclotron to the U400 cyclotron ("Phase 1") and the line from the MT25 microtron to the ECR-source of the U400 cyclotron's axial injection system ("Phase 2"), the lengths exceeding 120 m and 70 m, respectively. The results of the beam loss numerical simulation and the optimization of the basic parameters of the vacuum and magnet optic systems allow determining the main requirements for these systems which can provide effective transport of low energy beams.

1 INTRODUCTION

The Dubna radioactive ion beam accelerator complex (DRIBs) bases on two isochronous cyclotrons U-400M and U-400[1-2] that have been equipped with ECR ion sources. This accelerator complex will include two main ion guide lines for transport of low energy radioactive beams and their further acceleration: the line for light radioactive ions from the RIB - separator of the U400M cyclotron to the U400 cyclotron (Phase 1) and the transport line for heavy ions (^{238}U fission fragments) from the MT25 microtron to the ECR-source of the U400 axial injection system (Phase 2). The scheme of the DRIBs accelerator complex is presented in Fig. 1.

The study of the transmission efficiency of the DRIBs transport lines includes two main tasks:

- investigation of the radioactive ion beam loss caused by charge exchange with the residual gas to determine the requirements for the main parameters of the vacuum system and
- optimization of the transport lines that, in its turn, sets the requirements for the system of the magnetic optic elements.

2 BEAM LOSS DUE TO THE CHARGE EXCHANGE

Basic parameters accepted for simulating calculations of the transmission efficiency of radioactive ion beams are presented in Table 1.

Table 1: Basic parameters of radioactive ion beams for Phases 1 and 2 of DRIBs

Ion charge state, z	1+
Injection voltage, V_{inj}	15 kV
The length of the “Phase 1” line (from the RIB - separator to U400)	120 m
The length of the “Phase 2” line (from the microtron to U400)	70 m

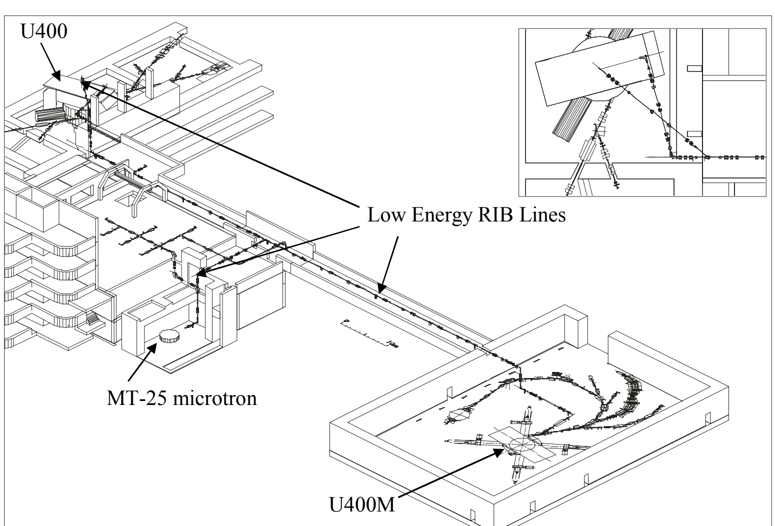

Figure 1: The DRIBs accelerator complex.

CP600, *Cyclotrons and Their Applications 2001, Sixteenth International Conference,* edited by F. Marti

The transmission efficiency of the beam over the path length L depends on the charge exchange cross-section between the ion beam and the residual gas and the pressure distribution in the transport line according to the following expression:

$$T = \exp\left\{ -3.3 \cdot 10^{16} \int_0^L P(\ell) \cdot \sigma(\beta) \cdot d\ell \right\}, \qquad (1)$$

where P is the pressure in Torr for the gas temperature of 293 K, $d\ell$ is the element of the path length in cm, β is the relative velocity (v/c) and σ is the sum of all the relevant capture and loss cross-sections in cm^2/molecule.

The energy of considered single-charged ions is about 15 keV. For this energy the single-electron capture cross-section is much higher than that of single-electron loss and that of multi-electron capture. So it is possible to apply the formula[3]:

$$\sigma_{z,z-1} = 1.43 \times 10^{-12} z^{1.17} E^{-2.76}, \qquad (2)$$

where $\sigma_{z,z-1}$ [cm^2/molecule] is the single electron capture cross-section, z is the ion (projectile) charge, E [eV] is the first ionization potential of the target (residual gas, N_2 in our case).

The transmission efficiency of the beam due to the charge exchange is shown in Fig. 2. As one can see, it is necessary to have the average pressure in a working range of lower than $5 \cdot 10^{-7}$ Torr to provide the transmission efficiency of better then 85%. In order to ensure that level of the average pressure in the transport lines the numerical simulation of the pressure distribution has been carried out by the computer program GENAP[4]. This program has been specially developed for solving this task for oblong geometrical configurations of vacuum chambers (ion guidelines). The study of the following main parameters has been carried out for the optimization of the vacuum system: diameter of the ion guideline, pumping speed, outgassing rate and the distance between pumps.

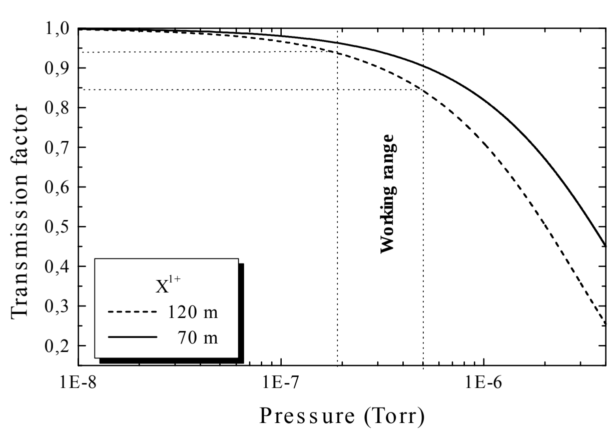

Figure 2: Transmission factor versus average pressure for beam lines of 70 m and 120 m in length.

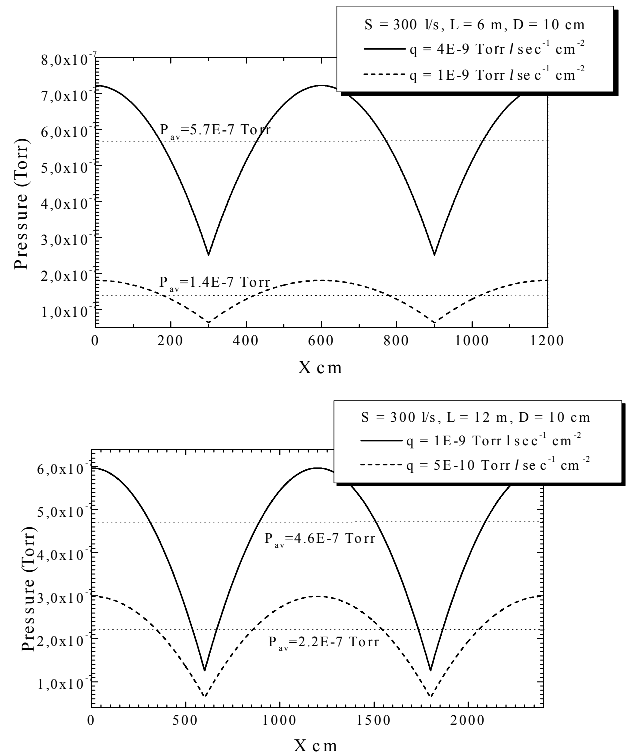

Figure 3: Pressure distribution for the periodic distances of 6 m and 12 m between the pumps (each of 300 *l* /s effective pumping speed) and its dependence on the specific outgassing.

The results of the numerical simulation of the pressure distribution under different conditions are illustrated in Fig. 3. Table 2 presents basic parameters obtained in the course of optimization calculations.

Table 2: Optimization results

	variant 1	**variant 2**
Interval between vacuum pumps L, m	12	6
Pumping speed of vacuum pumps S, l/s	300	150
Diameter of ion transport lines d, cm	10	
Specific outgassing rate q in working range, Torr·l/(s·cm^2)	$8 \cdot 10^{-10} \div 2 \cdot 10^{-9}$	
Corresponding average pressure in ion guide line P_{av}, Torr	$(2 \div 5) \cdot 10^{-7}$	
Corresponding transmission efficiency T, %	$95 \div 85$	

3 OPTIMIZATION OF THE ION OPTIC SYSTEM

The optimization of the ions transport lines has been carried out by means of the TRANSPORT program[5] in order to determine the main parameters of the ion optic system. The basic input parameters accepted for the calculations in addition to the above-mentioned data are shown in Table 3.

Table 3: Basic input parameters

	Phase 1	Phase 2
Maximum mass to charge ratio, A/z	10	140
Emittance $\varepsilon_x = \varepsilon_y$	$100\ \pi$·mm·mrad	

Figure 4 shows beam envelops along the transport lines of Phases 1 and 2 that have bean obtained as the optimization result of the ion optic system. The basic elements of the magnetic optic system are presented in Table 4.

4 CONCLUSION

The study of the transmission efficiency of the DRIBs lines has allowed to determine the main requirements for the vacuum system and to optimize the ion optic system of the transport lines. It provides effective transport of low energy ions (efficiency is not less then 85%) along the beam lines (of Phases 1 and 2) of the DRIBs accelerator complex.

5 REFERENCES

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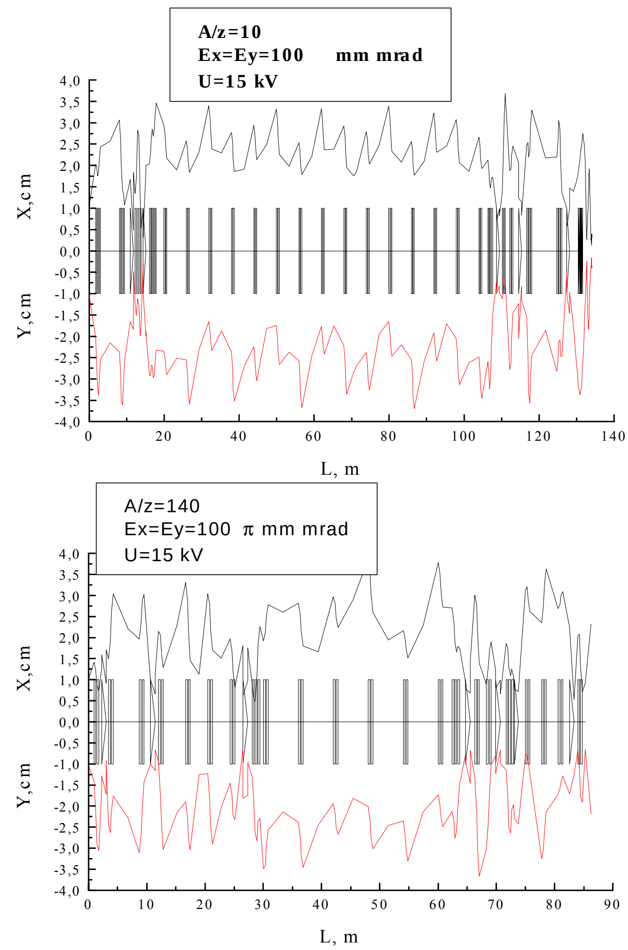

Figure 4: Beam envelops along the transport lines of Phases 1 and 2.

Table 4: Magnetic elements of the ion optic system

Magnetic element	**Required No.**	**Parameters**	
Quadrupole lens	29	Aperture 110 mm	Gradient of magnetic field 1.7 T/m
	53		Gradient of magnetic field 0.9 T/m
Correcting elements	20		Maximum deviation angle ± 0.57°
Bending magnet ± 90°	1	Aperture 70 mm, entrance and exit edge angles 20°	Magnetic rigidity HR= 0.21 T·m
Bending magnet 75°	1		
Bending magnet 90°	4		
Bending magnet 90°	4		Magnetic rigidity HR= 0.055 T·m