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INDUCED HEATING POWER EVALUATION IN RIB TRANSFER LINE OF SPIRAL2

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Abstract

The production of the future Radioactive Ion Beams at SPIRAL2 is studied in the case of an ECR ion source and helium as supporting gas. The RIBs transported in the transfer lines have a multi-component composition and the total current of the beams is mainly defined by helium ions. The total power of the helium component may reach 300 W. For magnetic optical elements the focusing force acting on the ions in the transfer beam line is strongly dependent on mass-to-charge ratio. For this reason the supporting gas ions will be lost at the initial part of the beam line between the ECR ion source and the analysing magnet. The helium beam losses and induced heating power density at the wall of the vacuum tube are evaluated in this report for the transport of Ar, Xe and U ion beams in the RIB transfer line of the future SPIRAL2 facility.

INTRODUCTION

The initial part of the future RIB line (see Fig.1) will start after the SPIRAL2 target and the ECR ion source with a conventional Einzel lens, a 1 T solenoid, a triplet of magnetic quadrupoles and a magnetic dipole for the mass analysis [1-4]. The beam line is designed to accept a transverse geometrical emittance of 80 π mm.mrad in the horizontal and vertical planes. Due to the difference in mass-to-charge ratio most of the contaminants (ECR ion source supporting gas and other ions produced by the target) must be suppressed by means of slits, collimators and magnetic analysis.

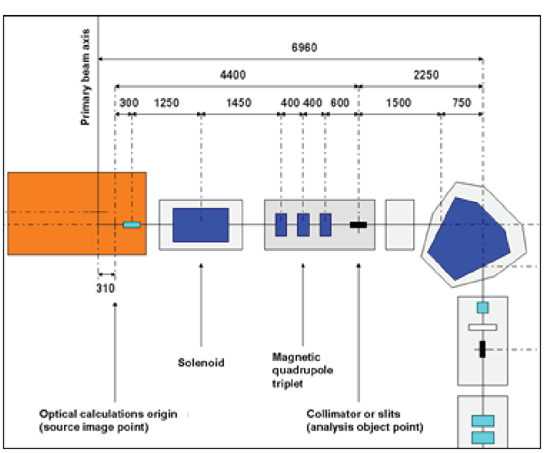

Figure 1: Scheme of the future beam line after the SPIRAL2 target and ECR ion source.

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With high flux RIBs reaching 10^{14} pps the total beam current is mainly defined by the ions of the ECR ion source supporting gas. In the case of helium its current may reach 5 mA at a 60 kV extraction voltage of the ECR ion source and the total power of the helium beam may reach 300 W.

The location of the helium beam losses at the wall of the vacuum tube in the initial part of the RIB transfer line are defined in this report. The induced heating power density of the lost particles is evaluated in the case of the transportation of Ar, Xe and U ion beams.

BEAM PARAMETERS

The beams of interest at the exit of the ECRIS are A=40 (Ar) and heavier ions as A =122 (Xe) and A =237 (U). All the beams consist of single charged positive ions. The supporting gas is He+. Initial beam parameters are contained in Table 1.

Table 1: Parameters of the Beams

Charge, Z	1
Mass number, A	40/122/237
Kinetic energy, W, keV	25/60/38
Beam diameter, mm	4.5
Emittance, $\varepsilon_{x,y}$, π mm×mrad	80
RMS emittance, ε_{RMS}, π mm× mrad	13.33
Charge distribution	Gaussian
Beam current (Ar^+,Xe^+,U^+), I, nA	1-1000
Helium beam current, I_{He}, mA	≤ 5
Helium beam power, W	≤ 300
Neutralization factor, F	0.7/1
Bρ, T×m	0.14/0.39/0.43

OPTICAL ELEMENTS SETTINGS (F=1)

The optical element settings for the analyzed beams calculated by the MCIB04 code [5] are contained in Table 2. The matching conditions correspond to [2-3]. The analyzed beam has a waist at the magnet object and image points for both horizontal and vertical motions. The beam sizes are equal to 2.25mm×7.45mm (horizontal × vertical).

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Table 2: Parameters of the Optical Elements

Analyzed beam	Ar/Xe/U
Einzel Lens voltage, kV	16/38/24
Solenoid field, B_S , kG	2.3/6.3/6.9
Triplet lenses, K1, m^{-2}	2.9/-9.7/12.7
Dipole magnet field, kG	1.9/5.2/5.7

The 100%-beam envelopes and beam line apertures are shown in Fig.2. The analyzed beam losses are equal to 0.2%. Losses occur at the analysing magnet aperture.

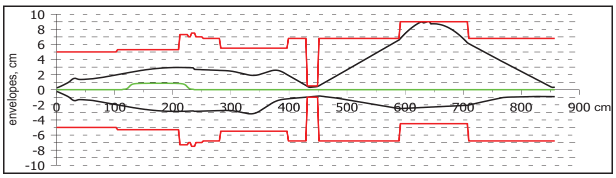

Figure 2: 100%-envelopes of analyzed beam and beam line apertures (red line).

HELIUM BEAM LOSSES POWER DENSITY

The beam losses power density dP/dS is defined as:

$$\frac{dP}{dS} \cong \frac{\Delta P}{\Delta S} \quad (1)$$

Here ΔP is the power of helium beam losses:

$$\Delta P = \sum I_{He} U_{ECR} / N_{He} \quad (2)$$

where U_{ECR} – is the ECR ion source extraction voltage, N_{He} – the number of macro particles representing the helium beam. The summation in Equation (2) is performed over all ions of helium that have been lost at the current step of integration of the equations of motion.

The element of surface area ΔS is defined by formula:

$$\Delta S = 2\pi R_c \left[h + 0.5 \times \left| R_p - R_c \right| \times \left(1 + R_p / R_c \right) \right] \quad (3)$$

Here h – is the value of current step of integration, R_p – the aperture radius at the previous step of integration, R_c –the aperture radius at the current step of integration. Equation (3) takes into account the increasing of surface area due to the change of the aperture radius along the beam line.

The whole helium beam losses power may be found by integration of equation (1) over the surface of the vacuum pipe. The result gives an estimation of the power loss P of the helium beam:

$$P = \int \frac{dP}{dS} dS \le I_{He} U_{ECR} \quad (3)$$

The equality corresponds to a 100% loss of the helium beam. In accordance with beam parameters data (see Table 1) the maximum power P is equal to 300 W.

Helium beam losses are 99.99 % in the case of Xe^+ analyzed beam and 99.96% in the case of Ar^+ analyzed beam. Losses occur at the locations of the quads and collimator. The helium beam losses power density in the case of xenon ions transportation is shown in Fig. 3.

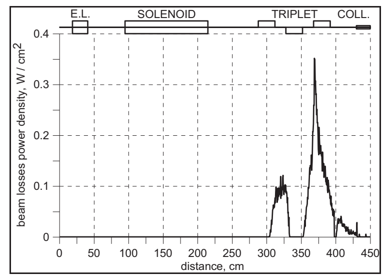

Figure 3: Helium beam losses power density in the case of xenon ions transportation.

The distribution of helium lost ions during transportation of uranium beam has a similar shape due to a small difference in magnetic rigidity. But the value of the total loss power is three times smaller than for Xe beam transportation. It is explained by the decrease as $U_{ECR}^{3/2}$ of the helium beam current in the case of uranium beam transportation. Due to the same reason the magnitude of total loss power in the case of Ar beam transportation is ten times smaller than for the case of xenon beam.

TRANSPORTATION WITH SPACE CHARGE (F = 0.7)

The influence of the space charge in the case of Xe and U beam transportation leads to a significant growth (about 30%) of the magnetic field of the solenoid. As in work [1] the analyzed beam has a hollow structure at the entrance of the triplet of lenses. This leads to a significant emittance growth of the analyzed beams (the emittance at the entrance of the triplet is 2.8 times greater than the initial one).

The beam sizes at the image point of the magnet are approximately equal to the initial ones. Therefore in the presence of space charge the resolution of the analyzing magnet doesn't differ significantly from the design value. The losses of the analyzed beam are about 20% and may be explained by strong emittance growth due to the hollow beam effect. The helium beam losses power density in the presence of space charge and in the case of Xe ions transportation is shown in Fig. 4 (red line). For comparison the same plot in the absence of space charge is shown also (black line). Almost all of the helium ions

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(99.95%) are lost in the channel between the solenoid and the object point of the analysing magnet.

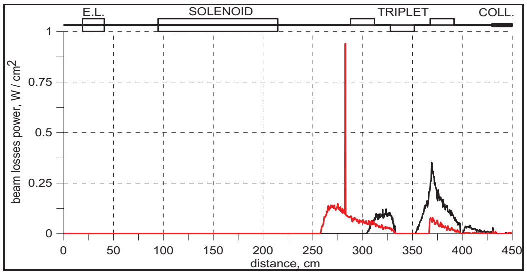

Figure 4: Helium beam losses power density in the case of Xe ions transportation.

In contrast to the case of full neutralization more than 60% of the helium ions are lost in the area between the solenoid and the triplet. One-third of them are lost at the point of reduction (from 7 cm to 5 cm) of the aperture of the vacuum tube. The significant change in the distribution of the losses is explained by the increase of the solenoid magnetic field in the presence of space charge forces.

As in the case of F =1 during the transportation of uranium beam the distribution of the helium beam losses has a similar shape. But the magnitude of the total power losses is three times smaller.

In the case of the argon beam transportation the defocusing force acting on Ar ions is the same as in previous cases of Xe and U ions transportation in the presence of the space charge.

The helium beam losses power density in the presence of space charge and in the case of Ar ions transportation is shown in Fig.5 (red line). For comparison the same plot in the absence of space charge is shown also (black line). Almost all of the helium ions (99.96%) are lost again in the channel between the solenoid and the object point of the analysing magnet.

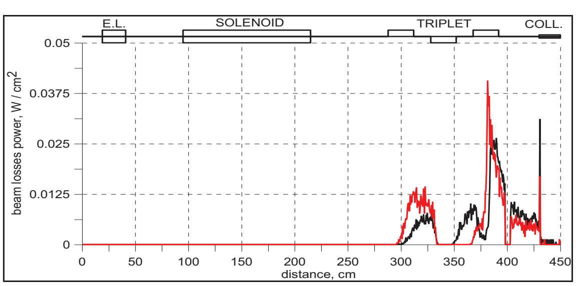

Figure 5: Helium beam losses power density in the case of Ar ions transportation.

In contrast to the cases of the Ar and U analyzed beams the distribution of the helium beam losses power density doesn't change significantly in the presence of space charge. This is explained by the relatively small value of the solenoid magnetic field (3.3 kG). Indeed the minimal value of the solenoid magnetic field that corresponds to the appearance of the helium beam losses between the solenoid and the triplet is equal to 4.1 kG in this case. For smaller solenoid fields, helium beam losses occur only inside the triplet and in the drift space between the triplet and the collimator placed at the object point of the dipole magnet.

CONCLUSION

The influence of the helium beam space charge leads to increase of the solenoid field (up to 30%). Quadrupole gradients do not change so significantly (increase not more than 10%).

For relatively small solenoid field $B_S \le B_m$ the helium beam losses occur only inside the triplet and in the drift space between the triplet and the collimator placed at the object point of the magnet. More than 99.9% of the helium ions are lost in this area.

In the case of Ar^+ ions transportation $B_m = 4.1$ kG while the solenoid field B_S is less than 3.3 kG for all values of neutralization factor *F*. For this reason the helium ions losses don't occur before the quadrupole triplet.

In the case of Xe and U ions transportation $B_m =$ 7.0 kG while the solenoid field $B_S < B_m$ in the case of neutralization factor $F = 1$ and $B_S > B_m$ in the case of neutralization factor F =0.7. Therefore the helium beam losses appear in the drift space before the triplet of lenses in the case of neutralization factor *F*=0.7.

In accordance with these results an additional cooling system of the vacuum pipe should be installed in the area between the solenoid and the object point of the magnet. The up-coming heat load calculations and the temperature rise evaluation should confirm this recommendation.

REFERENCES

[1] N. Kazarinov, F. Osswald, "Simulation of Hollow Beam formation at the Initial Part of RIB Transport Channel of SPIRAL2", Proc. IPAC2011, San Sebastian, http://jacow.org/.

[2] F. Osswald, A. Khouaja, M. Rousseau, "A Secondary Radioactive Beam Line Section for the SPIRAL 2 Project", Proc. HIAT 2009, Venice, p.346, http://jacow.org/.

[3] D.Boutin, N. Kazarinov, F. Osswald, C. Peaucelle, T.Thuillier, "RIB dynamics of the SPIRAL 2 Transfer Line", Proc. HIAT2012, Chicago, p.54, http://jacow.org/.

[4] F. Osswald, T. Adam, E. Bouquerel, D. Boutin, A. Dinkov, M. Rousseau, A. Sellam, N. Kazarinov, H. Weick, M. Winkler, "Transfer of RIB's Between ISOL Target and Experiment Halls at SPIRAL 2", Proc. IPAC2013, Shanghai, p. 82, http://jacow.org/.

[5] V. Alexandrov, N. Kazarinov, V. Shevtsov, "Multi-Component Ion Beam code – MCIB04", Proc. RuPAC'04, Dubna, Russia, p. 201, http://jacow.org/.