Methods of Compensation of Beam Vertical Divergence at the Exit of Spiral Inflector in Cyclotrons.

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INTRODUCTION

While the axial injection into the cyclotron, beam is turned from axial direction into median plane by means of inflector. Commonly used type of inflector is an electrostatic spiral inflector. The spiral inflector is easy to handle and has a good beam transmission factor.

On the other hand, the negative feature of spiral inflector is the beam vertical divergence at its exit. It leads to increasing of beam vertical dimension and aperture losses at the first orbits. The methods of compensation of the beam vertical divergence at the inflector exit are considered at present report

This methods are used at FLNR JINR cyclotrons and give a good results in transmission factor, beam quality and operation modes.

THE PROBLEM OF BEAM VERTICAL DIVERGENCE

The calculations and exploitation experience show the aperture losses in the cyclotron centre because of the beam vertical divergence at the inflector exit. It not only worsens the beam final intensity and quality, but decreases the inflector operation time.

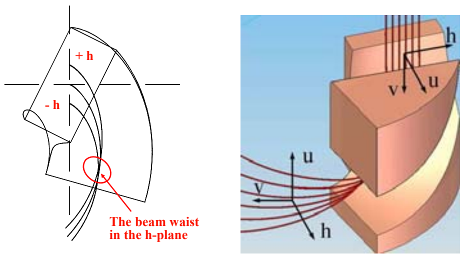


Fig.1. U400 spiral inflector. Rotated coordinate system u,h,v and test trajectories with initial shifting along h axis.

The beam vertical divergence at the inflector exit appears because the ions, shifted from the central ion trajectory, have different length paths inside the inflector, and so spend a different time in the inflector electric field. The farther ion is shifted from the central trajectory at the inflector entrance (especially along h axis), the more its vertical divergence at the exit.

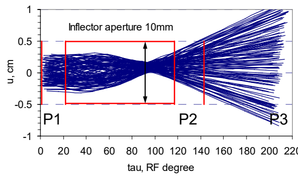


Fig.2. The beam form along u axis (vertical)
P1 – P3 are the check points at fig. 5.

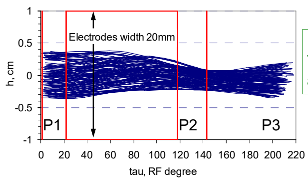


Fig.3. The beam form along h axis (median)

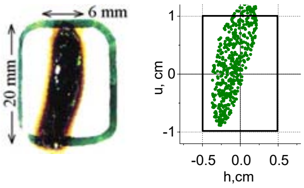


Fig.4. Experimental and calculated beam track at the exit window of the inflector box, U400 cyclotron

THE ADDITIONAL CORRECTING ELEMENTS

Usually to produce vertical focusing of the beam, the additional correcting element is placed between the inflector exit and the first accelerating gap. Such element could be either the passive magnetic channel [1] or the electrostatic quadrupole lens [2]. Unfortunately, the additional correcting elements need special place and equipment for installation at the cyclotron centre and it could be a problem especially for compact cyclotrons.

1. Passive magnetic channel

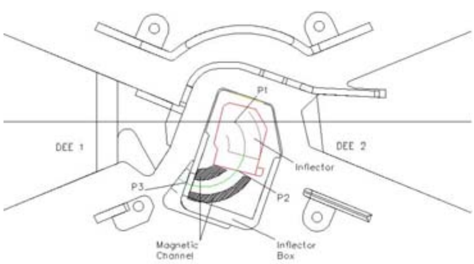


Fig.5. U400 cyclotron centre with passive magnetic channel.

At FLNR cyclotron U400, the passive magnetic channel was used for vertical focusing of injected beam, figure 5. The channel produces a decreasing radial gradient of the magnetic field for vertical focusing of injected beam. As a result, it gave the increasing of beam transmission factor at the cyclotron exit at about 1.4 times.

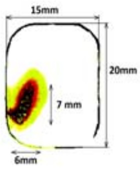
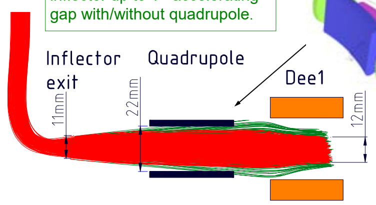


Fig.6. Beam track position at the exit window of the inflector box (P3 at fig.5) - result of magnetic channel usage.

2. Electrostatic quadrupole

The new FLNR cyclotron DC-280 is equipped with electrostatic quadrupole lens, placed after spiral inflector The lens allow to adjust injection mode operatively. Quadrupol with aperture 22mm and length 40mm has a potential at the electrodes up to 3kV. It could be uses not only for beam focusing, but additionally as a steering, to adjust the beam position at the first accelerating gap. Calculations shown that usage of quadrupol increases transition factor along acceleration from 75% up to 98 %.

Fig.7. Quadrupole lens. Beam vertical trajectory through inflector up to 1st accelerating gap with/without quadrupole.



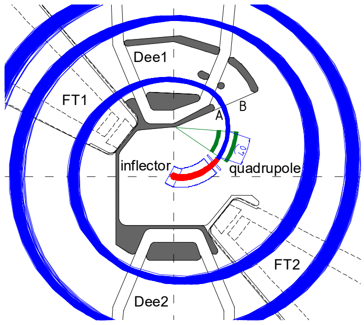


Fig.7. DC280 cyclotron centre. Injected/accelerated beam trajectory

SPECIAL FORM OF INFLECTOR ELECTRODES

At the present time, U400 cyclotron is equipped with spiral inflector with special form of electrodes [3]. At the new form spiral inflector, electric field not only bends the beam from the axial direction into the cyclotron median plane, but provides focusing of the beam inside the inflector. At this case the ions move closer to the central ion trajectory, what decrease the dispersion of the ions path length. The vertical dimension of the beam at inflector exit is decreased, figure 9. The experimental results with new inflector shown the increasing of the beam intensity at about 30%.

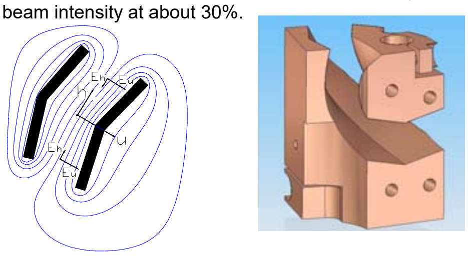


Fig.8. U400 spiral inflector with special form of electrodes.

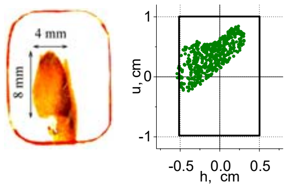


Fig.9. Real and calculated beam track position at the exit window of the inflector box

CONCLUSION

Different methods of compensation of the beam vertical divergence at the spiral inflector exit were used at FLNR new and operated cyclotrons. The calculations and experimental results showed a high efficiency of this compensation in increasing of the beam intensity. The choice of the method is dependent on constructive and operational features of cyclotrons.

REFERENCES

[1] M.Lieuvin et al., “Commissioning of Spiral, the GANIL radioactive beam facility” In: Proceedings of the 16th Conference on Cyclotrons and Their Applications, 13 – 17 May 2001, USA, p.p. 59 – 63.
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