COMPENSATION OF THE BEAM VERTICAL DEFOCUSING AT THE EXIT OF U400 CYCLOTRON SPIRAL INFLECTOR

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Abstract

The calculations and experiments on the beam dynamic at U400 cyclotron spiral inflector shows the presents of the vertical defocusing of the beam at the inflector exit. This leads to aperture losses of the beam at the cyclotron centre. In this present work the method of decreasing of the vertical defocusing effect of U400 cyclotron spiral inflector is presented. The decreasing of the vertical defocusing is achieved by means of special form of the inflector electric field. The calculations have shown the beam vertical envelope at the inflector exit has an appreciably smallest dimension and slope.

INTRODUCTION

The axial injection system of FLNR U400 cyclotron is in operating since 1996 [1]. The system uses the spiral inflector with electric radius A=2.5cm, magnetic radius R=2.56cm, aperture 1cm and no tilt. Design of the U400 spiral inflector was made with CASINO code. The form of the inflector electrodes and transverse electric field distribution at the electrode entrance, calculated with RELAX3D code, are presented in the figure 1. The original U400 inflector has the flat transverse form of the potential electrodes.

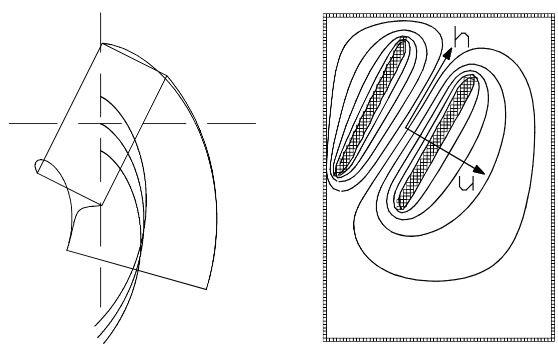

Figure 1: The top view of original form of U400 inflector electrodes and electric field distribution.

The calculations and experiments have shown that the optical property of the spiral inflector leads to the essential increasing of the beam vertical dimension and slope at the inflector exit. According to the results of numerical studies this effect takes place independently of the form of the beam at the inflector entrance. The beam vertical defocusing leads to the beam loses at the aperture of the inflector box exit window and the first accelerating gap. Moreover it worsens the cyclotron operation mode adjustment.

The results of numerical studies of the test beam transportation through the U400 spiral inflector are presented at the figures 2 – 5. The results are presented at the moving optical coordinate system (u,h,v) there u and h axis presents the inflector transverse plane, figure 1, and v axis directs along the central ion trajectory. At the calculations the computer 3D model of the inflector electric field distribution was used. The transverse emittanses at the inflector entrance are shown in the figure 2 [2,3]. The u-direction RMS emittance 0.006π·cm·rad and h-direction RMS emittance 0.008π·cm·rad. The form of the beam at u and h direction from the inflector entrance up to the first accelerating gap are shown in the figures 3 and 4. According to the figure 4, during transportation through the spiral inflector the beam receives strong increasing of the vertical dimension and slope.

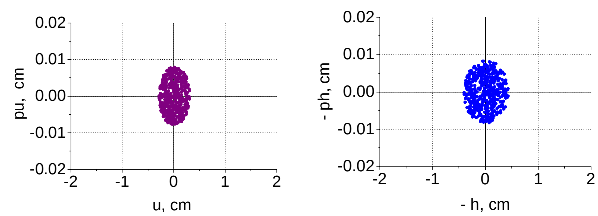

Figure 2: The transverse emittances of the test beam at the inflector entrance.

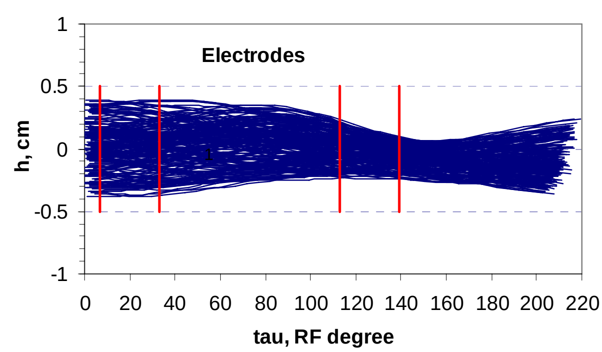

Figure 3: The form of the test beam at h-direction.

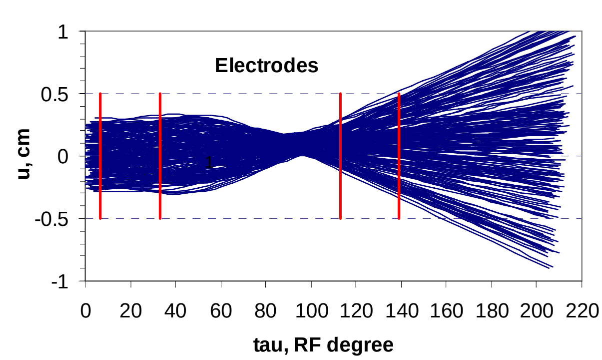

Figure 4: The form of the test beam at u-direction.

The numerical studies show that the vertical defocusing appears because the ions, shifted from the central ion trajectory along the h-axis, figure 1, have the different length paths inside the inflector. The ions, shifted at the start point towards the inflector curvature centre, have a smallest length of the path. The ions, shifted at the start point in the opposite direction, have a larger length of the path. Because of the different length of the paths, the beam has the waist in the h-plane near the inflector exit, figures 1 and 3. On the over hand, the ions with the different length of the paths inside the inflector spends a different time in the inflector electric field. That leads to the ions receive a different angle of rotation in the vertical direction. As a result, the ions with +h shifting at the start position receive +u shifting at the inflector exit. And vice versa, the ions with -h shifting at the start position receive -u shifting at the inflector exit. The calculations show the beam transverse emittances at the exit of the spiral inflector exit transform to the form, presented in the figure 5. For the test beam the area of the vertical (u-direction) RMS emittance 0.068π·cm·rad and horizontal (h-direction) RMS emittance 0.053π·cm·rad. The increasing of the emittances area regarding to the inflector entrance is about 10 and 6 times respectively. The transverse u – h form of the test beam at the exit of the original U400 spiral inflectors has increasing vertical dimension that leads to the aperture losses, figure 10.

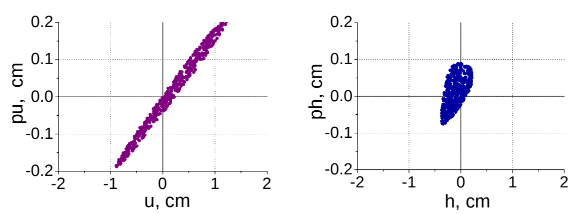

Figure 5: The transverse emittances of the test beam at the original U400 inflector exit.

The numerical studies show that the influence of ±u shifting of ions at the inflector entrance has a slight impact on the beam form at the inflector exit.

CONPENSATION OF THE BEAM VERTICAL DEFOCUSING

At the present time there are some methods of decreasing of the vertical defocusing effect of the spiral inflector. Usually it is used the additional correcting elements at the inflector exit, like as quadruple lens [4] or passive magnetic channel [5].

The numerical studies of the beam transportation through the spiral inflector show the possibility of compensation of the beam vertical defocusing by means of the special form of the inflector electric field. At the new form spiral inflector the electric field not only bends the beam from the axial direction into the cyclotron median plane, but provides the decreasing of the beam vertical defocusing effect of the spiral inflector [6]. To achieve it the additional, Eh component of the spiral inflector electric field is used. This component directs to the inflector centre and produces the focusing of the beam at the h direction. The using of this form of the electric field leads to decreasing of the beam vertical (u) dimension and slope at the inflector exit, compare figures 8 and 9. Accordingly, the vertical emittance is decreased too, compare figures 4 and 5. On the over hand that leads to the increasing of the beam horizontal (h) dimension and emittance, compare figures 3, 5 and 7, 9.

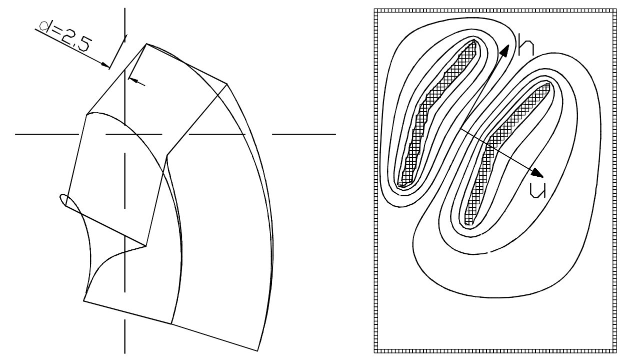

Figure 6: The top view of new form of U400 inflector electrodes and electric field distribution.

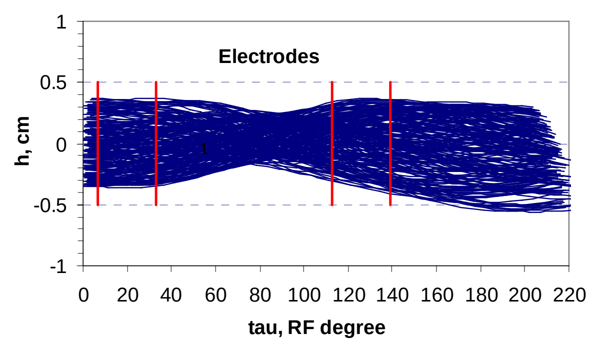

Figure 7: The form of the test beam at h-direction.

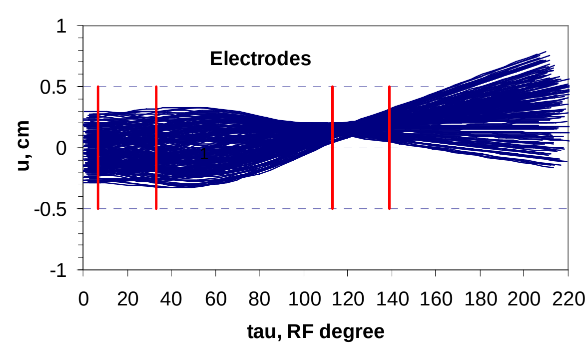

Figure 8: The form of the test beam at u-direction.

The effect of decreasing of the beam vertical dimension at the inflector exit is achieved by means of the h-direction focusing of the beam, mainly at the first part of the beam path inside the inflector. Because of the h-direction focusing, in the h-plane the beam waist shifts towards the inflector entrance, figure 7. In this case the beam ions move closer to the central ion trajectory. This leads to decreasing of dispersion of the ions path length in the inflector electric field and, accordingly, ions rotation angles in the vertical direction. The calculations have shown the beam transverse emittances at the exit of new form U400 inflector transform to the form, presented in the figure 9. For the test beam the area of the vertical (u-direction) RMS emittance 0.012π·cm·rad and horizontal (h-direction) RMS emittance 0.12π·cm·rad. The increasing of the emittances area regarding to the inflector entrance is about 2 and 15 times respectively. The calculations have shown the beam vertical envelope at the inflector exit has an appreciably smallest dimension and slope. The transverse u – h form of the test beam at the exit of the original and the new U400 spiral inflectors in comparison with the inflector box frame are presented in the figure 10.

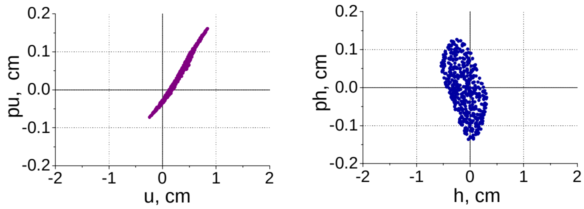

Figure 9: The transverse emittances of the test beam at the new U400 inflector exit.

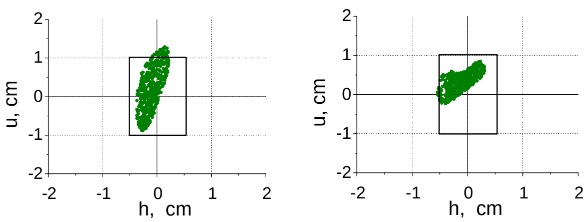

Figure 10: The transverse form of the beam at the original and new spiral inflectors exit.

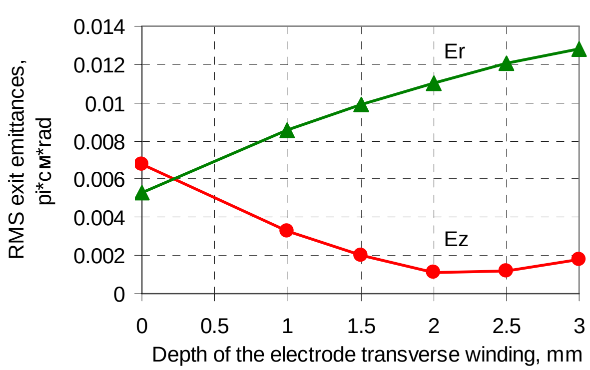

Figure 11: RMS exit emittances in depending of the depth of electrode transverse winding.

The electric field of the new spiral inflector with alternating-sign Eh component is formed with the help of the special form of the electrodes. The transverse form of the inflector electrodes is changed in to the winding form, like as in the figure 6. The convex upper electrode and concave lower electrode produce the electric field with Eh component, directed to the inflector centre. At the present work the calculations were made with the computer model of the new U400 spiral inflector with the different depths of winding of electrodes transverse form. The depths d=0 – 3mm are considered. The influence of the depth of winding of electrodes transverse form on the area of transverse emittances at the inflector exit is presented in the figure 11. It was found the depth d=2.5mm is optimal for the beam transverse dimensions and emittances. At the present time the new U400 spiral inflector is under construction.

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