U400 CYCLOTRON SPIRAL INFLECTOR WITH BEAM VERTICAL FOCUSING EFFECT

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Abstract

The main losses of the injected beam are localized at the centre region of the cyclotron. One of the problems is the defocusing action of the spiral inflector. At the present work the method of decreasing of the vertical defocusing effect of the spiral inflector is presented. The decreasing of the vertical defocusing is achieved by means of special form of the inflector electric field. At FLNR, JINR, the new type of the inflector was investigated and manufactured. At the present time the inflector is installed and works at the U400 cyclotron. The experiments with the new inflector have shown the increasing of the beam intensity and more tunable work of the cyclotron.

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. The U400 original inflector has the flat transverse form of the potential electrodes, figure 1.

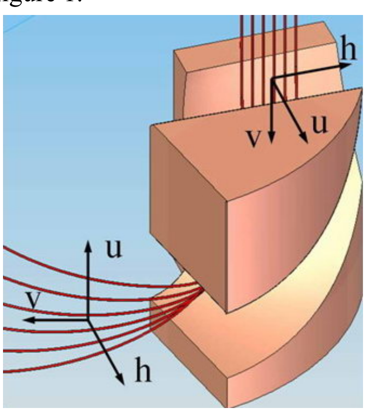

Figure 1: The model of U400 spiral inflector with original form of electrodes.

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. The beam vertical defocusing leads to the beam loses at the aperture of the inflector box window and at the first accelerating gap. Another problem of spiral inflector is phase dispersion of exit beam.

The results of numerical studies and experiment of the beam transportation through the U400 original spiral inflector are presented at the figures 2 ÷ 5. The results are presented at moving optical coordinate system (u, h, v) there u and h axis presents the inflector transverse plane and v axis directs along central ion trajectory, figure 1. The form of the beam at u and h direction from the inflector entrance up to the first accelerating gap are shown in the figure 3. During transportation through the spiral inflector the beam gets the increasing of vertical dimension and slope. The comparison of transverse radial (h-axis) and vertical (u-axis) emittanses at the entrance and exit of the original inflector have shown increasing in 6 and 10 times respectively, figures 2 and 4.

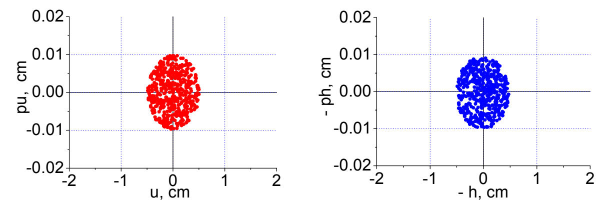

Figure 2: Transverse emittances at inflector entrance.

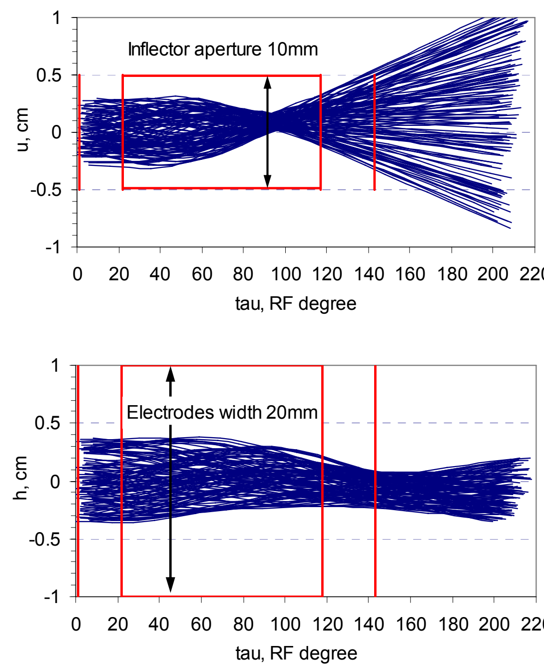

Figure 3: The form of the beam at u and h-direction from inflector entrance up to first accelerating gap.

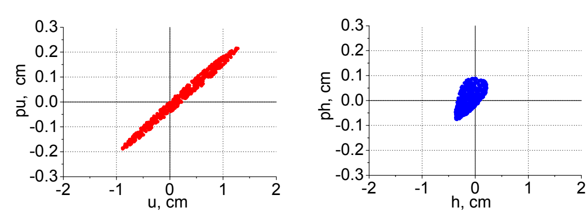

Figure 4: Transverse emittances at first accelerating gap.

The numerical studies have shown 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 and spend a different time in the inflector electric field. As a result, the ions with +h shifting at the start position has a larger path length and receives +u shifting at the inflector exit. And vice versa, the ions with -h shifting at the start position has a smallest path length and receives -u shifting at the inflector exit.

To find a form of the beam after inflector a termo-sensitive film was placed at the first accelerating gap. The gap window has 20mm of height and 10mm of width. Because the increases of beam vertical dimension there is beam losses at aperture, figure 5.

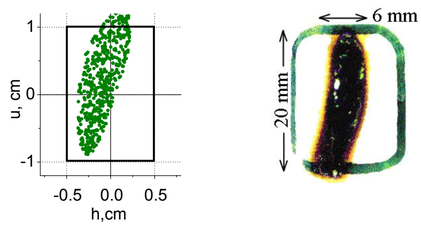

Figure 5: The calculation and experimental results - beam track at the U400 first accelerating gap window.

Moreover there is another problem – spiral inflector produce beam phase dispersion. The phase dispersion appears because not only different length paths of the ions inside inflector, but because the effects of accelerating and decelerating of the ions at the entrance and exit electric fringe fields. The phase dispersion gives a debunching effect and decreases the efficiency of the cyclotron buncher system. For the test beam with no phase dispersion at the inflector entrance the calculation gives about ±7 degree of the phase dispersion after the inflector exit, figure 6.

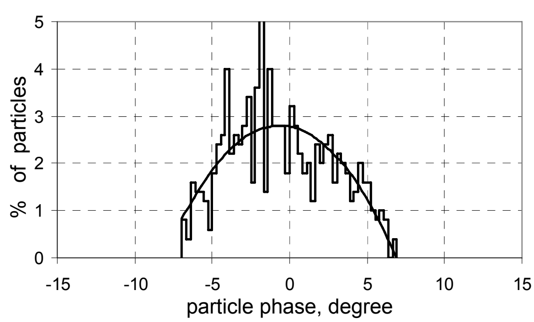

Figure 6: The beam phase dispersion after the inflector at the first accelerating gap.

CONPENSATION THE BEAM VERTICAL DEFOCUSING

At the present time there are some methods of decreasing of the vertical defocusing effect of the spiral inflector. Usually the additional correcting elements are placed after inflector exit and before first accelerating gap, like as quadruple lens [2] or passive magnetic channel [3]. Unfortunately these elements require free place at the cyclotron centre.

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. To achieve it the additional Eh component of the spiral inflector electric field is used.

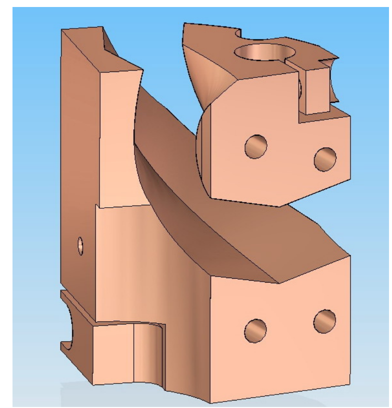

Figure 7: The new form electrodes of U400 inflector.

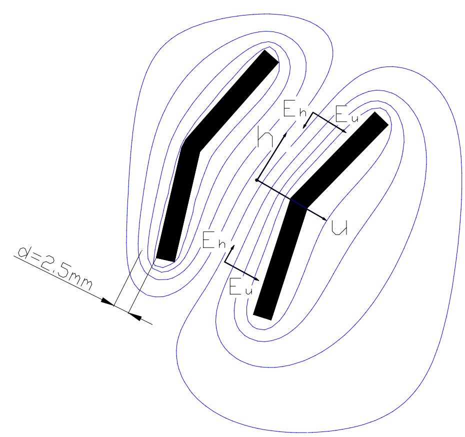

Figure 8: Electric field distribution at new inflector model. d - depth of electrode transverse bending.

The additional Eh component directs to the inflector centre, figure 8, and focuses beam at h-axis direction. In this case the beam ions move closer to the central ion trajectory. These leads to decreasing of dispersion of the ions path length in the inflector electric field and, accordingly, to decreasing of dispersion of ions rotation angle in the vertical direction. Summary the vertical beam dimension at inflector exit is decreased and the problem of aperture beam losses at the first accelerating gap is eliminated. On the over hand the increasing of beam radial dimension is take place but it is not so relevant for the beam motion, figures 9 and 11.

The beam phase dispersion at the exit of the new form inflector stay at about the same level, figures 12, but can be changed depending on the path length between inflector and first accelerating gap.

Calculations of transverse radial (h-axis) and vertical (u-axis) emittanses have shown their increasing from the entrance to exit of the new form inflector by factor 15 and 2 respectively, figures 2 and 10.

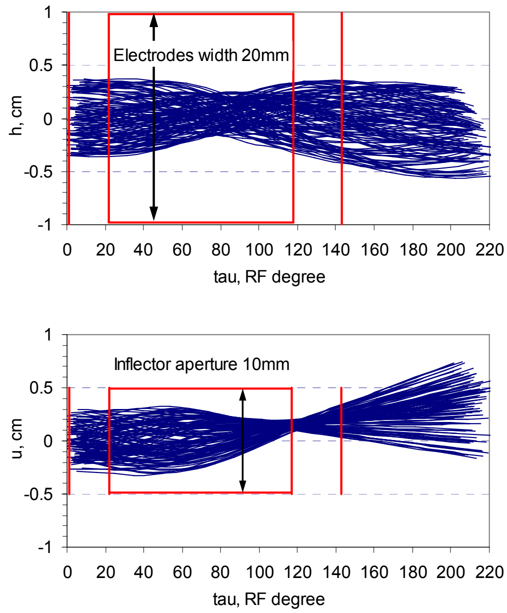

Figure 9: The form of the beam at u and h-direction from inflector entrance up to first accelerating gap.

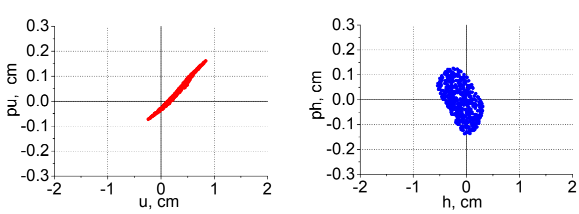

Figure 10: The transverse emittances of the test beam at the new U400 inflector exit.

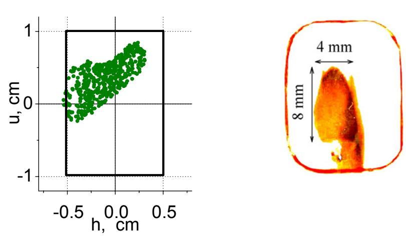

Figure 11: The calculation and experimental transverse form of the beam at the first accelerating gap window.

The special forms of spiral inflector electrodes are designed to produce the electric field with alternating-sign Eh component [4]. The transverse form of the new electrodes has the bending transverse profile, figures 7 and 8. The convex upper electrode and concave lower electrode produce the electric field with Eh component, directed to the inflector centre. The focusing depends on the bending depth, d parameter at figure 8. The different depths, d = 0 ÷ 3mm, of bending of electrodes transverse form were investigated at the computer model of U400 new spiral inflector [5]. The influence of bending depth on an exit beam parameters is presented at figure 12.

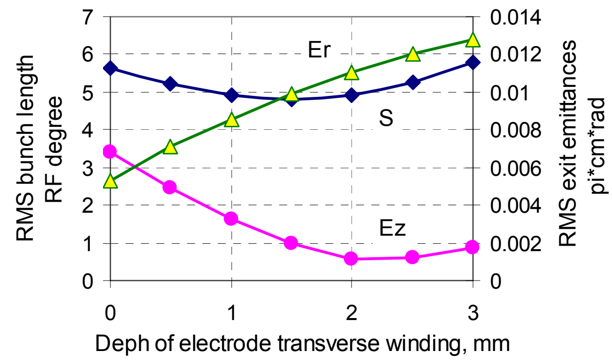

Figure 12: S - RMS bunch length and Er, Ez - RMS transverse emittances at the inflector exit in depending of the depth of electrode transverse winding.

In autumn 2009 the new spiral inflector with the depth of bending of electrodes transverse form d=2.5mm was manufactured and installed on U400 cyclotron. The electric and magnetic radiuses of the new inflector are the same as for original inflector and the original electrodes just were replaced with the new one. The first experiments with new inflector have shown not only the increasing of the beam intensity at about 30% but the operation makes the tuning of U400 cyclotron much easier and quicker. It is especially important because U400 cyclotron use 48Ca beam at experiments of super-heavy elements synthesis. At present time we have a plane to install a new inflectors at all FLNR cyclotrons and to employ it at new cyclotron projects.

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