Research for HIRFL new improvement project *

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Abstract According to the newest matching mode between the two cyclotrons at HIRFL, the beam obit properties were researched, especially for the harm of existing 'over-magnetic shim' in SSC as well as the trajectory in the new mode. The results obtained are encouraging.

Key words isochronous cyclotron, over-magnetic shim, matching mode, beam separation, effective rf voltage

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1 Introduction

The Heavy Ion Research Facility at Lanzhou-Cooling Storage Ring (HIRFL-CSR) is an accelerator complex system, which consists of two cyclotrons (SFC and SSC), a main cooling storage ring (CSRm) and an experimental ring (CSRe) (Fig. 1). The heavy ion beams accelerated from SFC or from SFC, SSC, are transported to CSRm, and then further accelerated by CSRm. The beam energy for the lighter heavy ions, such as carbon, nitrogen, Oxygen and so on, could reach 1000 MeV/u; and for the heavier ions, such as lead, uranium and so on could reach 400 MeV/u.

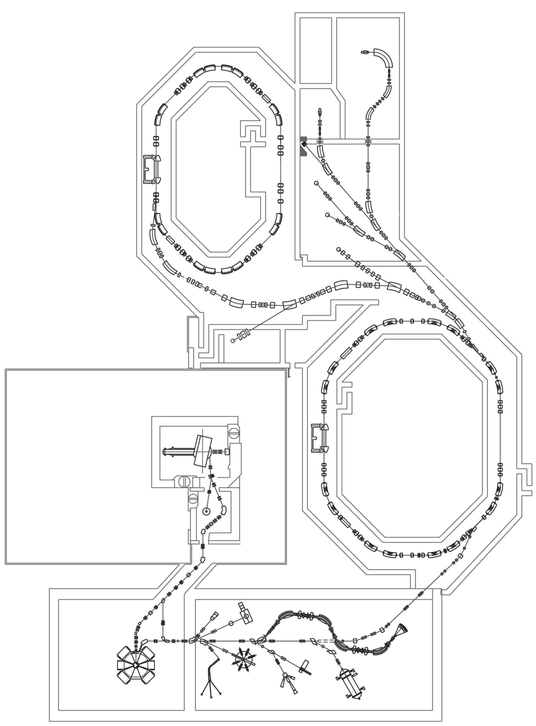

Fig. 1. The sketch of HIRFL-CSR.

CSRe called "Lanzhou spectrometer" is used for nuclear physical experiment. The HIRFL system, which consists of two cyclotrons，have already been operated for near 20 years. The CSR project has been finished and the beams of carbon, argon and xenon are accelerated in it successfully.

2 Existing problems

At present, the energy range extracted from SSC is from 5 MeV/u to 100 MeV/u. The matching modes between SFC and SSC have four kinds where one mode is $H_{\rm SFC}/H_{\rm SSC}$=3/4, covering about 22% energy range and the rest is 1/2, 3/2 and 3/6. The matching efficiency of the former is 100%, and the others are only 50%. It means that in this case, only 50% of the beams coming from SFC can be accelerated in SSC. The rest of them would be lost. It is a harmful thing for the beam intensity of SSC.

The other problem existing in SSC is that the rf voltage is not high enough. Although we have made some improvements and the rf voltage has increased, it still does not meet the design requirement. For example, when O^{8+} ions are accelerated to 100 MeV/u

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with rf frequency 12.7 MHz in SSC, the afforded rf voltage is only 170 kV, where the design requirement is 230 kV. In this case, $H_{\rm SSC}$=2 and the effective accelerated voltage is only

$$V_{\rm eff} = V_{\rm rf}\sin(H_{\rm SSC}\alpha/2) = 0.5V_{\rm rf} = 85\ {\rm kV},$$

where α=30°, which is the angle of rf cavity. You can see the effective rf voltage that could be used is too slow. So in the isochronous filed, the beam separation is very small. It is only 8 mm less than the beam width of 11 mm in the region of injection radius. So many particles in the accelerated beam of the first turn will be lost by hitting on the outside of injection system.

The other existing problem in SSC is the so-called "over shim". In the beginning of SSC design, considering the effect of the magnetic elements in the injection system when they are assembled, we put some irons in the edges of small radius of the second sector and the third sector (Fig. 2). While the results of magnetic field measurement with the injection elements indicate that the shim irons are too many, we could not cancel all of the effects, even where the maximum currents are used in the so-called 'nose coils' located in small radius of SSC sectors. Especially the accelerated beam trajectory is distorted in the injection region because of the existence of the first harmonic field. Fig. 3 shows the curves of radical positions of 20-turn beams along the angle of the exit of electrostatic inflector. The first one is the injection beam. The second one is the accelerated beam and its radial position is less than the injection one. It means that all of the second turn beam should hit on the inflector. After that the beam could not be accelerated any more, although the curve shows many turns of beam with very well centered trajectory after the seventh turn. Compared with 8 mm injection separation without the existing 'over shim' mentioned above, it looks very serious because of 'over shim'.

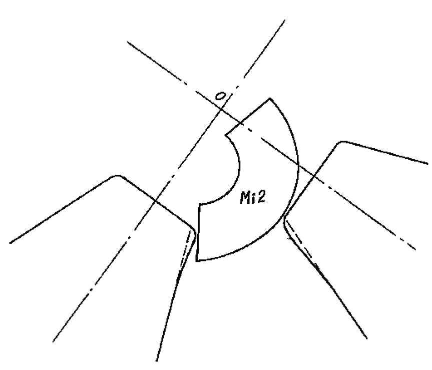

Fig. 2. The edge shim irons in the two sectors.

In order to overcome the endangerment coming from 'over shim', by decreasing the voltage of inflector and adjusting the position of the inflector appropriately, the beam could be accelerated continuously up to the extraction region in spite of the trajectory centering. Due to the acceleration with the beam precession, the energy spread of the beam will be increased a lot. The radial width of the beam would be increased seriously because of the spread and the distortion of the beam phase space. In this case, the beam in only 2° rf degrees could be extracted while in the normal case, it will be 8° rf degrees. So it is obvious that the 'over shim' is very harmful.

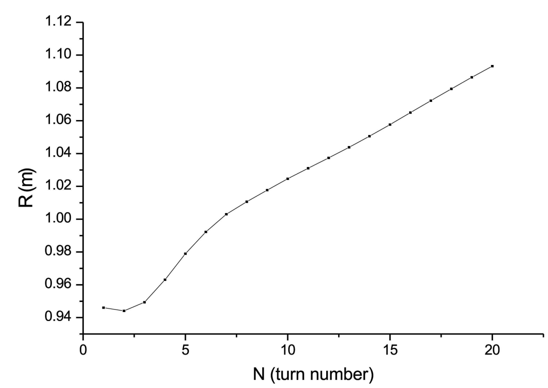

Fig. 3. The R-N curve with the first harmonic field.

3 The consideration in the new matching mode

According to the new matching mode[1] (Table 1), the range of rf frequency is changed from the present 6.5 to 14 MHz to 12 to 26 MHz. Fig. 4 gives the curves of voltage distribution in the new rf cavity. The voltage amplitude is increased a lot corresponding to the present cavity.

Table 1. The matching modes between SFC and SSC.

H1/H2	1/4	3/4	3/8
$E_{\rm SFC}$/(MeV/u)	8.47-3.33	3.33-1.89	2.07-0.48
$F_{\rm SFC}$/MHz	8.52-5.5	16.5-12.14	12.71-6.14
$E_{\rm SSC}$/(MeV/u)	100-38	38-20	22-5
$F_{\rm SSC}$/MHz	25.56-16.5	16.5-12.14	25.42-12.28

We compute the accelerated trajectory of O^{8+} with extracted energy 100 MeV/u in new mode, in the case of $H_{\rm SSC}$=4, and $F_{\rm rf}$ = 25.5625 MHz. In the computation, two values of rf voltage are used. One

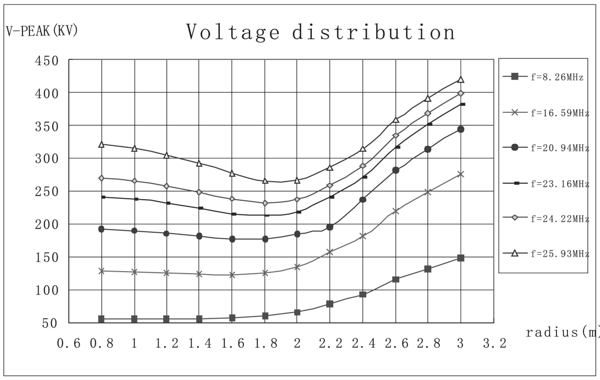

Fig. 4. The curves of voltage distribution in the new rf cavity.

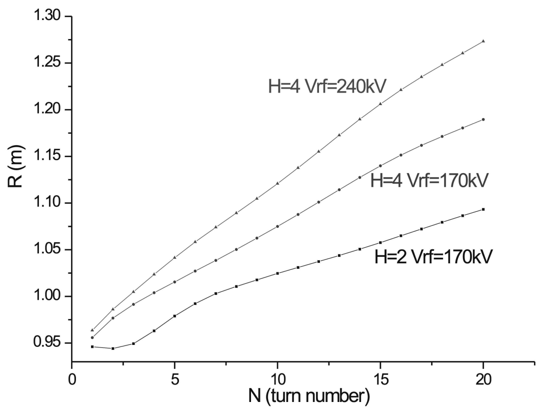

Fig. 5. The R-N curves along the exits of ESi5.

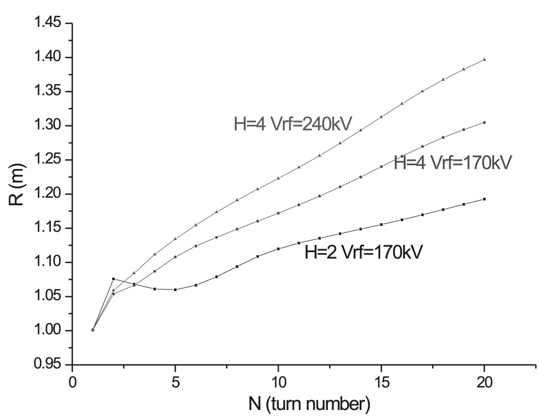

Fig. 6. The R-N curves along the exits of MSi4.

is 170 kV, which is afforded in the present cavity. The other one is 240 kV, which comes from the curves of Fig. 4 and multiplied 0.75 on the safe side. Fig. 5 and Fig. 6 give the radical positions of beam along the exits of ESi5 and MSi4 in 20 turns respectively in three states i.e. $H=2$, $F_{\rm rf}=12.7813$ MHz, $V_{\rm rf}=170$ kV; $H=4$, $F_{\rm rf}=25.5625$ MHz, $V_{\rm rf}=170$ kV; and $H=4$, $F_{\rm rf}=25.5625$ MHz, $V_{\rm rf}=240$ kV. You can see in Fig. 5, the beam in the case of $H=2$, $V_{\rm rf}$=170 could not be accelerated in regular mode; in the two cases of $H=4$, the beam separation on the exit of ESi5 is about 20 mm, the beam accelerated has no problem with centering trajectory. Fig. 6 indicates that in the three acceleration states, there is enough beam separation on the exit of MSi4, so the beam could not be lost. Figs. 7, 8 and 9 show the beam positions of the

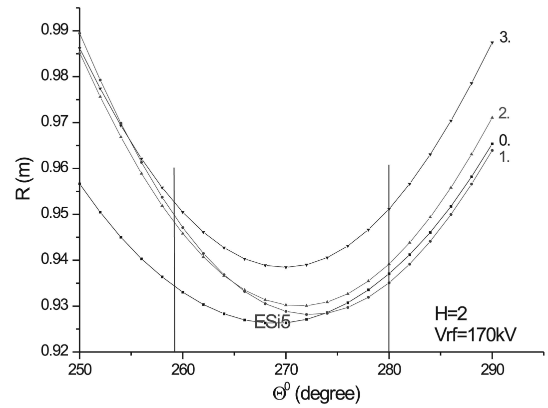

Fig. 7. R-Θ curves with $H=2$ and $V_{\rm rf}=170$ kV.

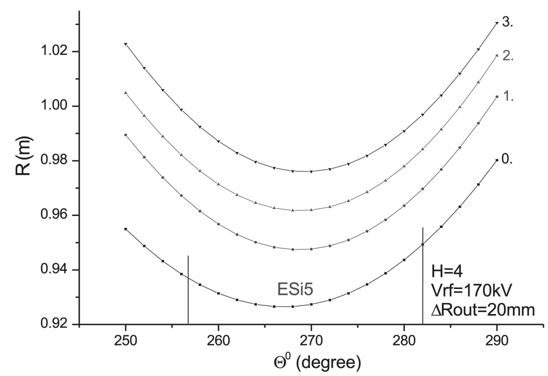

Fig. 8. R-Θ curves with $H=4$ and $V_{\rm rf}=170$ kV.

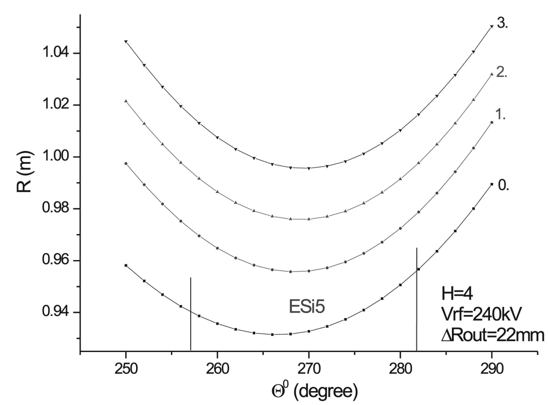

Fig. 9. R-Θ curves with $H=4$ and $V_{\rm rf}=240$ kV.

injection beam and the first three acceleration beams near ESi5 respectively. You can see that in the case of $H=2$ and $V_{\rm rf}=170$ kV, the beam could not be accelerated normally because the first acceleration beam hits on ESi5; and in the other two cases, where is no problem.

4 Conclusion

New matching mode can achieve 100% matching between SFC and SSC in all of the energy range which could be obtained in the cyclotron complex.

In the new matching, $H_{\rm SSC}$=4 and 8 could be used. According to the formula mentioned above, $V_{\rm eff}=0.87V_{\rm rf}$, the value is lager than $V_{\rm eff}=0.5V_{\rm rf}$ with $H_{\rm SSC}$=2. It is very favorable for injection and extraction of beams.

The existence of 'over shim' is harmful for the normal acceleration of beams. It is more serious when the rf voltage is lower especially. The transparency of beam is very low in this case.

In the new matching mode, when the rf frequency range is moved above, the rf voltage is increased. It s very benefitial for the acceleration, injection and extraction, even the effect of 'over shim' could be 'circled'. The beam could be accelerated with centering trajectory and the beam with high transparency could be obtained.

References

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