DC280 CYCLOTRON CENTRAL REGION WITH INDEPENDENT FLAT-TOP SYSTEM

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Abstract

At the present time, the activities on creation of the new isochronous cyclotron DC280 are carried out at the FLNR, JINR. The cyclotron DC280 is intended for accelerating the wide range of ion beams with A/Z= 4 - 7 to energy W= 4 - 8MeV/u and intensity up to 10pmcA. To achieve high-intensity ion beams the cyclotron is equipped with Flat-Top RF system. In the cyclotron DC280 the Flat-Top RF system is physically separated from main resonators. The investigation of the cyclotron centre region with independent Flat-Top RF system is presented. The simulation of the beams acceleration is carried out by means of the computer code CENTR.

DC280 «FLAT-TOP» RF SYSTEM

DC280 cyclotron has a four - sectors magnetic structure with sector angular size 45^o [1]. The main RF structure consists of two dees, placed at the "hills" between the sectors, Fig 1. The dees have an angular size $\delta_1 = 45^o$. The cyclotron accelerating system works at h=3 harmonic RF. In this case the effective accelerating voltage at the accelerating gaps is equal:

$$U_1 = U_0 \sin(h\delta_1 / 2) = 0.924 U_0 \qquad (1)$$

The acceleration voltage for DC280 cyclotron is U_o = 130kV, and the effective voltage at the acceleration gaps will be U_1 = 120kV.

One way to increase the beam intensity is a "flat-top" RF system. This system is intended to produce a broader flattop region of acceleration voltage that reduce the energy spread of accelerating particles and increase the beam intensity and quality. A flattop waveform can be received by the sum of the odd harmonics of the main frequency. As a rule the cyclotron "flat-top" system is a part of the main RF system and works at h_{ft} = 3h or 5h harmonic [2]. DC280 cyclotron "flat-top" RF system works on h_{ft} = 3h = 9 harmonic.

Because of the main dees with 45^o angular size works at h=3 harmonic RF, the use of the combined main and "flat-top" RF systems leads to decreasing of the "flat-top" system efficiency. It is illustrated in the Fig. 2 where the acceleration voltage along the beam central ion trajectory and the form of the dees voltage with corresponding RF phase are presented. The accelerating gaps of the main dees are placed near the edges of flattop of acceleration voltage. It decreases the "flat-top" system efficiency.

To avoid it the DC280 cyclotron "flat-top" system consists of two additional independent dees with optimal angular size $\delta_{ft} = 20^o$. The dees are placed at an angle 45^o to the main accelerating system, along the sector centre line, Fig. 1. In this case the total acceleration voltage is a superposition of the main and "flat-top" voltages.

$$U = U_1 \cos(\varphi) + U_{ft} \cos(3\varphi + \Delta\varphi) \qquad (2)$$

where φ – phase of the main accelerating voltage, Δφ - phase shift, considering the angle 45^o between the main and «flat-top» dees, $U_{ft} = U_1/9 \approx 13$kV – RF voltage amplitude at «flat-top» dees.

CENTRAL REGION

The central region of DC-280 cyclotron is designed for wide range of accelerating ions with A/Z from 4 to 7 with magnetic field variation from 0.6T to 1.32T. The ion beam is injected to cyclotron centre by means of two interchangeable electrostatic spiral inflectors with magnetic radiuses Rm = 7.2cm and 9.6cm. With the two interchangeable inflectors it is possible to maintain a high level of injection voltage in the range 50 to 85 kV for all working modes of DC280 cyclotron. In this case a 100% transmission of the injected beams through the axial injection system can be achieved.

The electric radiuses of both inflectors are the same and equal Ae=6cм. To avoid the sparking between the inflector electrodes the electrode voltage is not greater than ±16kV. Inflector is placed at cyclotron centre by means of radial evacuating system along the center of one of free valleys.

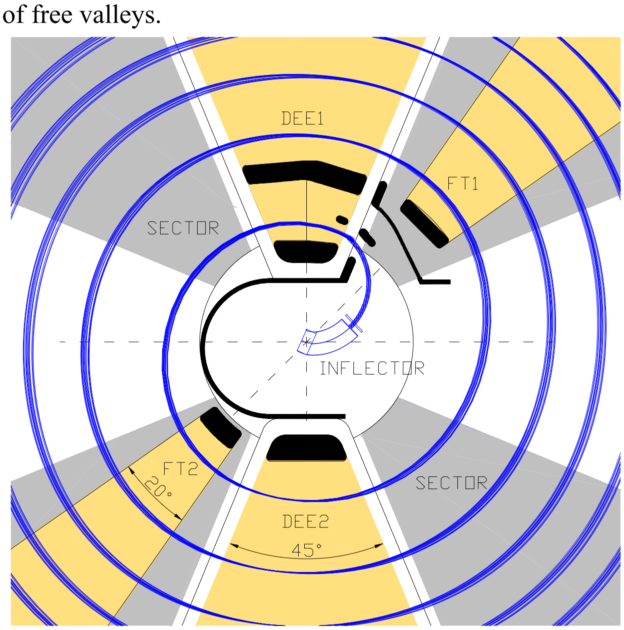

Figure 1: The central region of DC280 cyclotron. The positions of the main (Dee1 – Dee2) and independent «flat-top» (FT1 – FT2) RF systems.

The beam acceleration of the all working modes starts from one dee, Fig. 1. Because of the two different magnetic radiuses of the spiral inflectors the double puller of this dee is used. The puller combines two start radiuses 13.5cm and 17cm. The change of the working modes in the frame of the working diagram is carried out with RF and magnetic systems parameters readjustment and, if necessary, with changing of the inflector.

For the small radiuses of the central region the beam parameters is strong depends on the accelerating gaps width. On the one hand, to decrease the beam energy spread at the accelerating gaps, the gaps angular sizes should be as less as possible.

On the other hand, the width of accelerating gaps at the central region is limited with the vacuum sparking effect criteria. For DC280 cyclotron with amplitude of dees voltage 130kV and RF frequency range 7.3 - 10.4MHz the accelerating gap width must be no less than ≈16mm or ≈5^o angular size at the cyclotron central region. It corresponds to 15^o phase spread of the main, 3-th RF harmonic and 45^o phase spread of 9-th RF harmonic. In the case of independent «flat-top» system with voltage 13kV the gap width must be no less than ≈1.5mm that means only 4.5^o phase spread of 9-th RF harmonic.

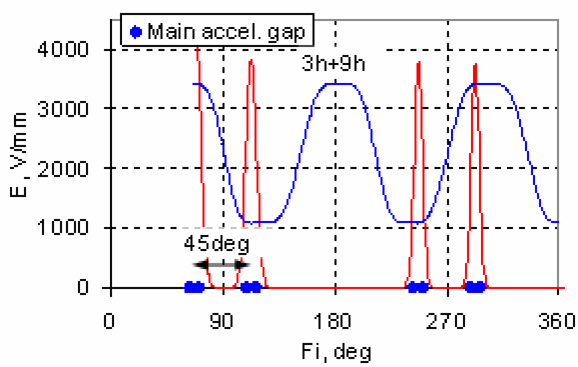

Figure 2: The acceleration voltage along the central ion trajectory at 1-t orbit and the form of dees voltage with corresponding RF phase in the case of combined main and «flat-top» RF systems.

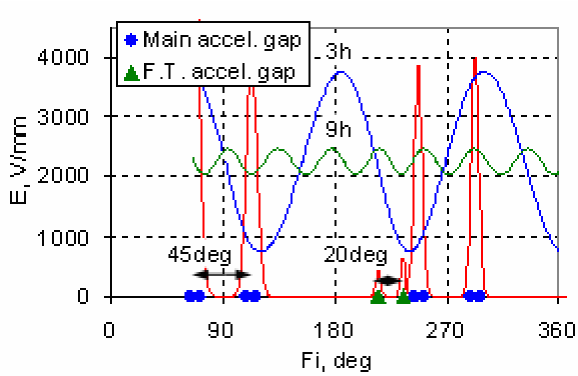

Figure 3: The acceleration voltage along the central ion trajectory at 1-t orbit and RF phases of main and «flat-top» dees voltage in the case of independent «flat-top» RF systems.

The calculations were made for two cases of the independent «flat-top» RF systems positions – before and after the main dees along the beam trajectory. The trajectory analysis results have shown no essential differences between these variants. As an example the «flat-top» system position before the main dees is considerate, Fig.1.

The calculations were made for the ion beam with A/Z=4 at the magnetic field level 0.9T and injection voltage 55kV. At this accelerating mode the beam trajectory has a minimum radius of the first orbit. This radius defines the admissible size of elements of the cyclotron central region.

In calculations a beam phase spread ±20^o RF frequency with zero energy spread at the start point, before first accelerating gap, were taken. The analysis of the beam acceleration at the central region of DC280 cyclotron was limited with radius R ≈ 48cm that corresponds to 5th initial turns. To estimate the efficiency of the «flat-top» RF system at the cyclotron centre the three variants of acceleration modes were considered: without «flat-top» system, with combined main and «flat-top» systems and with the main and independent «flat-top» RF systems.

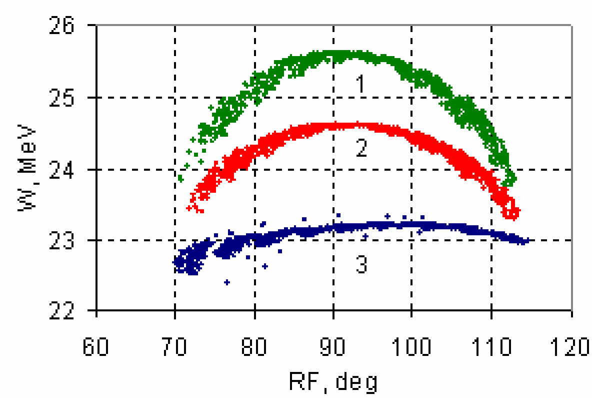

Figure 4: The beam energy spread at the 5-th orbit for cases: 1- without «flat-top» system; 2- combined main and «flat-top» systems; 3- main and independent «flat-top» RF systems.

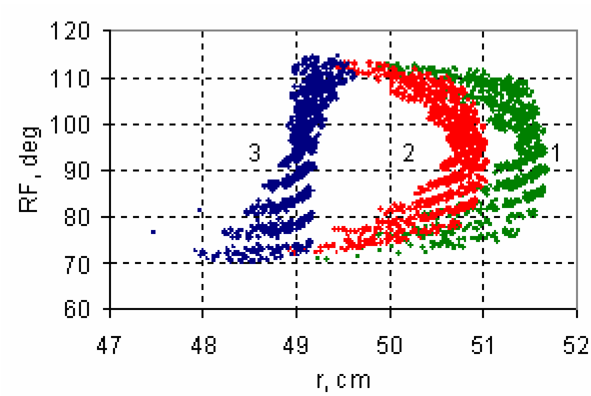

Figure 5: The beam radial and phase distribution at the 5-th orbit for presented cases 1, 2, 3.

The calculations have shown that at the 5 initial orbits the beam receive the energy spread ≈12% without «flat-top» system, ≈ 8% with combined main and «flat-top» systems and ≈ 2% with the independent «flat-top» system, Fig. 4. In all considered cases the phase size of the beam has a small changing. However, the received energy spread in the first and second cases leads to considerable increasing of the beam radial size, Fig. 5, and reduces the efficiency of the further acceleration. The highest efficiency of the «flat-top» system in the last case is received because of optimal «flat-top» dee angular size 20^o and small width of accelerating gaps 5mm.

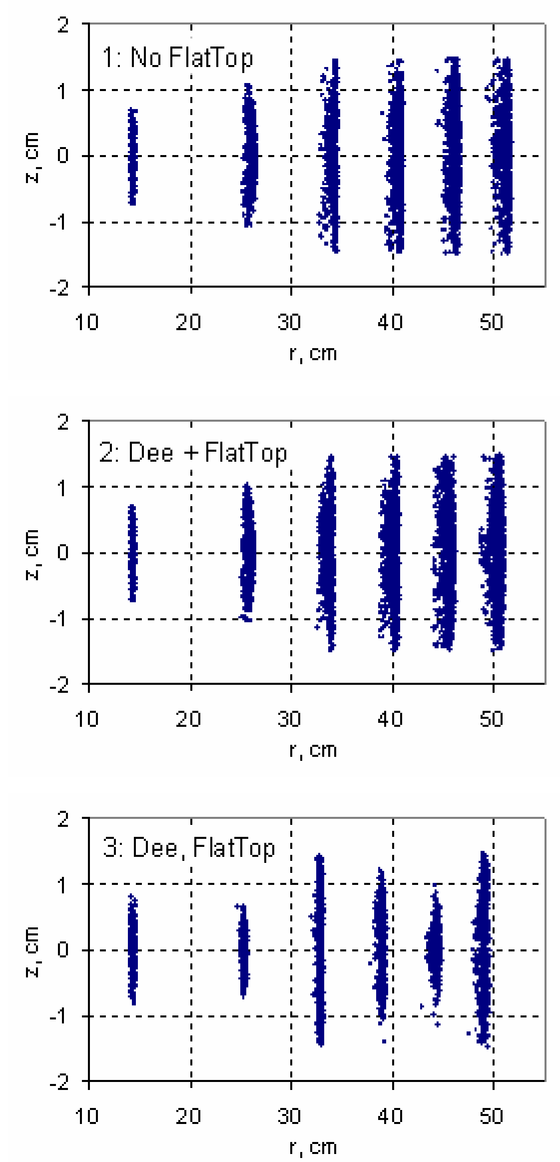

Figure 6: The beam transverse form for 5 initial orbits in the considered cases of «flat-top» system configuration.

The comparison of the beam transverse form for 5 initial orbits in considered cases of «flat-top» system configuration is presented in Fig. 6: 1 - without «flat-top» system, 2 - with combined main and «flat-top» systems, 3 - with independent «flat-top» system. The third case, the independent «flat-top» system with dee optimal angular size lets to decrease the beam energy spread that leads to decreasing vertical and radial transverse size of the beam.

The case when the voltage at the independent «flat-top» dees has a phase with shift from optimal value, leads to increasing of the beam energy spread, Fig. 7. The calculations for the first orbits have shown that 5^o RF phase shift leads to 6% energy spread, 10^o RF phase shift leads to 10% energy spread, 20^o RF phase shift leads to 15% energy spread.

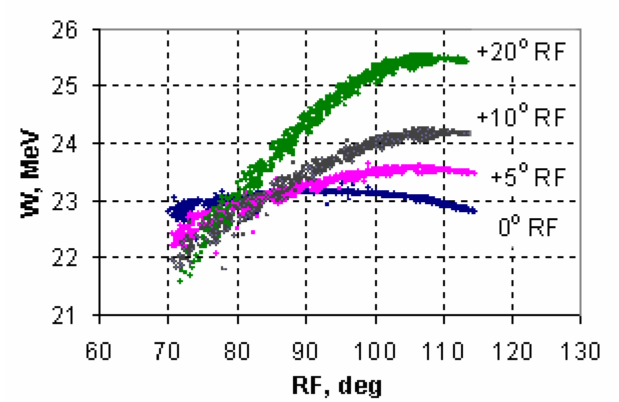

Figure 7; The beam energy spread at the 5-th orbit for some cases of «flat-top» system RF phase shift from optimal value.

CONCLUSION

The influence of «flat-top» system on the beam acceleration at the central region of DC280 cyclotron is considered. The cyclotron accelerating system works at h=3 harmonic RF and consist of two main dees with 45^o angular size and 16mm width accelerating gaps. The «flat-top» system works at h=9 harmonic RF and in case of combined main and «flat-top» systems these parameters are not optimal for it work. The independent «flat-top» system with optimal angular size 20^o and small width of accelerating gaps 5mm is used at the DC280 cyclotron. In this case the beam energy spread at the first turns is considerably decreased. It leads to decrease of transverse radial and vertical beam sizes and increase of the further accelerating efficiency. The geometry of the DC280 central region allow to place the additional independent «flat-top» dees at an angle 45^o to the main accelerating system, along the sector centre line.

REFERENCES

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