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THE EXPERIMENTAL RESEARCH OF CYCLOTRON DC-280 BEAM PARAMETER

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Abstract

The DC-280 is the high intensity cyclotron for Super Heavy Elements Factory in FLNR JINR. It was successful commissioned in 2018 [1] and the design parameters were obtained [2,3]. It was designed for production of accelerated ions beam with intensity up 10 pμA to energy in range 4 - 8 MeV/n. The beam power is up 3,5 kW. The diagnostics elements shall be capable of withstanding this power. Moreover such intensity beam required continuous control for avoid of equipment damage. Special diagnostic equipment were designed, manufactured and commissioning. During the design the calculation of thermal loads was made. Some of them were tested before installation on cyclotron. Diagnostic elements used on DC-280 cyclotron are described in this paper.

The special Faraday cup was designed for beam current measurement. The moving inner probe and multylamellar probe are inside the cyclotron. The Scanning two-dimension ionization profile monitor was produced for space distribution analysis of accelerated high intensity beam. Inner Pickup electrode system with special electronic was created for beam phase moving analysis. Time of flight system based on two pick-up electrodes for energy measured was placed in transport channel. These and over diagnostic system were commissioned and tested. The results present in report.

THE TEST OF THERMAL LOADS RESISTANCE

The DC-280 is the high intensive accelerator with beam power up 3,5 kW. For predicting the damage from hitting of the beam on elements, the modeling [4] and testing of prototypes of elements with the electron gun were carried out. It was collaboration of Flerov laboratory of nuclear reaction (JINR) and the Faculty of Mechanical Engineering of the Brno University of Technology (FME BUT During this work the Faraday cup was tested [4].

We heated the sample by electron beam with energy 100 keV. The power was concentrated in the spot with size Ø8 mm. Vacuum level was 10^{-6} Torr. In the process of experiments the temperature in different point of the cup were controlled. The visual monitoring of the beams hitting points was provide. The test results were compared with model ones.

We provide test of the normal work mode, the emergency modes: the hitting of the high intensity beam on the element and work without the water cooling. Series of repeating of high intensity beam and cooling for testing of construction resistance to repeating loads were produced.

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The tests show, that this construction of the Faraday cup head from Al is able to withstand power 3500 W without of the damage in area Ø8 mm. The surface of Faraday cup was started destroyed only under beam with power 4200 W. Furthermore the test show the efficiency of cooling with half of cooling water flow. The construction does not damage after series of periodic thermal loads. Thus the construction correspond to requirements.

FARADAY CUP CONSTRUCTION

The design of Faraday cup was presented in [4] in frame of DC-72 project was updated for DC-280. The cup was changed for reduce of distance between the inner surface of cup and water cooling channel. The design was optimization for decreasing of mistakes of current measuring by secondary electron emission on the edge of cup. The magnet system on permanent magnets, part of the design, was moved closer to entry. The magnet system on permanent magnets, part of the design, was moved closer to entry diaphragm. The diaphragm size was reduced, the taper angle was enlarge up to 80^0. The design was optimized by FLNR constructors. The sketch of Faraday cup present on Fig. 1. The new construction was successfully tested and is used on DC-280.

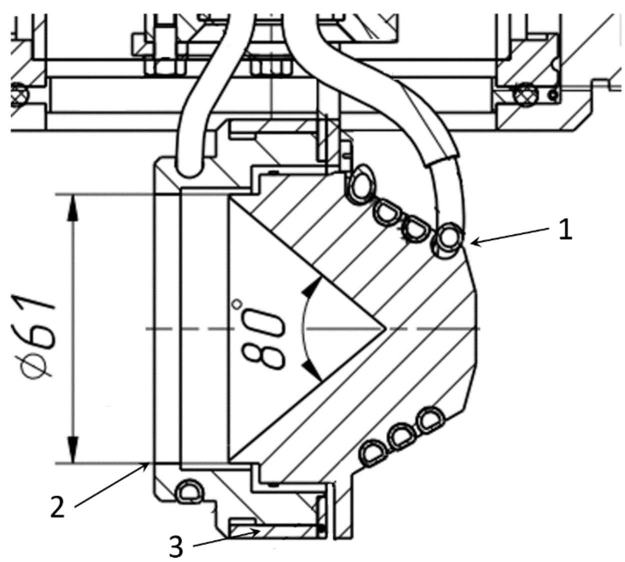

Figure 1: Sketch of the Faraday cup: 1- Water cooling channel; 2- diaphragm; 3- magnet system.

INNER CYCLOTRON PTOBES

For measuring of ions beam current inside the cyclotron two moving probe are used. One is placed before the entry to deflector second is diametrically opposite. They

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mark PR2 and PR1 respectively. The probe moving in radius range from 263 to 1800 mm. It have water cooling system and possible to take the ion beams with power up 1500 W. The linear moving system based by servo motor with reduction gear is used for moving. It give accuracy of position better them 0,5 mm.

Special plate bellows with high work length is used for separation of vacuum part. Moreover there is the sliding seals for moving the probe head in to the gateway. It gives us possibility for operative service, moreover we can place on head of probe the foil for imprinting of the beam form.

Diagnostic head is placed in grounded screen for protect from RF interference. Probe head have special form with sides which hinder moving the electrons from diagnostic part to ground screen. The sides high is 4 mm. These sides and the strong vertical magnetic field exclude the error from the charge getting with moving the secondary electrons from diagnostic head to ground screen.

The moving multylamellar probe is used for control of beam trajectory between the deflector and magnet channel. It have 5 lamella with width 5 mm and one on external radius with width 25mm. We can put on the probe on a beam trajectory by a pneumatic actuator. The dependence between the place of the lamella and intensity of beam gives us information about the place and size of ion beam after deflector.

The schema of cyclotron diagnostic elements is presented on Fig. 2.

CONTROL OF BEAM CURREN DURING ACCELATION

The described earlier devices are used for control of beam current in different points of cyclotron on various stage of acceleration. Three Faraday cups are placed in axial injection system. One is on HV part and two on ground part. They provide the control efficiency of ions transportation from ECR source to center of cyclotron. They mark IFC1-IFC3.

Moreover IFC1 together with bending magnet IM90 are used for analysis beam from the source and separation the needed ion with needed A/Z ratio. The IM90 have bending radius 90 cm. The collimator placed before the IFC1 can be used for increasing resolution.

We use the moving probe PR2 for control the intensity of the beam. It is earlier, than PR1, on the beam way and last before extraction. The needed ion is divided from impurity on radius 400mm. The rotation beam current between IFC3 and PR2 (R=400) gives us efficiency of capture to acceleration. For improving of capture we use Polyharmonic buncher [5]. The simulation predict the capture efficiency up 70%.The experimental results presented in [1-3] match with it.

Comparing the beam intensity on different radius we define the efficiency of acceleration. We try to get maximum intensity on each radius during the tuning of cyclotron. Thus we fine tune radial correction coils to produce the magnetic field correspond to isochronic regime.

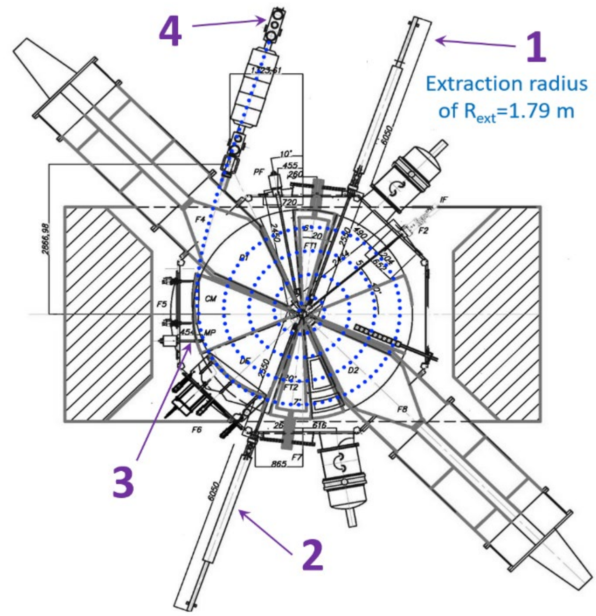

Figure 2: Schema of cyclotron diagnostic elements: 1, 2-inner moving probes PR1and PR2. 3 Multylamellar probe; 4-Faraday cup T0FC1.

We can define the shift of the beam orbit center along inner probe move direction use combination of PR1 and PR2 probes. There are four couple of azimuthal correction coils inside the cyclotron for correction beam orbit center place.

During the experiments we obtain the efficiency of acceleration inside the cyclotron more than 90%.

We use the Faraday cups placed on transport channel for measuring the intensity. There are 7 Faradays cups: Two, T0FC1 and T0FC2 in beginning part, and 5, T1FC3-T5FC3 after commuting magnet [6]. Moreover, the 4 section loss monitor placed along channel in important places. They have overture Ø60mm. It indicate on the exit of the beam from channel aperture and protect the equipment from thermal damage.

During the experiments we obtain the efficiency of transport more than 90%. The full efficiency of acceleration from Ion source to experimental setup is about 50%.

Moreover the algorithm of automatically measure of intensity on different stage of acceleration was made to simplify the regular using.

BEAM PROFILE CONTROL

For control of beam profile an axial injection system we use the moved luminophore combine with camera. Luminophore have the pneumatic actuator identical to Faraday cup. The Luminophore placed in water cooling holder, rotated to 45^0 to beam direction. Camera placed opposite the luminophore. In axial injection system, there ion have low energy, we use the quartz glass. Then luminophore is put on, we can see the luminous spot. The brightness is correspond to intensity, so we can see profile.

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There is luminophore on the transport channel to. But there it made from Al_2O_3. In spite of the water cooling of holder, the plate luminophore can work with beam intensity up 20 pnA. The luminophore destroyed under more intensive beam.

The Scanning two-dimension ionization profile monitor was designed for control of high intensity beam [7]. It based on the collection of products of the residual gas ionization by a passing beam. It give us profile of the beam in real time without of destroy of beam structure. It give us possibility to evaluate of beam current during experiments.

MEASURING OF ENERGY

For measuring of energy we use TOF method. There are two capacity ring Pick up electrodes in beginning part of transport channel. The signal go through amplifier and couple calibrated cable line to analyzing electronics. The long of fly base is 2203 mm. System of treatment of signal promptly give information about the ions energy. System successful works. The measured energy matches with calculation results and other systems results.

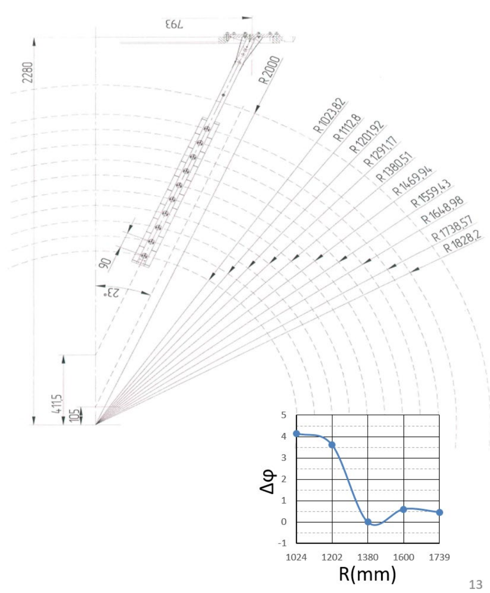

Figure 3: Placing of phase moving control system, and example of analisis for $^{40}Ar^{+7}$ (F=8.51 Hhz; E=5.2 MeV/n).

PHASE MOVING CONTROL

For analysis of phase moving of beam during the acceleration the special system was created. It based on ten pair of capacity Pick-up electrodes. It placed in special holder inside cyclotron. One electron from each pair under the median plane second above. The scheme of place of system in cyclotron is presented on Fig. 3.

We use the second harmonic filter to divide the useful from signal. Comparing the signals we get the shift in time of moving the beam bunch on different radius. After calibrate amendments we get information about phase moving during the acceleration.

Similarly compare the signals from two electrodes from one pair we can evaluate the shift beam trajectory from median plane. But this requires high accuracy of placing of systems and control of identical of electrodes in pair. We preparing system to this experiment end plane to test it soon.

We provided series test and find some problems with electronics and we upgrading it now. Moreover we create the software for operational processing signals.

CONCLUSION

Since end of 2018, then DC-280 start to work, main diagnostic elements were tested. Some of them, as Faraday cups, were modernized. The system of phase moving control is commissioning now.

Moreover experiments showed the need of additional diagnostics system. We are going to place the nondestructive intensity probe before each experimental setup. We are planning to estimate the emittance using existing possibility and compare with measuring by special systems.

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