EXPERIENCE OF THE MGC-20 OPERATION AND ITS PROSPECTS

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The first beam of the MGC-20 cyclotron designed in NIIEFA was obtained in 1969. Up to now seven MGC-20 cyclotrons operate successfully in Russia, Finland, Hungary and North Korea. NIIEFA specialists have proposed a new cyclotron design which in future will be offered for the same purpose as the MGC-20 cyclotron. First, we decided to increase the maximum proton energy up to 24 MeV. Second, power consumption of the cyclotron electromagnet and high-frequency accelerating system was decreased. Third, an improvement was introduced in to the beam extraction system. It is planned to design a completely automated cyclotron control system.

1. On the MGC-20 cyclotron

The MGC-20 cyclotron is a variable energy compact sector-focusing machine intended for acceleration of light ions (hydrogen, deuterium, helium-3 and helium-4) up to energies of 5 - 20 z^2/A MeV (where z is the charge number, A is the mass number of an accelerated ion) [1].

Nowadays, the 8th similar cyclotron is to be delivered to the Nuclear Research Centre, ARE. First, it should be noted that the MGC-20 cyclotron was designed as a universal machine both for applied purposes (production of radionuclides, in particular, for medicine, the activation analysis of a substance, study of wearing, etc.) and fundamental researches in atomic and nuclear physics. When the cyclotron is operated in educational centres, it could be used for training. Thus, being non-specialised, the cyclotron may be used as the basis for supporting a direction of researches which is of paramount interest for a customer.

Long-term operation of the cyclotron in various scientific centres, production and medical institutions in Russia and abroad clearly demonstrated its advantages and directions of updating.

Primarily, interest is provoked to the field of application provided by the MGC-20 cyclotron. The universal machine attracts a customer who is interested simultaneously in various fields of application and is not yet sure which is of paramount importance.

The cyclotron is constructed on the basis of a compact electromagnet with the pole diameter of 103 cm. The magnet gap in the "hills" is 72 cm. Concentric coils are baked with the epoxy filler in the ducts of water cooled copper disks installed on the poles. The disk thickness is 6 mm. The electromagnet field is shaped so that power supply of the concentric coils necessary to provide the isochronism over the range of energy control and type of an accelerated ion is about 200 W, i.e. approximately 0.5% from the cyclotron magnet supply power [2].

The design of the vacuum chamber, consisting of a shell with flanges and two covers, also contributes to the cyclotron compactness. The welded covers are used with the central part of a cover made of magnetic steel and being a part of the magnet system. For decoupling of the magnetic gap forming and the vacuum chamber tightening, the vacuum chamber cover is designed so that it functions as a decoupling diaphragm.

A resonator with the frequency tuning by means movable 3-segment panels in the resonator tank relative to a dee rod is used in the cyclotron. Similar resonator is reliable due to no movable short. Frequency tuning is simple and easy.

Final stages of the high-frequency generator are made by the scheme of a triode with a grounded grid resistant to parasitic excitation. Two final stages with resonators as the anode cicuit are located directly on the resonator tank without a supply feeder. Triodes are excited from a wide-band prefinal stage.

The cyclotron is equipped with a simple and reliable arc source of ions with a hot cathode axially inserted through a hole in the pole and upper cover of the chamber. The hole for the source head is somewhat displaced relative to the magnet pole centre thus providing appropriate conditions for magnetic field generation in the central area of the cyclotron.

The amplitude of the first harmonic of the azimuthal inhomogeneity appearing as a result of the hole is rather appreciable, but the beam quality is not significantly deteriorated due to its closed localisation. The beam centering is provided by harmonic coils located in the "valleys" of the cyclotron in the central zone [3].

For the past years some changes were done in separate systems compared to the original project. In particular, unreliable trimming capacitors in the resonance system of the cyclotron designed for overlapping the frequency range of the machine were replaced with movable claddings of dee rods, which at high frequencies were completely collapsed and had no affect on the high frequency system operation. The frequency range of the cyclotron was shifted to lower frequencies: the range became 8-24 instead of 9-27 MHz. In the process of cyclotron updating such important units as the ion source and systems of stabilised power supply, beam extraction and high voltage power supply of the deflector, inner probe and target together with the system of the beam scanning over the surface of the target surface were improved. Power supply systems of the cyclotron have undergone major changes due to application of new components. In the beam transport system smaller apertures (70 mm instead of 100 mm) were used that allowed to apply quadrupole lens doublets of smaller sizes without water cooling. And at last, the 8th cyclotron model is to be equipped with a computer control system, which should perfect consumer characteristics of the cyclotron complex.

2. Operational experience

Deep energy control of 4 species of ions necessitates the availability of the resonance system with controlled frequency. Using a double-dee 180^0 system, a necessary coefficient of the frequency overlapping is 3 when operating at the 1st and 3rd harmonics. The necessary overlapping coefficient is too large for a panel-type resonator and, as a consequence, additional control devices (capacitors or movable claddings of rods) are needed and the loss power is increased. These losses at high frequencies limit the duty factor of the high-frequency system to 0.5 to guarantee the operation reliability of the cyclotron. Therefore, it would be preferable to lower the frequency range by reducing the overlapping coefficient to 2. In this case it is desirable that the acceleration mode of the first harmonic was kept as the main mode.

Change of the frequency range will also allow to eliminate the specific feature of the MGC-20 cyclotron connected with the fact that the low-energy range of double-charged helium ions is provided by acceleration at the 3rd harmonic and the beam intensity is 5-10 times reduced. Power consumed from the mains by the high-frequency system depends both on the loss-power of the resonance system and the generator efficiency. The efficiency of the generator using the triode scheme with a common grid in final stages is not more than 50%, whereas tetrode schemes give a possibility to have the efficiency up to 80%.

As the operation experience demonstrates, the 50% efficiency is a good value for the beam extraction coefficient. On the one hand, it is due to the versatility of the machine. On the other hand, capture of a wide phase band in the central area of 180^0 dees also makes definite contribution to the coefficient reduction. Deflector is located in a fixed space between dees. For this purpose, the dees of 180^0 angle length in the centre are cut (starting from the half of the final acceleration radius) to provide free space for the deflector location. Such a fixed position of the deflector limits its length and, consequently, fixes the maximum energy of the extracted beam.

As to the final energy of the accelerated beam, an increase of protons' energy approximately up to 24 MeV would be desirable for production of radionuclides on the cyclotron. It should be noted that the magnet structure of the MGC-20 cyclotron allows to accelerate protons up to energies higher than 20 MeV. In the nominal regime the cyclotron magnet is far enough from strong magnetic saturation.

In shaping the magnetic field for the MGC-20 cyclotron to be delivered to Egypt, studies of the forced mode of the magnet excitation at 450A current in the main coil have been performed. Fig.1 shows the distribution of an average magnetic field for the excitation level of 450 A trimmed by the concentric coil. A calculated isochronous magnetic field for acceleration of protons up to 22.5 MeV also is displayed. Fig.2 presents the radial distribution of vertical betatron oscillation frequency. The frequency for the mode of protons' acceleration up to the extracted beam energy of 20 MeV is shown in the same figure. This energy of the outer proton beam was obtained on the MGC-20 cyclotron.

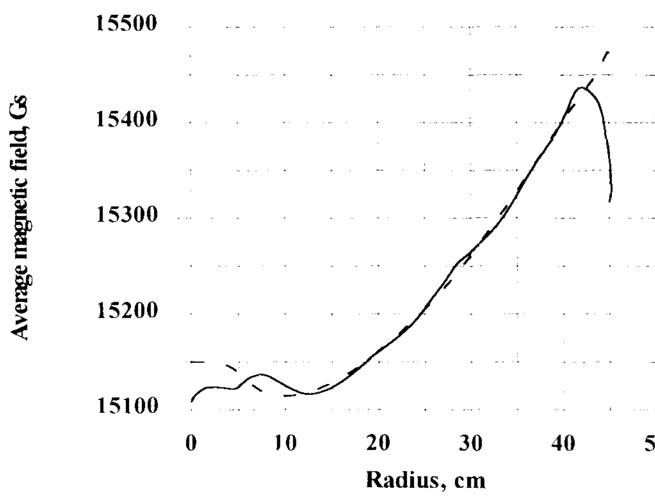

Fig. 1. The curve of shaped magnetic field of 450 A coil current. Dashed curve shows isochronous field for an energy of 22.5 MEV

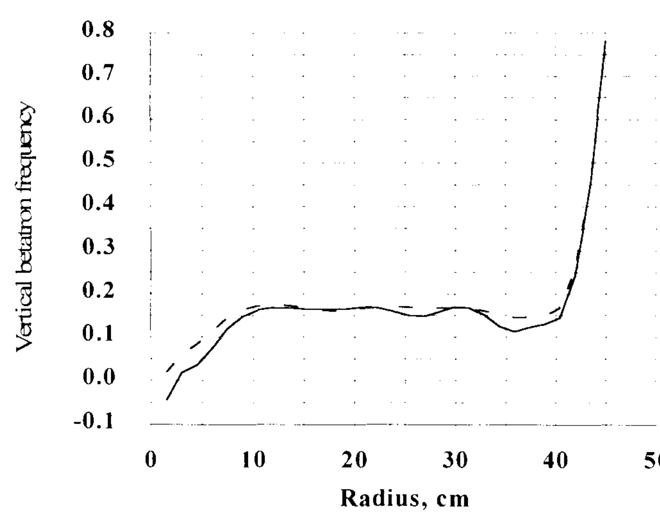

Fig. 2. Frequency of vertical oscillations in the mode of protons' acceleration up to energy of 22.5 MeV. Dashed line is the same for 20 MeV energy

Practically, only insignificant change of the cyclotron sector edge is needed to obtain the final energy of 24 MeV.

3. Project of the compact cyclotron

A project of a compact cyclotron has been worked out allowing for the operation experience in the Efremov Institute, NIIEFA. Below, in Table 1 are given specific features of the compact variable energy cyclotron.

Table 1

Beam	
energy of accelerated ions, MeV	5-24 z^2/A
maximum current of the beam (inner/outer), μa	
protons, deuterons	200/50
double-charged helium ions	50/25
Magnet structure	
pole diameter, cm	103
number of sectors	3
gaps ("hills"/"valleys"), mm	70/120
magnetic field induction in the centre ,T	1.55
consumed power, kW	35
weight, t	25
High-frequency system	
number of dees	2
angle length of a dee, degrees	90
frequency of the accelerating voltage, MHz	12-24
Harmonics used	1, 2
dee voltage, kV	35
power losses per one resonator, kW	15
output power of the generator, kW	40
Power consumption	
maximum, kW	100
in the stand-by mode, kW	12

The cyclotron is constructed on the basis of a shielding-type magnet with the pole diameter of 103 cm, as has been analysed to be expedient. Such a type of magnet improves the design and layout of the cyclotron, and in this case the armour is simultaneously both the magnetic core and the vacuum chamber wall.

Taking into account modern trends, special attention was paid to reduction of the loss power in designing the magnet at an increase of the maximum protons' energy up to 24 MeV. The magnet supply power was limited to a value of 35 kW.

The cyclotron vacuum chamber consists of a casing and two - upper and lower - covers. The chamber casing - a cylinder with the outer diameter of 200 mm, wall thickness of 200 mm and the height of 200 mm is simultaneously the magnetic core. Each cover comprises 3 parts: 60 mm thick pole tip of magnetic steel, annular damping plate of non-magnetic steel welded with the pole tip and rigid tightening flange. Disks with sectors and windings of the central and outer harmonic coils located in "valleys" are installed on the pole tips. Copper disks with concentric coils also functioning as claddings are mounted on the chamber covers assembled with the sectors.

The main units of the magnet and the vacuum chamber are axially symmetrical bodies, thus providing their fabricability and higher accuracy of the cyclotron magnetic field shaping.

Two 90^0 dees are fastened to rods with the resonators. The dees are not coupled conductively, an electronic circuit provides the push-push acceleration mode.

The arc source with a filament cathode is inserted into the vacuum chamber through a hole in the upper beam of the magnet.

Operating vacuum of the cyclotron is provided with 3 diffusion pumps with water cooled traps. The pumping speed of each is 630 l/s for nitrogen and 2300 l/s for hydrogen.

The cyclotron will be equipped with an automated control system that will switch on or off the equipment, put the accelerator to the pre-set mode and control operation of all the systems of the cyclotron. There will be no manual control duplicating the automated control system with the aim to reduce the number of relay units and provide higher operation reliability of the cyclotron. Computer control must improve such an operational characteristic of the cyclotron as the reproducibility of the accelerator modes, decrease time for the cyclotron transition from one operation mode to another and reduce the discreteness of accelerated ions energy control. Fig.3 shows the lay-out diagram of the cyclotron

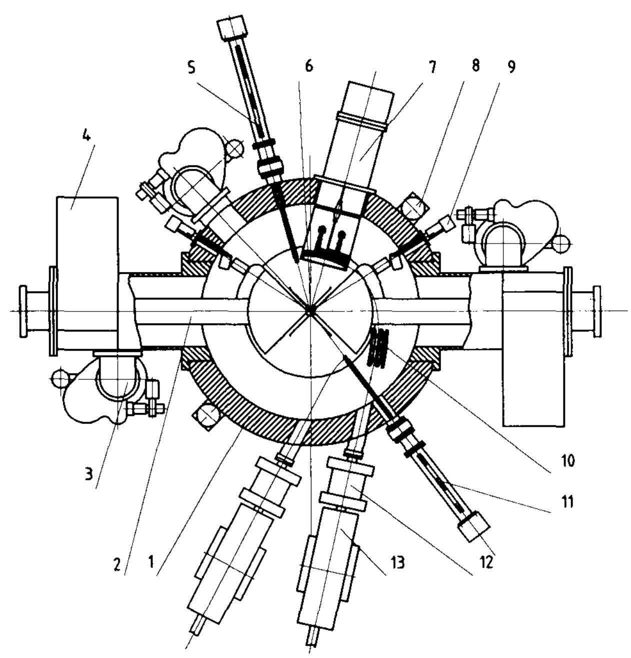

Fig.3. The lay-out diagram of the new cyclotron design. 1. Electromagnet. 2. Resonance system. 3. Diffusion aggregate. 4. HF final stage. 5. Beam probe. 6. Ion source. 7. Deflector. 8. Lift. 9. Trimmer. 10. Magnetic channel. 11. Stripping device. 12. Positioning magnet. 13. Lens.

The accepted lay-out scheme of the cyclotron allowed an additional option - acceleration and extraction of negative hydrogen ions. The works on study of this possibility were performed in cooperation with Dr. Solin in Radium Institute, St. Petersburg. Acceleration, extraction and measurements of the extracted beam emittance were done. The standard ion source of the MGC-20 cyclotron was used. An outer beam of protons with 20 μ A intensity at 10 MeV energy was produced using a thin stripping foil.

In this project a provision is made for transportation of the beam extracted using H^- stripping.

4. Conclusion

Attention should be paid to one more feature of the project. Suggested approaches also allow to update operating facilities of the MGC-20 type. It may be the following:

1. Updating of the HF-generator applying final stages made in the generator tetrode scheme. In the prefinal stage with a reducing output new components are used.
2. Updating of the HF-system by reducing the dee angle length. In this case available resonators with one tank per two rods are remained.
3. Increase of the accelerated particles energy. In this case in addition to reduced dee angle length the magnet structure and beam extraction system are updated.

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