ISBN: 978-3-95450-240-0 ISSN: 2673-5539 doi:10.18429/JACoW-RuPAC2021-FRA05

CYCLOTRON SYSTEM C-250

K.E. Smirnov†, Yu.N. Gavrish, A.V. Galchuck, S.V. Grigorenko, V.I. Grigoriev, R.M. Klopenkov, L.E. Korolev, K.A. Kravchuck, A.N. Kuzhlev, I.I. Mezhov, V.G. Mudrolyubov, Yu.K. Osina, Yu.I. Stogov, M.V. Usanova,
JSC «NIIEFA», 196641, St. Petersburg, Russia

Abstract

JSC "NIIEFA" is designing a cyclotron system that generates intensive proton beams with final energy in the range of 30-250 MeV. We have adopted a non-standard technical solution: at the energy of less than 125 MeV negative hydrogen ions are accelerated with the extraction of protons by the stripping device; at higher energies protons are accelerated, and the beam is extracted by a deflector and a magnetic channel. The isochronous dependence of the magnetic field on the radius for different final energies is provided by changing the current in the main coil and tuning the correction coils.

The cyclotron electromagnet has an H-shaped design with a pole diameter of 4 meters, a four-sector magnetic structure, and high spirality sectors. The dees of the resonance system are formed by delta electrodes and placed in the opposite valleys; stems are brought outwards through holes in the valleys. The operating frequency range is 24-33.2 MHz. The power of the RF generator is 60 kW.

The cyclotron complex is equipped with a branched beam transport system and target devices for applied research on the radiation resistance of materials. Computer control of the cyclotron and its associated systems is provided.

MAIN TECHNICAL FEATURES

The JSC "NIIEFA" is designing a cyclotron system comprising a proton cyclotron, a developed system of beamlines, samples' irradiation system and utilities. The most complicated problem of this project is construction of a unique cyclotron generating proton beams with an energy varied in the range of 30-250 MeV. Cyclotrons with the energy variation over such a wide range are not available nowadays.

The method of negative ions' acceleration with the extraction of protons with a stripping device, which is standard for low-energy cyclotrons, cannot be applied as the binding energy of an additional electron is lower than 0,8 eV. With an increase in the energy of a negative ion when it is moving in a strong magnetic field, rapidly grows the probability of this electron detachment, and, consequently, a decrease in the beam intensity.

To reduce losses, it is necessary to lower significantly the induction of the electromagnet, which will result in a corresponding increase in the diameter of magnet poles. Therefore, at energies higher than 100 MeV, protons are used as accelerated particles. To provide the isochronous motion of protons with different final energy, it is necessary to change the magnetic field induction and its dependence on the radius over wide limits corresponding to the relativistic increase in the proton mass.

To make less stringent requirements to the magnetic field forming, a non-standard decision was adopted. We decided to use negative hydrogen ions as particles to be accelerated in the final energy range of 30-125 MeV; at energies of 125-250 MeV, protons are used.

The ion source is an inner radial Penning-type cold-cathode source.

ELECTROMAGNET

The iron core of the electromagnet is of an H-shaped design, a four-sector magnetic structure and high helicity sectors. The mode with the 1.08 T induction in the center of the magnet and 1.35 T at the final acceleration radius corresponding to the final energy of 250 MeV was chosen as the basic mode. In this mode, the induction dependence on the radius corresponding to the isochronous motion is realized by turning on the main coil only through the shape of the central plugs, sector side plates, and sector chamfers.

To vary the final energy over the range of 250-125 MeV, the isochronous dependence of the magnetic field on the radius is provided by decreasing the current in the main coil and turn on of correction coils located on sectors. The beam is extracted from a fixed final radius by means of a deflector and magnetic channel.

At lower final energies, we used the magnetic field formed for an proton´s energy of 125 MeV (with reversal of the polarity). A beam of required energy is extracted by moving the stripping device with a thin carbon foil.

The electromagnet is shown in Fig. 1 and its parameters are given in Table 1.

Figure 2 shows trajectories of extracted beams. Green color shows protons after passing the deflector; in red are shown negative hydrogen ions and in blue are given protons at the output of the stripping device foil. The deflector is located in the upper left valley; the stripping device foil can be moved over the gap between left sectors.

† npkluts@luts.niiefa.spb.su

ISBN: 978-3-95450-240-0 ISSN: 2673-5539 doi:10.18429/JACoW-RuPAC2021-FRA05

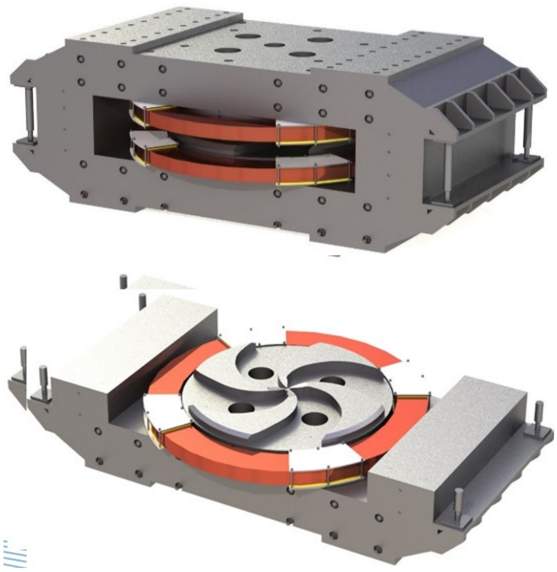

Figure 1: Electromagnet.

Table 1: Parameters of the Electromagnet

Magnet sizes, mm	8100×5360×3600
Pole diameter, mm	4000
Number of sectors (per pole)	4
Lifting height of the upper movable half-yoke, mm	1000
Induction in the center of the magnet, T	0.8-1.08
Final acceleration radius, mm	1800
Helicity at the final acceleration radius	54°
Air gaps, sector/ valley, mm	100/500
Consumed power, kW, no more than	104
Magnet mass (Fe/Cu), t	720/34
Number of correction coils	15×8
Consumed power, kW, no more than	16

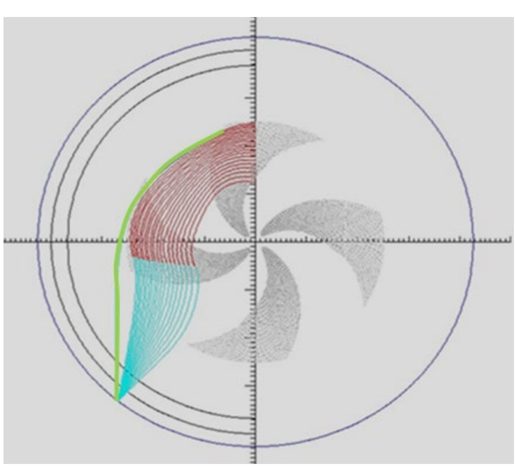

Figure 2: Trajectories of extracted beams.

To align axes of beams with different energies with the axis of the beamline ion tube, a matching magnet is used. The center of the magnet coincides with the point, in which intersect trajectories of proton beams with different energies.

RESONANCE SYSTEM

From Fig. 2 it is seen that trajectories of proton beams with energies in the range of 30-125 MeV practically completely occupy a part of the valley near to the pole edge. This circumstance makes us to use the resonance system with delta-electrodes and dee stems located in through holes made in the magnet valleys.

In such a version, the resonance system includes four coaxial resonators. Each of these resonators consists of a dee cover (a δ-electrode) and corresponding valley cladding as well as a short-circuited section of the coaxial line formed with a dee stem and a tank.

Figure 3 shows the layout of the resonance system in the electromagnet. The dee with stems and a pair of resonators are given in Fig. 4.

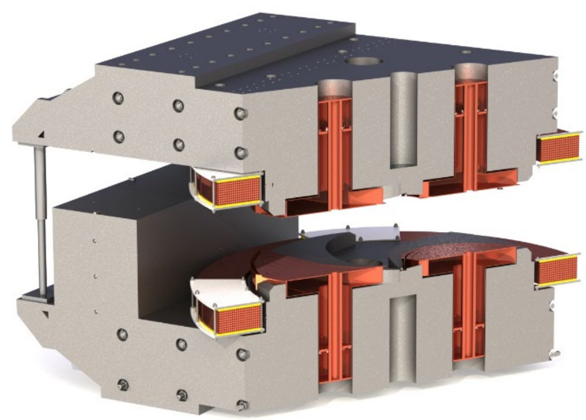

Figure 3: Layout of the resonance system.

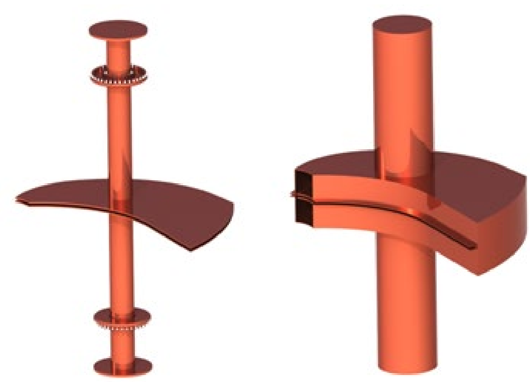

Figure 4: Model of a pair of resonators.

The in-phase operation of all resonators is provided due to a galvanic contact between pairs of ''the upper and bottom dee covers" and between dees in the center of the magnet (a puller).

To vary the frequency in a specified range of 24-33.2 MHz, we change the length of coaxial sections by moving synchronously shorting flanges with ball contacts.

ISBN: 978-3-95450-240-0 ISSN: 2673-5539 doi:10.18429/JACoW-RuPAC2021-FRA05

The maximum active loss power in the resonance system with the RF-voltage amplitude at the final radius of 100 kV is about 50 kW. The resonance system is equipped with an RF-power capacitance input device, an RF probe and two electromechanically-driven trimmers.

RF-POWER SUPPLY SYSTEM

The RF-power supply system operates in the frequency range of 24-33.2 MHz. Structurally the equipment of the system is divided into 3 units, namely, cabinet of the main equipment, amplifier final stage and high-voltage power supply.

The main equipment cabinet houses master oscillator, preamplifier, amplifier pre-final stage as well as system for monitoring, control, protection and measurements and ancillary equipment. The cabinet is shown in Fig. 5.

Figure 5: Cabinet of the main equipment.

The amplifier final stage (Fig. 6) in a separate cabinet will be installed in a direct vicinity to the resonance system. The final stage is developed on the basis of the GU – 66A generator triode with an output power up to 100 kW. The RF power is output from the final stage through an isolating capacitor and connector. The final stage is connected to the device of the RF- power input to the resonance system either directly or with a short section of a coaxial feeder.

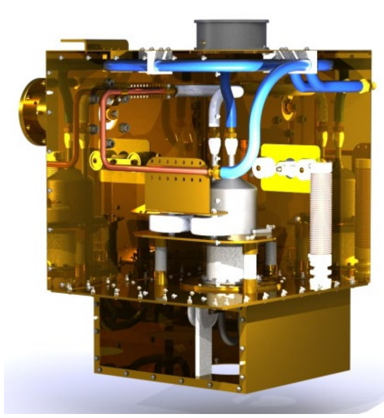

Figure 6: Model of amplifier final stage.

We plan to construct a high-voltage power supply of the inverter type with the output voltage of 10 kV, current of 13 A and voltage stability of 5×10^{-3}.

BEAM TRANSPORT SYSTEM

In the project worked out in the JSC «NIIEFA», the system of beamlines providing the delivery of the proton beam to three separately located target rooms is considered (Fig. 7).

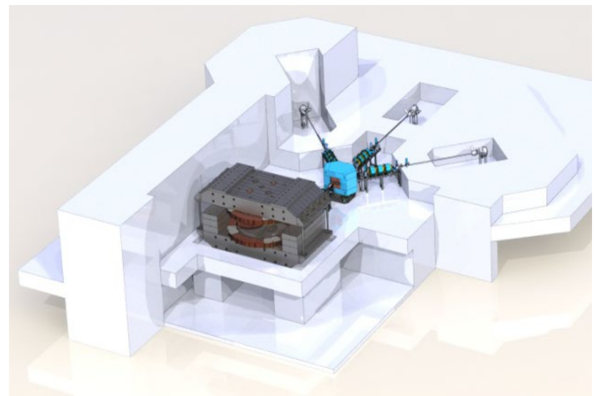

Figure 7: Layout of the cyclotron system main equipment (project).

The beam transport system comprises a matching magnet, electromagnetic lenses, correcting magnets and diagnostics. The central beamline can be equipped with a neutron converter.

UTILITIES

The cyclotron system is automatically controlled. The automated control system should provide monitoring, diagnostics and control of the operation of the cyclotron and all its associated systems. In an emergency situation, either separate equipment or the whole cyclotron system should be automatically turned off.

CONCLUSION

The cyclotron system with control of proton energy and beam current over such a wide range is a unique experimental instrument to be applied for research in the field of radiation material science and for studying the radiation strength of materials. It is for the first time that researches will get an opportunity to use proton and neutron beams to form irradiation fields with a wide range of energies and intensities. As a result, new experimentally-proved knowledge in the field of radiation physics will be obtained.

Nowadays, designing of the system is being completed, and production of the main units and systems has been started.