GATCHINA ISOCHRONOUS CYCLOTRON

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ABSTRACT

A design and construction of a $75-80\,MeV\,H-$ ion cyclotron with intensity of $100\mu A$ is in progress in Petersburg Nuclear Physics Institute. The cyclotron is to be used both for medical purposes (radio pharmaceuticals production) and for the investigations in nuclear physics, solid state physics, etc. To decrease the expenditures the iron yoke of the 1 *Gev* synchrocyclotron magnet model is utilized for a cyclotron magnet system. The accelerator itself is installed in the building of the operated synchrocyclotron and uses the existing electric power and water cooling systems. We assume the design of the cyclotron main systems to be completed this year, the building reconstruction has been finished, magnet assembly is in progress now.

1. INTRODUCTION

In Petersburg Nuclear Physics Institute up to now is in operation synchrocyclotron that accelerates protons up to $1\,GeV$ at beam intensity $1\,\mu A$.[1)] The accelerator is applied for studies in physics of elementary particles, nuclear physics as well as for proton therapy and radioisotope production for medicine, etc. For increasing radioisotope production, for organization of the ocular melonome irradiation facility as well as for extending the traditional studies of short-lived isotopes it was decided to build a $75-80\,Mev\,H-$ ion accelerator with beam current $100\,\mu A$.

2. GENERAL DESCRIPTION

To minimize the expenditures while designing the cyclotron an attempt was made to use at most the existing synchrocyclotron infrastructure, i.e. the building, the bridge crane for 30 tones, the electric power , water cooling, ventilation systems, etc. The iron yoke of the existing synchrocyclotron magnet model is used for a magnet system. Such an approach provides saving of the resources at the cost of the restriction in the variety of design solutions.

Tab. 1 and Fig. 1 show the main cyclotron parameters and the plain view of its arrangement is given in Fig. 2. Probably,the energy of $75-80MeV$ is nearly the maximum possible one for an $H-$isochronouse cyclotron with the magnet pole diameter of $2m$. The $75-80MeV$ energy and the possibility to regulate it are necessary for isotope production using some reactions unattainable at lower energies. The $H-$ ions acceleration enables to perform smooth energy regulation of the extracted beam. The intensity of $100\,\mu A$ is necessary for isotope production and is limited both with an ion source and the chamber activation.

The vertical focusing at the final radii has been achieved due to 60^o spirals. Another way, e.g. the flatter enlargement at a given average field, would lead to a hill field growth and $H-$ ion losses in the result of $H-$ dissociation in magnetic field.

The chamber has an unusual design . The magnet pole tips and the harmonic coils are located outside the vacuum chamber. The chamber from stainless steel having relatively thin lids and being large in size is mechanically attached to a pole tips that provides relative rigidity under the action of atmospheric pressure.

3. MAGNET AND MAGNETIC FIELD STRUCTURE

The cyclotron magnet was designed in such a way that the iron of the existing synchrocyclotron model to be used for it. Design of the magnet was done with the aid of the $2D$ magnetic field code *POISSON*. Magnet of the model was completely reconstructed. The new $2m$ diameter poles were manufactured, the side yoke height was made $500mm$ lower, the support plates for the lower and upper yoke bars were introduced, the holes were drilled to inject the beam vertically, newly insulated coils were manufactured. To have an access inside the chamber the upper magnet bar with a pole and the chamber lid can be lifted on $450\,mm$ using four hydraulic jacks.

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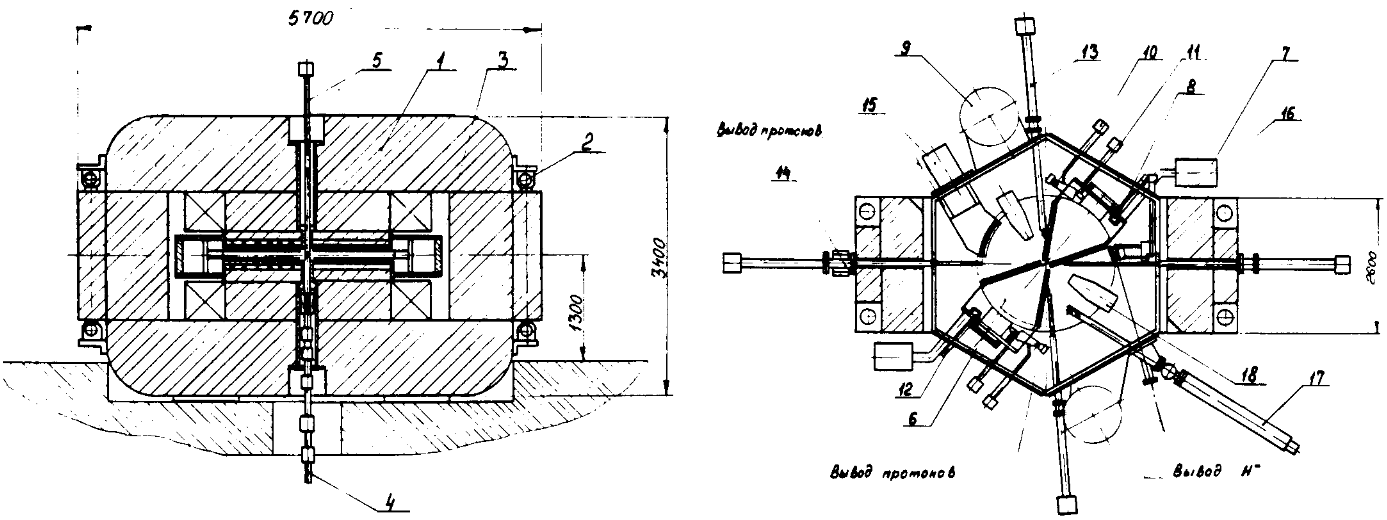

Fig. 1. General view of cyclotron. 1 - Electromagnet, 2 - Hydraulic jack, 3 - Vacuum chamber, 4 - External injection system, 5 - Axial injection deflector, 6 - Resonance system (dee), 7 - Final cascade of RF generator, 8 - RF power input, 9 - Vacuum pump, 10 - Tuning condenser, 11 - Trimmer of automatic frequency tuning, 12 - RF probe, 13 - Diagnostics probe, 14 - Septum protection foil, 15 - Extraction system deflector, 16 - Magnetic channel, 17 - Stripping device, 18 - Cryopanel.

The magnetic field structure was chosen to be a 4$-$ sector one the maximum flatter value of 0.04 and the maximum spiral of 60^o. Under such conditions and at $1.352\,T$ field in the center the $H-$ losses make $3-5\%$ due to dissociation. Azimuth variation of the magnetic field that is the hill and valley gaps, the flatter and spiral were simulated using the magnet model before its reconstruction at $1:1.3$ scale. The magnetic field isochronism and flatter is planned to be corrected using a set of sector ring iron shims while making magnetic measurements. To regulate the first harmonic the valley coils were installed. They are subdivided into four groups along the radius.

4. ACCELERATING SYSTEM

The cyclotron accelerating system is composed of two identical 1/4$-$ wave dee subsystems excited at a fixed frequency of $41.2\,MHz$ (second harmonic of ion revolution). Two 60^o dees are conductivily coupled in the center and together with the resonance tanks form a uniform 1/2$-$ wave system with a maximum voltage in the center and 17% voltage drop at the final radius. At $60\,kV$ the accelerating system provides $200\,keV$ energy gain per turn. The dee plates thickness is $15mm$, the dee aperture is $30\,mm$, the gap between a dee and a ground plaque is $33\,mm$.

The excitation generator has a common pre-amplifier of power up to $15\,kW$. The output of this pre-amplifier via two fidder lines is switched onto two final cascades $40\,kW$ each placed in the chamber vicinity. Each of the resonance subsystems is inductively coupled via loop with the output cascade anodes, thus forming their resonance anode contours. The power supply rectifier is of $10\,kV$ and $160\,kW$. The automatic amplitude, frequency and phase control systems are envisaged.

5. CHAMBER AND VACUUM SYSTEM

The chamber frame of hexagonal shape is welded of nonmagnetic steel. The chamber walls are of duralumin. The two of them that face the side yoke are undetachable. The chamber lid is welded of a bimetal sheet, i.e. nonmagnetic steel and copper. The copper lid surfaces serve as ground plaques for the resonance system. The steel lid sheets have the channels to let the cooling water through. The application of bimetal sheets enable approximately by 3 times to decrease the out gassing surface and to diminish the load on vacuum pumping means.

Due to the large recharge cross-sections on the residual gas molecules at $H-$ ions acceleration a high oil-free vacuum is required. The maximum load on the pumping means originates from an inner source and gas desorption from the surface. The estimations show that to reach $10^{-7}\,Torr$ for air and $10^{-6}\,Torr$ for hydrogen it is necessary to provide the following pumping speeds: with an internal source $100\,m^3/s(H_2)$, $25\,m^3/s(H_2O)$, $10\,m^3/s\,(CO_2 and N_2)$ and $5\,m^3/s$ (hydrocarbon). The necessary pumping speed of hydrogen drops abruptly

MAGNET	Pole diameter	$2.05\,m$
	Valley gap (max.)	$386\,mm$
	Hill (min.)	$146\,mm$
	Number of sectors	4
	Spiral angle (max.)	60^o
	Field in center	$1.352\,T$
	Flatter (max.)	0.04
	Extraction radius	$0.85 - 0.90\,m$
	Ampere-turns	$3.4 * 10^5$
	Power	$120\,kWA$
	Weight	$250\,tones$
RF SYSTEM	Frequency	$41.2\,MHZ$
	Voltage	$60\,kV$
	Harmonic	2
	RF Power	$2 * 40\,kVA$
VACUUM	Pressure	$10^{-7}(N_2), 10^{-6}\,Torr(H_2)$
	Turbomolecular pumps	$2 * 10\,m^3/s$
	Evaporation getter pumps	$2 * 60\,m^3/s(H_2)$
	Cryopanels, two , N_2	$S = 0.3\,m^2$
H- SOURCES	Internal Ehlers Pig	
	External:	
	surface plasma, pulsed	
	surface plasma, stationary	
	multi pole source	
	voltage	$20\,kV$
EXTRACTION	Energy	$45 - 80\,MeV$
	Method	Stripping

Tab. 1. Gatchina cyclotron parameters.

down to $10\,m^3/s$ for an external source. Based on the above estimations the vacuum system was composed of two turbomolecular pumps $TMNG - 10000$ with the pumping speed of $10000\,l/s$ each, two evaporation getter pumps $NDMA - 20$ with $60000\,l/s(H_2)$ pumping speed each and of $0.3\,m^2$ cryopanels. The estimations show that the beam losses due to the residual gas make 10% at an internal source and 5% at the external injection.

6. SOURCES AND INJECTION

The cyclotron design envisages the application of internal and external sources. An internal source (Penning type with a filament thermal cathode, an anode and a cathode reflector) is considered to be a source for the accelerator operation at initial stage.

An external source has a number of advantages. Primarily, there is no gas leakage into chamber and there is a decrease of $H-$ ion losses. Several types of external sources have been considered. The most well developed in Russia source is a surface-plasma one designed in Novosibirsk and applied at Moscow Meson Factory.[2] The source operates in a pulse mode with a single pulse duration of $1\,ms$, duty factor of 10 and a pulse current up to $10\,mA$. But, the pulsed mode of its operation does not correspond to the continuous mode of cyclotron operation. A version of a surface plasma source with continuous operation is under consideration.

To inject $H-$ ions into the cyclotron an axial injection channel has been designed. This channel happens to be a universal one for various types of sources and is composed of two magnetic lenses, a focusing solenoid and two quadruples. The transition from one type of a source to another one is done by changing the switching mode of the channel optic elements. A type of channel with a $SmCo_5DC$ magnet is under study. An electrostatic mirror and a spiral deflector are considered to be a deflector. A testing stand is now built to experiment with an axial injection system.

7. BEAM EXTRACTION

The main means of extraction is the $H-$ stripping on a thin carbon foil. The stripping probe with a magazine of 4 foils moves along the radius from 750 mm to 900 mm and over 30^o angle along azimuth providing beam energy variation from $45\,MeV$ to $80\,MeV$. In case of a necessity to extract $H-$ ions (e.g. for injection into a storage, etc.) there is a place envisaged for a system of $H-$ ions extraction using a processional or regeneration mechanism of beam injection into an electrostatic or high frequency deflector with a septum protection by means a recharged foil, as it was proposed in $TRIUMF$ cyclotron.[3] However, this system at present is on paper and, thus, is a system of the second order.

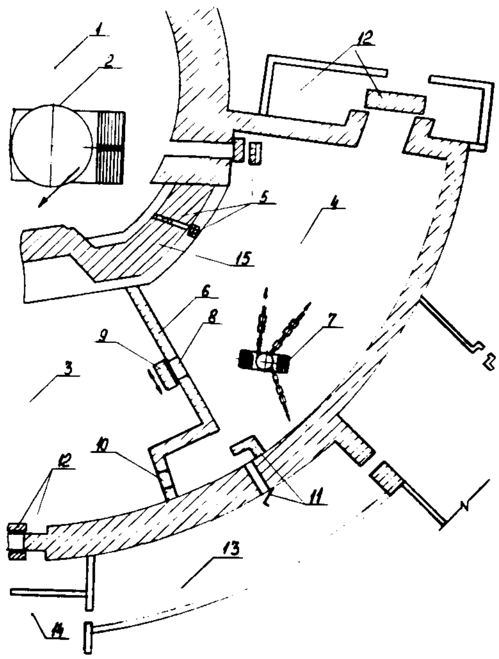

Fig. 2. Scheme of cyclotron arrangement. 1 - Hall of synchrocyclotron, 2 - Synchrocyclotron, 3 - Experimental hall, 4 - Cyclotron hall, 5 - Additional shielding, 6 - Wall separating the cyclotron hall, 7 - Cyclotron, 8 - Opening for crane passage closed by a wheeled block, 9 - Crane cargo opening, 10 - Cyclotron hall entrance, 12 - Shielding doors, 13 - Control hall, 14 - Laboratories, 15 - Shielding wall from iron block.

8. RADIATION ASPECTS AND SHIELDING

The aspects of induced activity are of great importance during a cyclotron design. To reduce an induced activity and to catch an H^o particles beam formed during $H-$ ions decomposition all the chamber elements are shielded along the perimeter with graphite screens made of $50 * 50\ mm\ bars$. The screens are attached to easily detachable aluminum panels fixed to the chamber. The screen application reduces the dose power by 2 times when the chamber walls are made of Al and by 5 times when they are of SS. The estimations show that at $10\% (10\ \mu A)$ beam losses the dose power of $\gamma-$irradiation of an induced radioactivity in one hour after switching off the accelerator at $1\ m$ distance will not exceed $0.1\ rad/hr$ after a long time operation. At the maintenance time the screens are taken out of the chamber to reduce additionally the personnel irradiation. To protect against an H^o particles beam all the chamber mechanisms are located, if possible, outside the median plane. The magnet coils insulation provides a 10 year operation and the rubber vacuum gaskets are meant for one year service approximately.

The biological shielding against the irradiation of an active cyclotron is solved by installing it in the experimental hall of the existing synchrocyclotron. The $4\ m$ thick walls are made of heavy concrete. For the protection of the personnel assembling the cyclotron against the secondary particles beam of the synchrocyclotron a $1.2m$ thick and $4.8m$ high protective wall has been built. It protects personnel against meson beams (but not full proton beam) extracted into another area of the hall. The aspects of shielding of personnel that works in the synchrocyclotron hall will be considered and solved later on during the new accelerator commissioning by means of local shielding and beam traps.

9. PRESENT STATUS

The main cyclotron systems design is planned to be finished this year. The cyclotron magnet has been almost finished and the manufacturing of its spiral sectors is coming to an end. The shielding wall and the basement construction has been accomplished and the magnet assembly started. An automated system for magnet measurements based on the Hall probes is finished to be built.

A high frequency system is being simulated on models 1 : 2 and 1 : 1, the $41.2\ MHz$ $15\ kW$ generator was put into operation and the design of $40kW$ final cascades of the generator has been finished.

The internal $H-$ ion source design is now being checked at a stand, as well as, the evaporation getter pumps of $NDMA - 20$ type are under testing. A pulse external $H-$ ion source and the power supply system have been manufactured. An axial injection model construction has been started.

Provided the financing be substantial, the first cyclotron beam could be generated in two years.

10. REFERENCES

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3) Mackenzie, G.H., et al., "Plans for the Extraction of Intense Beams of $H-$ Ions from the TRIUMF Cyclotron," in **Proceedings of the 10th International Cyclotron Conference** (Michigan, USA, 1984), p.233.