STATUS REPORT ON THE ALMA-ATA ISOCHRONOUS CYCLOTRON

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The 150-cm isochronous cyclotron in Alma-Ata has an extraction radius of $R=66,5$ cm, a K-number of 50 MeV and is in regular operation since 1972. The improvements made during the last years are given. New beam transporting system was completed. The first stage of the system for accelerating voltage amplitude stabilization was put into operation. An instrument for spatial external beam density measurements was developed. The project of the ongoing improvements of the cyclotron by increasing its pole tips diameter from 150 cm to 200 cm is outlined. Magnetic field properties of the new system were studied with model magnets. Preliminary orbital analyses were made using the measured field data.

Beam transport system

Initially the 150-cm cyclotron in Alma-Ata was put into operation in 1965 as an ordinary cyclotron with azimuthally constant magnetic field, fixed frequency and single external beam line. After conversion of the cyclotron into variable energy isochronous cyclotron the one beam line was a serious obstacle in carrying out experiments with external beams. So work was undertaken to rebuilt the beam transport system. Recently the main part of this work was completed and fig. 1 shows the main components of the new system. It has the full length of 25 m and comprises two 50° bending magnets, a switching magnet for ±40° bending, fourteen quadrupoles and affords an opportunity to work in three shielded halls, including the cyclotron vault. The system is provided with two correction magnets for steering the ion beam to the axis of the beam line in horizontal plane. In vertical plane the beam is aligned. There are also four steering magnets for beam adjustment in two planes at each target in experimental hall. From the switching magnet the ion beam can be bent in four directions in the main experimental hall, where shielding walls from movable blocks can be erected. The "left" line with total bending angle 140° is used for obtaining of low energy spread beam in experimental area. Use of collimators with 1 mm slits made it possible to improve the relative energy spread up to $1,5\cdot10^{-3}$. This preliminary beam collimation permits substancially decrease the radiation background produced by the collimators placed in front of the targets. The other beam lines are the high intensity beam lines. The dashed lines in fig. 1 indicate the planned additional beam line.

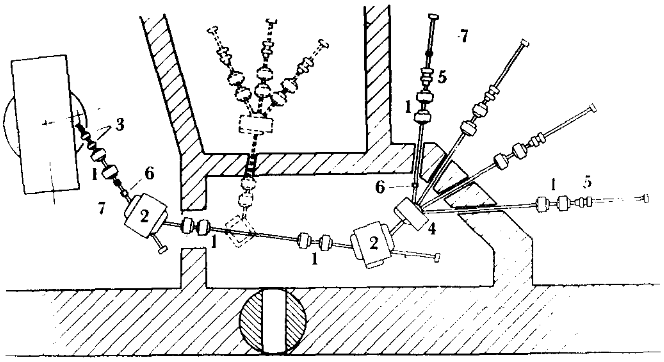

Fig. 1. A plan view showing the main components of the beam transport system: 1-quadrupole lenses, 2-bending magnets, 3-steering magnets, 4-switching magnet, 5-adjustment magnets, 6-collimators, 7-time of flight pick-up probes.

Beam diagnostics

For efficient tuning and performance of the isochronous cyclotron the accelerated ions beam diagnostics system is used. Such a system becomes especially essential for development of computer aided cyclotron automatic control system. The initial work on beam diagnostics performed in Alma-Ata were presented in Ref.[1,2]. Here are presented the results of the works in designing beam measuring devices

Beam characteristics in the phase plane are obtained by using the specially designed measuring system. It consists of two slit collimators movable in transversal plane in horizontal and vertical directions and ion beam current measurer which is located at 1,2 m distance with respect to the slit. The scheme of the scanning probe is presented in fig. 2. Current measuring probes are the Faraday cups eight all in all. Their length is 10 mm, and diameter - 8 mm. They are made of copper and are fastened to the vertical plank of a frame holder. In front of the Faraday cups the carbon-duraluminium collimator with vertical slit is fixed. A bias potential up to 300 V can be supplied to collimator in order to suppress secondary particles, emitted by the measuring probes. Uniform motion of the Faraday cups in horizontal plane is defined by uniform rotation of cylinder on the surface of which there is spiral slot. The stroke of the feedthrough is 110 mm and the position of the Faraday cups can be measured with 0,1 mm precision.

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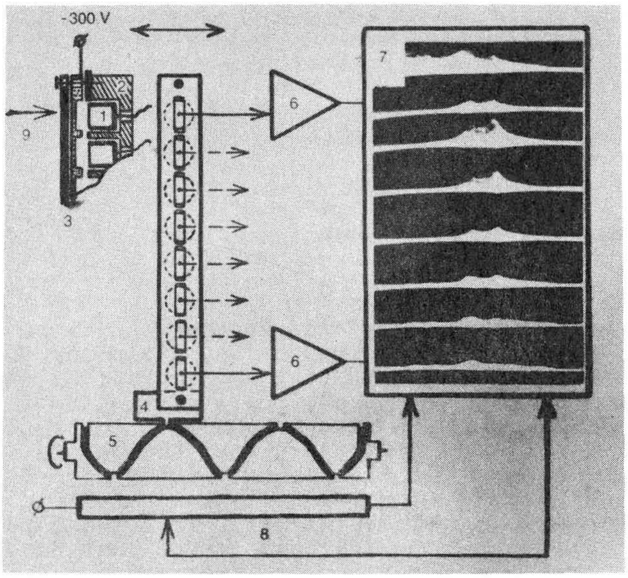

Fig. 2. Block diagram of the beam scanner: 1-Faraday cups, 2-cups holder, 3-collimator, 4-driver, 5-rotatable cylinder, 6-operational amplifier, 7-display, 8-linear potentiometer, 9-ion beam.

Signals from Faraday cups via operational amplifiers (k=500) are delivered to a 8-channel display synchronized with scanner motion. This remotely operated system affords an opportunity to make effective beam parameters measurements in a large current range namely from $5\cdot10^{-12}$ A to $2\cdot10^{-5}$ A both for constant and pulsed cyclotron operation mode. As an example beam density profile across the beam line is shown in Fig. 2.

For ions energy measurements the time of flight technique is used. At precisely determined length of beam line (L) two cylindrical capacity pick-up electrodes are located (Fig. 3). The signals from these electrodes via preamplifiers are registered by wide-band two-channel device (250 MHz) with accurasy $0,2\cdot10^{-9}$ s. Shifted in time these signals of nanosecond duration allow one to determine time interval between two electrodes. This measurement is done by using the coaxial cable delay in one of the channels of the measuring device. We were measuring the time interval between two signals from these electrodes with subtraction the whole number of particle periods thus approaching the accuracy of 0,5 %.

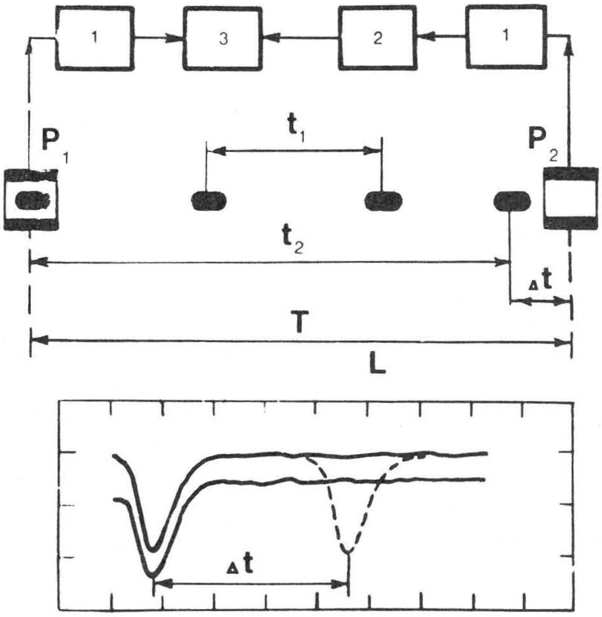

Fig. 3. Simplified block diagram of time of flight measurement system: 1-wide band preamplifier, 2-control delay line, 3-display, P_1,P_2-capacity probes, T-time of flight, Δ t-time measured on the display screen; vert. scale: 50 mV/div, horiz. scale: 5 ns/div.

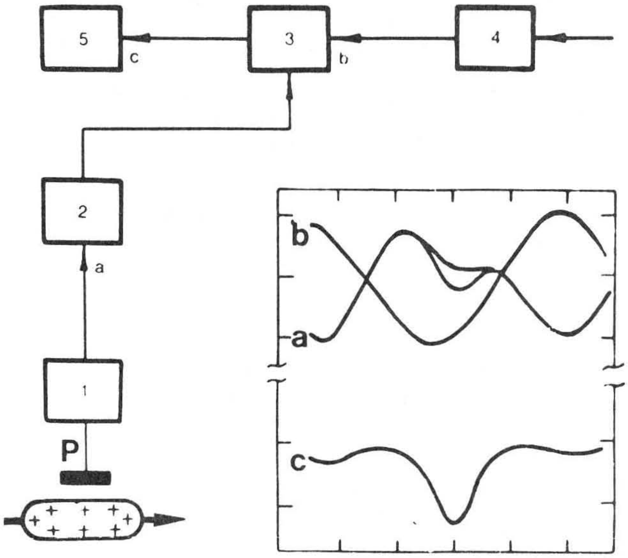

Fig. 4. Simplified block diagram of the phase measuring system: 1-UHF-line repeater, 2-filter, 3-RF mixer, 4-delay line, 5-display, 6-pick-up probe; vert. scale: 50 mV/div, horiz. scale: 10 ns/div, a) phase probe signal, b) RF reference signal, c) reclaiming signal.

For internal beam diagnostics a new micropulses measuring system was developed. On capacity pick-up electrodes located inside the vacuum chamber at different radii the signal is induced by HF accelerating field and by ion pulses. Beginning investigation of time and phase characteristics of internal beam pulses we wished to obtain beam signal in which should be presented the information on phase and ion density time distribution in ion pulse. To pick out beam signal and at the same time to preserve it's time characteristics we used a peculiarity of the induced signal. As HF resonator has a very high Q-value then accelerating voltage is almost sinusoidal with small contribution of higher harmonics. The beam signal with it's time duration of $(5-15)\cdot10^{-9}$ s order has many harmonics. It is this feature which was used while designing the electronics device the scheme of which is shown in fig. 4. The signals induced by ion beam on capacity electrodes are summed in tetrode field-effect transistor with high input impedance. Then it is amplified in the next stage with low output impedance and is delivered to the input of high frequency filter with cut-off frequency of about 19 MHz. In this case on filter output we have signal free of HF noise but it's time structure does not corresponds to ion density distribution in beam pulse as the first harmonic component is absent. To recover beam signal shape the first harmonic signal is delivered to the second input of mixer via phase shifter. The phase shifter is made using the delay line which is controlled by means of varicaps with phase and amplitude regulation.

Accelerating voltage amplitude stabilization

Cyclotron performance and accelerated ions beam quality are significantly determined by accelerating voltage stability. Usually this is carryed out by accelerating voltage amplitude and resonator frequency control systems. Some time ago a frequency stabilization system was put into operation[3] at the cyclotron facility in Alma-Ata and for many years it functions successfully. An input electric power at the voltage of 380 V also was stabilized with 1% accuracy. However during the cyclotron running in pulsed mode the instability of accelerating voltage amplitude can sometime achieve 10 %.

To decrease this value down to $5 \cdot 10^{-3}$ a control system for accelerating voltage stabilization was developed. It represents the one loop static control system for HF voltage envelope amplitude regulation.

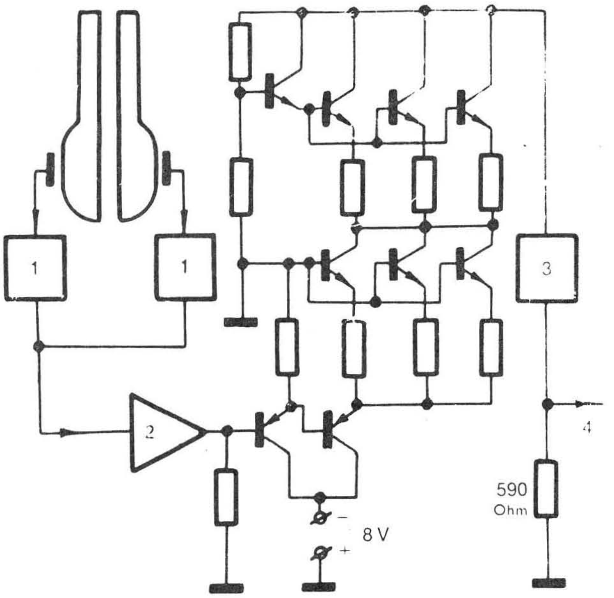

Fig. 5. Block diagram of the electronics for the voltage amplitude stabilization system: 1-amplitude detector, 2-operational amplifier, 3-power source (600V/1A).

Block diagram of the system is presented in fig. 5. It operates on the basis of comparison of the HF voltage envelope and the direct current reference voltage. Two capacity dividers are placed directly at the accelerating chamber. The voltage on the capacitors C_1, C_2 are proportional to HF dee voltage. These signals from the output of semiconductor detectors after summing are compared in the operational amplifier with reference voltage. Error signal after amplifying in the output amplifier is delivered to the third grid of the second stage valve of the five-stage HF power amplifier affecting by this the amplitude of the accelerating voltage.

Performance quality of the described system has been estimated directly with an oscillograph by cutting off the upper part of HF voltage on the detecting elements by semiconductor diodes to increase measurement sensitivity. These measurements have shown that stability of accelerating voltage amplitude in pulsed mode of the cyclotron operation for macro duty factor 2-100 and in the frequency range of 8,5 - 18,5 MHz is not less than $5 \cdot 10^{-3}$ which is illustrated by fig. 6. The frequency band width of the considered stabilization device is 300 kHz.

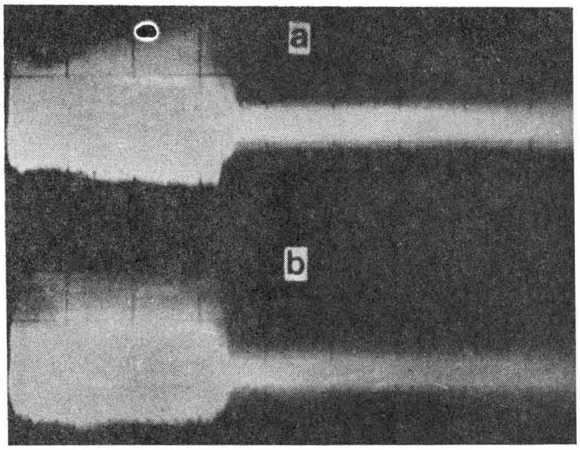

Fig. 6. The beam signals on the time of flight probes:
a) without amplitude stabilization,
b) with amplitude stabilization;
horiz. scale: 100 us/div.

The project of 200-cm cyclotron

Since the spring of 1972 the 150-cm Kazakhstan isochronous cyclotron is successfully used to serve low energy nuclear physics, radiation physics and some commercial applications. At the same time there is necessity for higher energy especially for heavy ions. To meet these demands it was decided to consider the possibilities of increasing cyclotron energy factor by increasing pole diameter from 150 cm to 200 cm and at the same time not changing the main components of the accelerator facility as far as it is possible A short description of the main components and systems of the planned isochronous cyclotron is given below.

It is supposed that the magnet structure will be as follows. A pole face diameter - 200 cm, an extraction radius - 88 cm, the gap between the sectors - 15 cm, the gap in valleys - 35,8 cm. The azimuthally varied magnetic field is produced by the three pairs of sectors with spiral angle of 55° at the extraction radius (fig. 7).

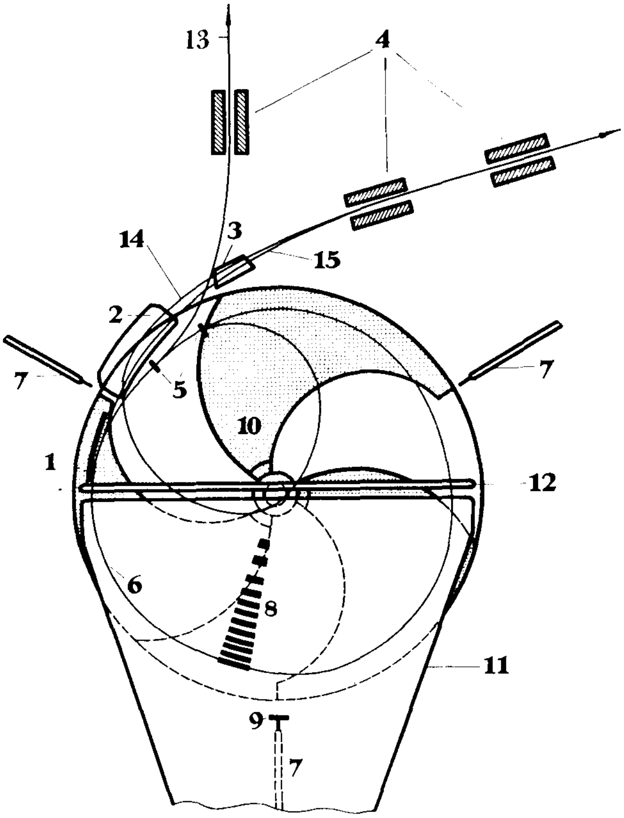

Fig. 7. General layout of the cyclotron main components: 1-electrostatic deflector, 2-electromagnetic channel, 3-magnetic channel, 4-steering magnets, 5-stripper foils, 6-equilibrium orbit, 7-beam probes, 8-pick-up probes, 9-moveable pick-up probe, 10-pole sectors, 11-dee, 12-dummy dee, 13- protons extracted beam, 14- heavy ions extracted beam, 15- light ions extracted beam.

For given ratio of yoke cross section area and pole surface, which is equal to 1,08 the 1200 A current supply is expected with the maximum value of the magnetic field in the centre at 16 kG. The main magnetic field properties were studied with the 1/4 model magnet.

The inner PIG-type ion source will be introduced vertically. It is supposed that the accelerating system will be the quarter-wave panel resonator provided by mechanical device for frequency changing. Coarse tuning will be made by panel replacement and fine tuning - by capacity trimmers. The resonator will be loaded by one 180° dee. The frequency range will be 6,5 - 19 MHz. For obtaining the desired maximum value of dee voltage of the level of 120 kV the required power of the oscillator is expected to be 250 kW. We hope that this system will be suitable for computer aided cyclotron performance.

The extraction system components are presented on the fig. 7. It consists of a short electrostatic channel, an electromagnetic channel, a shielding channel and steering magnets. To increase the turn separation of the final orbits it is planned to use precessional beam extraction. Maximum proton energy is expected to be 60 MeV. For their effective extraction it is planned to accelerate negative hydrogen ions with their subsequent stripping by carbon foil. The anticipated resulting beam energies are presented in fig. 8.

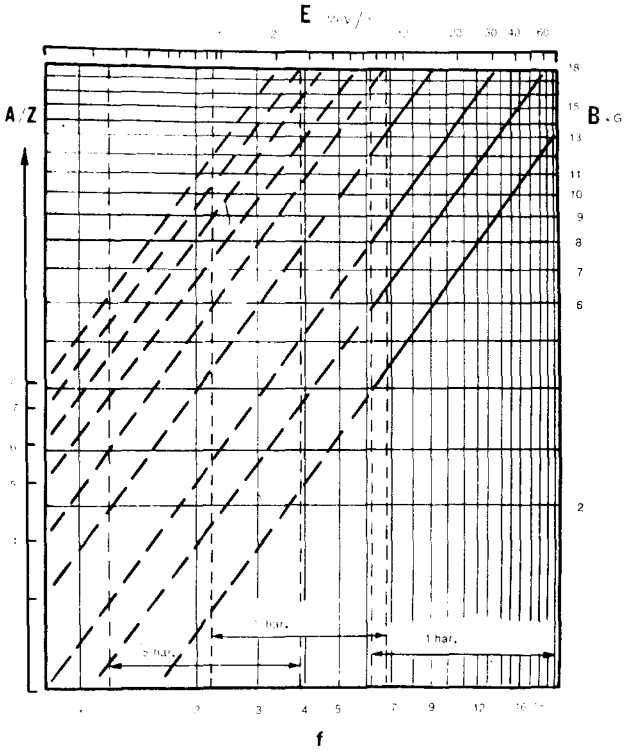

Fig. 8. Acceleration energies for various ions versus magnetic field and particle orbit frequency.

References

1. A.A. Arzumanov, V.N. Batischev, V.D. Berger, A.M. Voronin. M.S. Gorcovets M.H. Nigmatov. International seminar on isochronous cyclotron technique. Report No 1069/PL, Kracow - Poland,327, (1978).

2. A.A. Arzumanov, A.M. Voronin, M.S. Gorcovets, Trudy Sedmogo Vsesojuznogo Soveschanija po uskoriteljam zarjagennych tchastits, v. 2, Dubna, 62, (1981).

3. O.K. Anisimov, A.A. Arzumanov, V.N. Batischev, V.I. Gerasimov, M.S. Gorcovets, V.G. Kruglov. B.A. Volkov, A.M. Voronin, IEEE Trans. NS-26, No 2, 1912, (1979).

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