Proceedings of the Eleventh International Conference on Cyclotrons and their Applications, Tokyo, Japan

COMMISSIONING OF THE JINR PHASOTRON

A.A. Glazov
Joint Institute for Nuclear Research, Dubna

Summary. In 1985 the JINR phasotron was set into operation. A proton beam was extracted from the accelerator chamber and directed to the head element of the beam transport system. Hard work of a large team of scientists, engineers and workers headed by professor V.P.Dzhelepov has successfully ended.

1. Introduction.

The JINR phasotron is a quite new accelerator located in the building of the LNP synchrocyclotron. The magnet yoke with new windings, the magnet power supply system and two 40000 l/sec oil-vapour diffusion pumps were only taken from the old accelerator.

Let us consider the main parameters and structure peculiarities of the accelerator in short. The proposal to construct a synchrocyclotron (phasotron) with spatial variation of magnetic field on the basis of the JINR synchrocyclotron was first published in 1969[1]. The main idea was to greatly increase the accelerating voltage to "cyclotron" values by significantly narrowing the range of frequency variation via radially growing magnetic field with spatial variation. Compared with a conventional synchrocyclotron, here the increase in intensity under an assumption that intensity is limited with defocusing action of the beam space charge is expected to be

$$I_p/I_s = (V_p/V_s)^{3/2}(K_s/K_p)^{1/2} \qquad (1)$$

where V is the accelerating voltage amplitude, $K = 1-n/(1+n)^{2}$, $n = r/B\cdot dB/dr$. Increase of the accelerating voltage also allows using a more effective ion source of cyclotron type and the cyclotron optics of the first turn, which leads to increasing the current and improvement of the beam quality.

Analytical and numerical calculations of particle dynamics helped to choose the magnet field configuration, ensuring the optimal mode of beam acceleration and extraction at maximum possible field increase $B_{max} = 1.3675\ B_o$:

$$B_z(r,\ ) = B(r)+B_N(r)\cos(r/\lambda - N\varphi), \qquad (2)$$

$$B(r) = B_o\exp(0.359S^2+0.831S^6-2.351S^8+1.5S^9-0.025S^{10}), \qquad (3)$$

where $B_o = 1.1902$ T, $S = r/r_m$, $r_m = 2{,}7$ m, $\lambda = 15$ cm, $N = 4$.

2. Magnetic field.

The magnetic field is created in the gap of the electromagnet with an E-shaped core, its poles being 6 m in diameter. The field-shaping magnetic system is part of the accelerating vacuum chamber. It consists of four pairs of spiral shims, producing the spatial field variation; profiled circular shims, determining the radial dependence and several systems of fine correction (Fig. 1). To keep geometrical dimensions unchanged with and without vacuum in the chamber, a prestressed structure with a system of chamber wedging in the electromagnet gap and peripheral catches were used. To shape the magnetic field, one can employ:

1. Iron rods 10 mm in diameter, placed in valleys between spiral shims.
2. Side iron plates on spiral shims.
3. Sector shims between disks.
4. Concentric and harmonic coils in the central region of the accelerator.

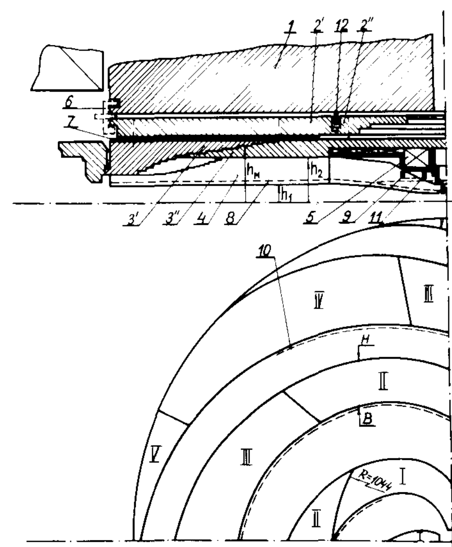

Fig. 1. Schematic drawing of the magnetic system:
1 - pole, 2,3 - disks, 4 - spiral shims, 5 - concentric coils, 6,12 - armature for fixation, 7,11 - sector shims, 8 - iron rods, 9 - harmonic coils, 10 - side shims.

By means of these elements the working field of the accelerator was shaped with an accuracy 10^{-3} (Fig. 2)[2].

Employing variations and magnetic field increasing with radius leads to a more narrow working range of frequences as compared with ordinary synchrocyclotrons 14.41 f 18.18 (MHz). This was accompanied however with a sharp decrease of the interpole gap of the magnet, and for the dee aperture chosen to be 10.0 cm the gap between the dee and the chamber plating is 8 cm.

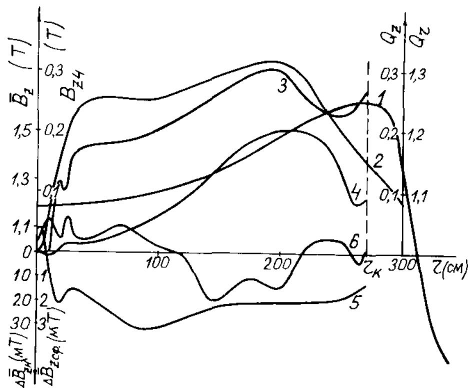

Fig. 2. Parameters of the magnetic field: 1 - B_z, 2 - B_{z4} (T), 3 - Q_z, 4 - Q_r, 5 - $B_{z\,initial}$, 6 - $B_{z\,final}$ (mT).

3. Accelerating system.

Analysis of various possibilities showed that the best accelerating resonant HF system for the JINR phasotron is a uniform line tuned by two identical rotating capacity variators, so that the voltage applied to the most important unit, i.e. the variator did not exceed quite a high accelerating voltage of 40-50 kV [3]. Owing to a large length of the line, the variators and HF generator can be placed behind the radiation shield, which is an organic part of the line design, in the place where the fringing magnetic field practically equals zero.

A schematic view of the resonant line is shown in Fig. 3 (a). The dee frame is made of stainless steel and covered with 1.5 mm copper plates. The copper is cooled with distilled water supplied through two inductors placed symmetrically on both sides of the dee in the places of the lowest voltage. The dee bias is also applied through these induction. Three tubular air-cooled alumina insulators are used as dee supports. To make the structure more rigid, three columns are put in the intermediate chamber along the system axis.

The use of mechanical systems for frequency tuning automatically leads to long backward running, when the system frequency returns from the final state to the initial one. Owing to the fact that reduction of the backward running allows increasing modulation frequency and, consequently, intensity of accelerated particles, a unique variator with a larger working period was developed. The larger working period was achieved by using rotor blades of small angular length and stator blades of complicated shape, profiled in height and thickness (Fig. 3 (b)). On the upper frequency of the range at the maximum variator voltage the working gap is 7 mm, and on the lower frequency at 60% of the maximum voltage it is 4 mm. The rotor is grounded by the collector capacitor with the working gape 1.5 mm. The capacity of variators changes from 1000 to 6000 pF for 59 disks. This is enough for covering the working frequency range with a "safe-quard" margin.

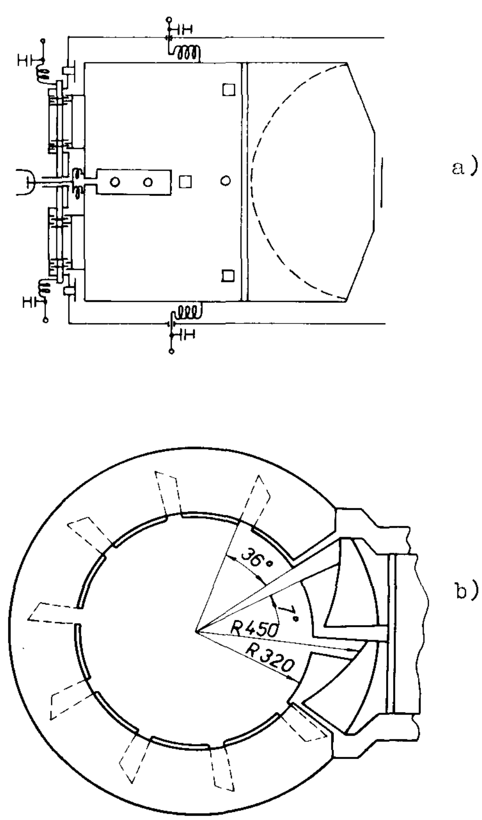

Fig. 3. High frequency system:
a) resonant line, b) rotating capacitor (frequency variator).

To excite the radio-frequency system, a high power oscillator is used. It is based on a powerful triode (see the diagram in Fig. 4). The elements L_k, C_{oc}, L_{oc} ensure stable oscillation only in the working range of frequences. Conjunction with the resonance line is provided by means of a half-wave feeder about 1.5 m long through inductors installed on both sides of the cut in the line, made for extraction of the cross mode of oscillations

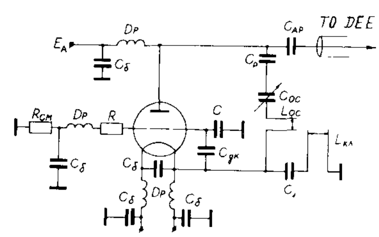

Fig. 4. Oscillator.

from the working frequency range. Fig. 5 shows characteristics of the r.f. system versus the rotation angle of the variator rotor.

4. First beam.

A complex test of accelerator systems late in 1983 showed that the electric field did not ensure proper axial focusing in the middle of the accelerator because of the phase motion of ions. Requirements to the median plane symmetry become too high in this case ($B_r \sim 0.5 \div 1$ Gs) [4]. So it was decided to

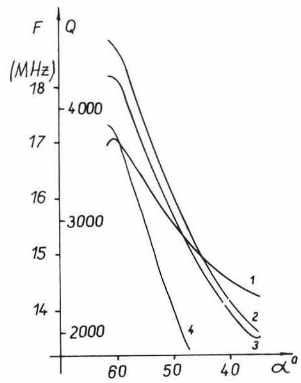

Fig. 5. 1 - Q-factor, 2 - working frequency without trimming capacitors, 3 - with capacitors, 4 - frequency cross mode versus the angle of turn rotating capacitor.

change the field configuration $B_z(r)$ in the zone of radii of the first phase oscillation. Numerical calculations determined the law of $B_z(r)$ variation with the bump amplitude 30 Gs and minimum at R = 18 cm which allows the phasotron acceleration with the accelerating voltage amplitude 30 kV at a significantly larger tolerance to the field symmetry (B_r 3 ÷ 5 Gs). For B_r correction "by beam" in the central region in radii 16.5 ÷ 35 cm, 7 concentric coils of fine correction were installed over chamber plating. The maximum current in a winding was 10 A [5].

At the initial operation of the accelerator in February 1984 a 670 MeV beam was obtained on the final radius 270 cm [14]. After losses during the first phase oscillation with R ⩾ 50 cm the current remained practically unchanged, except insignificant losses at R ~ 2 m where a shift of the median plane was observed. The optimum accelerations was obtained at supplying power to three concentric coils of coarse correction (R = 18 ÷ 38 cm), fine correction (R = 16.5 ÷ 18.6 cm) and stabilisation. The latter is placed on the pole of the electromagnet.

5. Commissioning.

The most important accelerator element to be in operation at the general commissioning of the accelerator was the beam extraction system. The regenerative extractor with a ferro-current channel (Fig. 6) are used as an extraction system of the JINR phasotron [8].

The front wall of the ferro-current section is made of two flat water-cooled copper conductors with the current 11 kA. The effective inlet thickness of the septum is 4 mm.

The radial position and fields of the regenerator and peeler are shown in Fig. 7 [9].

The presence of the beam extraction system in the chamber causes a significant field perturbation on radii 184÷274 cm with a maximum deviation 800 Gs. A preliminary shimming of the perturbation was performed at the stage of the accelerator field formation. It was performed by means of easily detachable elements, placed over the chamber plating, in order to provide a possibility of accelerator working in two modes: without extraction system at the initial operation and with the ex-

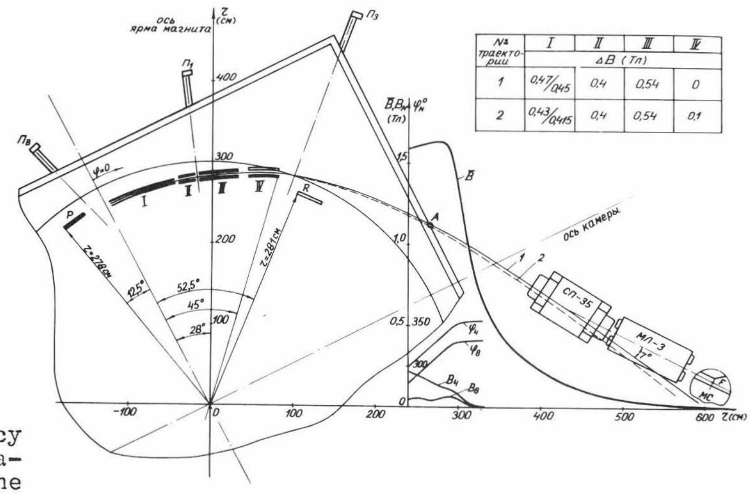

Fig. 6. Extraction system:
I - iron-current section of the magnetic channel, II-IV - iron sections, P - peeler, R - regenerator.

traction system at the general start-up.

Final shimming of perturbations on the edges of channel sections was carried out after the initial operation by means of iron pieces, placed directly on the sections.

Besides operation of the extraction system, commissioning of the accelerator implied operation of the r.f. system with the duty factor 1:1 (for each rotor blade) at the accelerating voltage 40 kV during the capture. This required better working vacuum, and liquid nitrogen buffles were made for all vacuum pumps, evacuating the accelerating chamber.

At the same time a "strengthened" field bump with the amplitude 60 Gs was formed in the centre, and a system of beam stretching by a C-electrode was installed in the chamber [11,12,13].

A series of experiments on selection of position of the regenerator, peeler and channel sections in April 1985 resulted in extraction of the 657±5 MeV beam in the given direction. The beam shape along the extracting trajectory (Fig. 6) are shown in Fig. 8. The extraction efficiency, measured by the induced activity and by the calorimetric method, exceeded 50%.

After extraction of the beam from the accelerator chamber a "beam" correction of the field was performed in a series of short runs. This allowed us to remove additional coils of fine correction in the centre and eliminate losses on the R ~ 2 m. The optimum shape of the accelerating voltage without phase losses was selected by the anode modulator (Fig. 9).

Since 80% of future experiments require a stretched beam, the stretching system was put into operation. At the identification of frequency-time programmes for each rotor blade at the frequency of recapture in the C-electrode the extracted beam uniformly fills the stretching period equal to 85% of the modulation period of the main programme. The integral intensity of the stretched beam is about 50% of the unstretched one.

In view of adjustment of physical equipment and beam transport system the accelera-

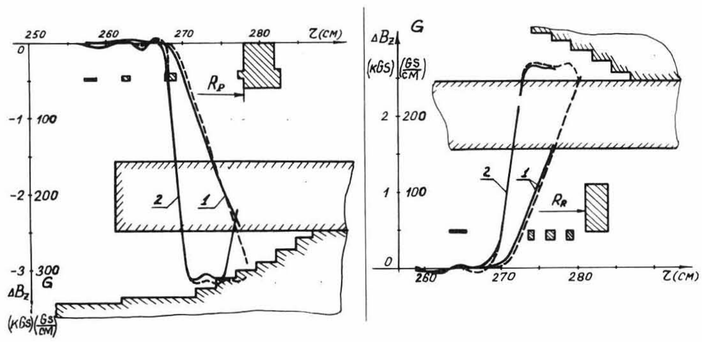

Fig. 7. 1 - magnetic field (kGs) and 2 - its gradient distribution (Gs/cm): a) peeler, b) regenerator.

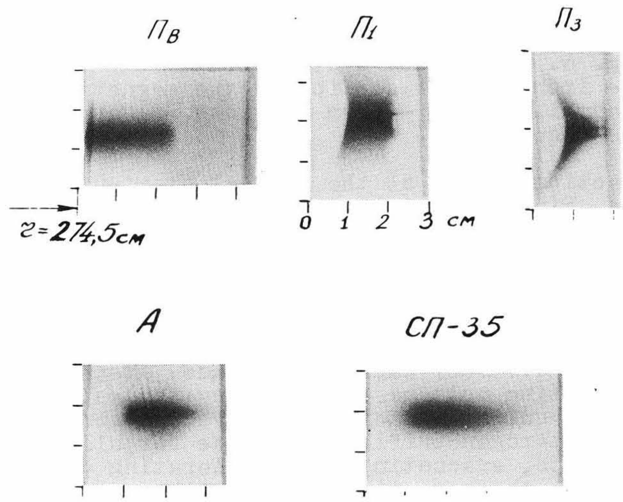

Fig. 8. The beam shape along the extracting trajectory Fig. 6.

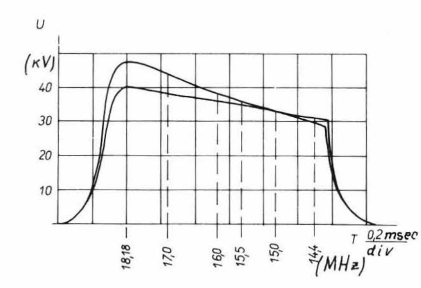

Fig. 9. The shape of the accelerating voltage. Maximum and ordinary value.

tor operates with lower intensity. The maximum mode with the internal current 8.6 μA was obtained at V_{acc} = 40 kV, F_M = 400 Hz and the pulsed power supply of the ion source (I = 5 A, = 50 μsec).

Since construction and assembly work goes on at daytime, the accelerator operates from 16 to 8 o'clock in the morning; it operates 24 hours in Saturday and Sunday. The schedule is followed with the reliability 70%.

The total beam time is about 3000 hours.

References

1. A.A. Glazov, et al. Atomic Energy, 1969, v. 27, No 1, p. 16
2. Yu.G. Alenitsky, et al. Eighth All-Union Accelerator Conference, Dubna, 1983, v. II, p. 83
3. A.A. Glazov, et al. Ninth All-Union Accelerator Conference, Dubna, 1985, v. I, p. 320
4. S.B.Vorozhtsov, et al. JINR, R9-84-25, Dubna, 1984
5. Yu.G. Alenitsky, et al. JINR, R9-84-152, Dubna, 1984
6. Yu.G. Alenitsky, et al. Ninth All-Union Accelerator Conference, Dubna, 1985, v. I, p. 289
7. Yu.G.Alenitsky, et al. Ninth All-Union Accelerator Conference, Dubna, 1985, v. I, p. 313
8. A.T. Vasilenko, et al. JINR, R9-12586, 1979
9. S.B. Vorozhtsov, et al. Ninth All-Union Accelerator Conference, Dubna, 1985, v. I, p. 316
10 N.L.Zaplatin, et al. JINR, R9-85-258, Dubna, 1985
11 S.B.Vorozhtsov, et al. Ninth All-Union Accelerator Conference, Dubna, 1985, v. I, p. 308
12 Yu.G.Alenitsky, et al. JINR, R9-85-199, Dubna, 1985
13 A.A.Glazov, et al. JINR, 9-82-110, Dubna, 1982
14 Yu.N.Denisov. Tenth International Conference on Cyclotrons and their Applications, East Lansing, 1984, p. 494