STATUS REPORT OF 1 GEV PNPI SYNCHROCYCLOTRON

N. K. Abrossimov, S. P. Dmitriev, V. A. Eliseev,
E. M. Ivanov, Y. T. Mironov, G. F. Mikheev, G. A. Riabov

1 GeV PNPI synchrocyclotron (SC) provides widespread research program in nuclear and applied physics and also in a medical proton therapy and production of radiopharmacology for medicine purpose. At 1970-1993 SC has been on routine operation 5500-6000 hours per year [1]. But since 1993 SC is in operation only 1500-2000 hours per year due to deficient financing. PNPI SC is comparatively power-consuming installation: SC- power-consumption is 1.6 MW, beam transport lines 0.2-1 MW, another technological equipment 0.2-0.5 MW and total power-consumption is 2-2.5 MW. The main parameters of a SC are presented in Table 1, and beam parameters in Table 2.

Table 1

SC parameters	
Pole diameter	6.85 m
Gap	0.50 m
Magnetic field at extraction radius	1.78 T
Frequency range	$30 \div 13$ MHz
Amplitude of an accelerating voltage	8 kV
Repetition rate	40-60 Hz
Internal beam intensity	3 μA
Extraction efficiency	30%
Macro duty cycle	50%
Vacuum	10^{-6} Torr
Magnet weight	8000 t

After long-term improvement program the accelerator and experimental area are being represented an unique installation. Briefly the main features of 1 GeV SC facility can be formulated as follows.

1. For acceleration of proton up to the 1 GeV energy a unique high-frequency accelerating system with a frequency span ratio Fmax/Fmin= 2.3 has been developed by means using a rotating condenser with a factor Cmax/Cmin=40 [2].

2. The electrostatic focusing in a centre of SC provides increasing the beam intensity in $5 \div 10$ times [3].

3. Original system for a long burst operation of SC beam has been developed by means using a C-electrodes. Nonusual features is an application low power 5 kW resonance system with ferrite frequency variator and synchronization with beam as well on frequency as on phase [4].

4. 30% efficiency non-linear regenerative extraction system has been developed with record efficiency for synchrocyclotrons with an open ion source central geometry [5].

Table 2

SYNCHROCYCLOTRON BEAM PARAMETERS

Main proton beam

Particle	P, GeV	ΔE/E, %	Intensity, s^{-1}	Channel	Application
p	1	1	$\sim 6 \cdot 10^{12}$	P1,P2,P3	main proton beam
p	1	1	10^8	P2	medicine beam of small beam size $3 \div 5$ mm^2
p	1	10^{-3}	10^8	P2	spectrometric beam
p	1	1	10^{10}		second proton beam with focus at accelerator hall

Secondary beams parameters

Particle	P, MeV/c	Δp/p, %	Intensity, $s^{-1} \cdot \mu A^{-1}$	Channel	Application
π^+	450	6	10^6	π1-channel	achromatic regime
π^-	450	6	$3 \cdot 10^5$		
π^-	250	$2.5 \div 12$	$10^5 \div 10^6$	π2-channel	achromatic regime surface mesons
π^+	250	$2.5 \div 12$	$3 \cdot 10 \div 1.6 \cdot 10^7$		
μ^+	29	12	$3 \cdot 10^4$		
μ^-	160	10	$9 \cdot 10^4$	μ-channel	separated beam
μ^+	175	10	$3 \cdot 10^5$		

Neutron beam

Energy, MeV	Intensity, s^{-1}	Pulse duration	Frequency, Hz
10^{-2} eV–100 MeV	$3 \cdot 10^{14}$	10 ns	50

5. Secondary beam system consists of π1-channel for high energy $\pi^{\pm}$-meson beams, π2-channel for low energy $\pi^{\pm}$-meson beams and for surface μ^+-meson beam, μ-channel [6].

6. Pulsed n-beam on TOF neutron spectrometer (GNEIS) is being up to now one of the best in the world n-beam source in an energy range 10^{-2} eV up to 100 MeV [7].

7. Medicine irradiation facility has been developed on 1 GeV proton beam. The facility is intended to irradiation the local intra-cranium targets by using the method of stereotaxic irradiation. The facility consists of medicine beam line, the medicine annex with an irradiation area, computer controlled movable treatment-table, equipment for a beam diagnostic and dose control. The beam diameter is 3–5 mm and the one-time dose is equal 120-180 Gr. Up to now 1000 patients have been treated on Gatchina SC [8].

8. The second proton beam with small intensity which acts in parallel with a main beam opens up opportunity to increase the patient irradiation as high as 10 times [9].

As a result of a long-term improvement program PNPI SC has been progressing to the stage of synchrocyclotrons after fundamental and expensive reconstruction with long time shut-down.

During 1994-1995 years the program of current improvement has been continued.

• It was continued modernisation of the beam system: the beam diagnostic system based on profilometers has been modernised, it was put into operation system for remote shutting the beam line by beam dampers, the location of the magnetic elements is controlled by accurately located geodetic marks. One of the high priority problem is a research of short living isotopes far from stability region on IRIS complex. On Fig. a modernised beam transport line on a target of IRIS-mass-separator is shown. A length of the beam transport line is 60 m, the beam transmission is 90%, beam spot on a target is 10 mm.

• New system for position control of the magnetic channel by using a distance-inductively transducer has been put into operation.

• Low intensity proton beam for testing and calibration multiwires ionisation chambers has been developed.

• It was developed specialised and metrologically certificated the beam for radiation tests of materials. The dose field diameter can be changed from 1 to 25 cm, radiation dose is $10 \div 10^3$ rad, the nonuniformity of the dose field is $< 5\%$, the contribution of the scattered neutrons to a dose is $< 1\%$.

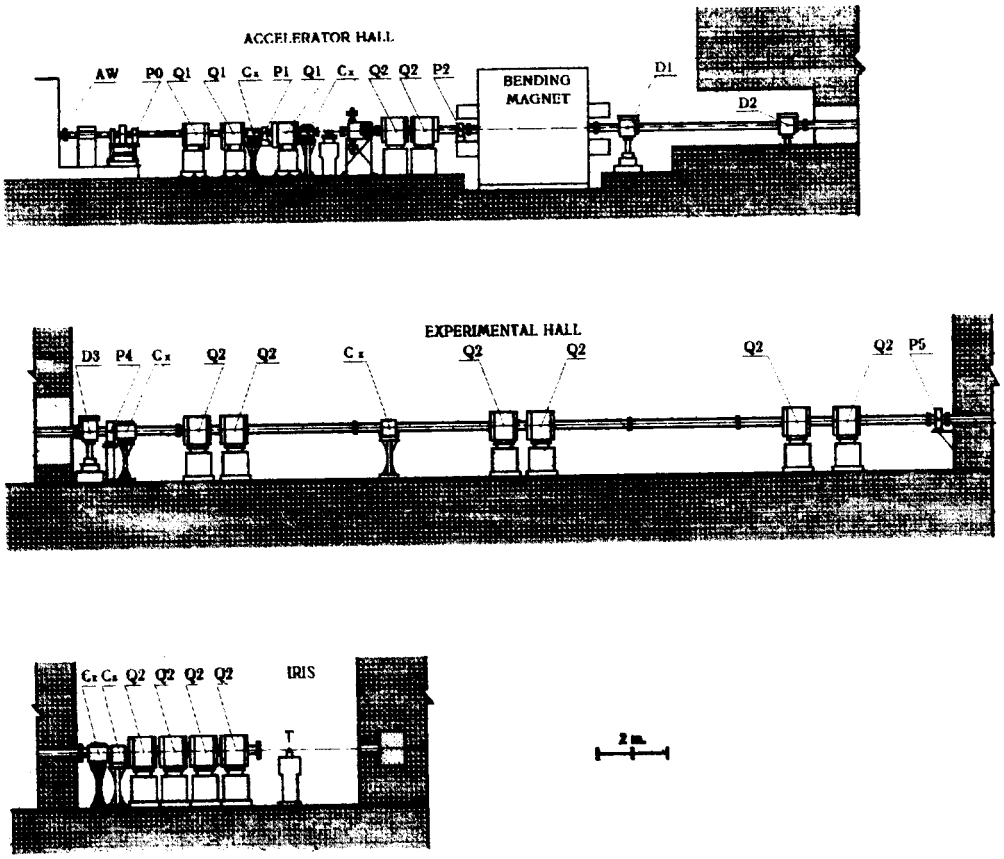

Fig. AW — accelerator window, P0,P1,P2,P4,P5 — profilometers, Cx — X-magnet-corrector, Cz — Z-magnet-corrector, Q1 — quadrupoles 10K50, Q2 — quadrupoles 20K50, D1,D2,D3 — beam dampers, T — mass-separater target

SC is a part of High Energy Physics Department of PNPI. The research program on HEP-Department consists of the experiments on Gatchina SC, on Russian and foreign accelerator centres. Gatchina SC is being used as well for home research program as for development, testing and calibration the equipment for experiments on the another research centres.

At present time Gatchina SC provides the experimental program on nuclear, elementary particles and solid state physics. The main directions of investigation can be formulated as follows:

• Nuclear spectrometric investigations on the experimental complex IRIS of the atomic nucleuses produced by the 1 GeV protons. The program includes the investigation as well a light neutron-redundant nucleuses Li as a measurements of the effective charge distribution radius of the isotopes of rare-earth elements in the region $N = 82$.

• Research with polarised nuclear targets on a 1 GeV beam line. The next-future experiment is the measurement of the transfer of polarisation in the small angle elastic pp and pn-scattering.

• Study of production η and π^0-mesons at interaction protons and pions with nucleons and nucleuses.

• Research of magnetic phase transitions by means μSR-method in various alloys.

Among the applied program the most significant are as follows:

• The patient treatment on 1 GeV proton beam. During 1994-1995 107 patients have been treated on Gatchina irradiation facility.

• Irradiation of materials and components on 1 GeV proton beam.

• Testing and calibration multiwires ionisation chambers on high energy detectors.

• The 1 GeV energy of proton is optimal for investigation the physical and technological problems of transmutation of long living nucleuses from radioactive waste.

By comparison with an another accelerators such as meson factory, SC remain a most cheap source of proton and meson beams. The proton and meson beam parameters provide a widespread research program which does not require high intensity meson beams.

For example, on the SC an original spectrometric beam with energy resolution $\Delta E/E \sim 3 \cdot 10^{-4}$ in combination with the magnetic spectrometer with a corresponding resolution have been developed. This installation allowed to perform program of an investigation nuclear matter distribution in light nucleuses by means investigation elastic scattering. Other example is the μSR-method, not required muon beam of high intensity.

An additional point to emphasise is that more higher energy of a proton beam in comparison with meson factories provides an opportunity research production K-mesons and η-mesons, as well as investigations on higher energy of pion beams, nonaccessible on meson factories.

After 25 years of the operation 1 GeV SC continue to be one of actively acting and most cheap proton and meson beam facility in a country. There is an actual program on nuclear and applied physics, in nuclear medicine and so on. The test beams are used for a preparation equipment for an external scientific program. And at last SC play a role of "kindergarten" as far as provide a training and education program for young generation of the scientists and engineers for the future work on physics centres around the world.

REFERENCES

1. *Abrossimov N.K. et al.,* //JTPh, 1971. V.41. P.1769.
2. *Abrossimov N.K. et al.,* //JTPh, 1971. V.41. P.1222.
3. *Abrossimov N.K. et al.,* Proc. VI-th All-Union Conf. on Charg. Part. Accel., Dubna 1979. V.1. P.227.
4. *Abrossimov N.K. et al.,* Proc. III-th All-Union Conf. on Charg. Part. Accel., M., 1973. V.2. P.94.
5. *Abrossimov N.K. et al.,* //Nucl.Instr. and Meth., 1975. V.126. P.221-230.
6. *Abrossimov N.K. et al.,* Proc. V-th All-Union Conf. on Charg. Part. Accel., M., 1977. V.1. P.183.
7. *Abrossimov N.K. et al.,* //Nucl.Instr. and Meth., 1985. V.A242. P.121.
8. *Abrossimov N.K. et al.,* //Medicine Radiologie N 8. 1987. P.10.
9. *Abrossimov N.K. et al.,* Proc. X-th All-Union Conf. on Charg. Part. Accel., Dubna 1987. V.2. P.174.

EXPERIMENTAL DETERMINATION OF THE EXTERNAL BEAM MATRIX ON 1 GEV SYNCHROCYCLOTRON

E. M. Ivanov, G. A. Riabov

The critical question for the beam optics calculations is a correct determination of the input beam parameters. Presented report is devoted to description the procedure of the experimental determination of the extracted beam parameters on 1 GeV synchrocyclotron.

In fields of linear forces the transversal movements in planes x and z are independent and the beam phase space can be characterised by two 2-dimensional symmetrical matrixes σ_x and σ_z, each of which will be transformed along a beam line under the law [1]

$$\sigma(s) = R(s)\ \sigma_0(s)\ R^T(s)\ , \tag{1}$$

where σ_0 is initial matrix, R(s) is optical matrix of transition. An element of a matrix $\sigma_{11} = < (x - \bar{x})^2 >$ is a mean square beam size, which can be received from profile measurement. From (1) we receive expression

$$\sigma_{11}(s) = \sigma^0_{11}(s)\ R^2_{11}(s) + 2\sigma^0_{12}(s)\ R_{11}(s)\ R_{12}(s) + \sigma^0_{22}(s)\ R^2_{12}(s)\ , \tag{2}$$

which is a parabola equation in a drift space (since $R(s) = 1, R(s) = s$).

To measure the beam profile the profilometers developed at PNPI SC was used [2]. The beam ellipse parameters which are elements of matrix can be determinated by measuring the profiles for three profilometer position. The most accurate measurements can be done in drift space as far as the transfer matrix can be determinated accurately. The procedure is very sensitive to the accuracy in determining the beam profile. This situation is illustrated on Fig.1. When a beam envelope, shows up as a parabola with small curvature, small errors in profile can result in physically incorrect result. Parabola, passed through 3 measurement