THE 70-GeV PROTON SYNCHROTRON

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The parameters of the 70-GeV proton synchrotron were published in the Proceedings of the International Conference on High Energy Accelerators in 1963[1]. The accelerator status during the period before its startup was reported at the Frascati conference in 1965, as well as at the Washington and Cambridge conferences in 1967.

The accelerator began to work in October 14, 1967. Since then particle dynamics has been investigated, the systems of the slow proton beam guiding onto the internal targets were put into operation, and secondary beams were formed. Brief information on the present accelerator status is given below.

The Accelerator

A 100-MeV linac serves as the injector for the accelerator[2, 3]. In February, 1968, the current of accelerated protons at the linac output was brought up to 100 mA. The measurements showed that the width of the instantaneous energy spectra remains practically eqaul to the width of the total spectrum of low current beam, up to 10 mA. However, with the acceleration of intense beams, from 50 to 100 mA, the rf field level in the cavities drops considerably. This field drop leads to a shift of the spectrum center of gravity during the proton pulse, consequently the width of the beam integral spectrum increases and reaches 1%-1.5% by the 0.2-level. This leads to non-uniform filling of the proton synchrotron buckets.

Figure 1 represents an integral beam spectrum with current 65 mA. The spectrum width at the 0.2-level has a 0.7% spread. The beam with such a spectrum, after additional reduction of the momentum spread by the debuncher, practically fills the bunches uniformly in the ring chamber.

Figure 2 shows the oscillograms of the proton current pulses at the preinjector output; the buncher is placed between the preinjector and the linac. Proton injection into the ring accelerator takes place during one revolution of 11.5 μsec duration; there are technical possibilities for three-revolution injection. Magnetic optics elements that connect the linac and the ring accelerator were adjusted to obtain the optimum matching of the beam phase shape to the synchrotron acceptance on the basis of the measured beam emittance at the injector output.

To eliminate large particle losses at the earlier revolutions and at the beginning of the acceleration, a correction of the orbit distortions at low fields and an increase in the betatron-oscillation frequencies were required. The values of the maximum radial and vertical closed orbit deviations before and after corrections are given in Table 1.

Table 1

Effects of Correction on Closed-Orbit Deviations

	Deviations (cm)	
	Radial	Vertical
Without corrections	±5	±2
Shunting windings and injection unit corrections	±1.5	±2
10th harmonic of the field	±1.5	±1

Injection field about 76 G

At the first stage the radial orbit deviations were reduced by field leveling in electromagnet units with the aid of shunting one of the additional windings with the active resistances of calculated value and by removing the screening action of the vacuum chamber in which particle injection into the ring accelerator takes place. This chamber is of a large radial dimension and is made of 2-mm-thick stainless steel.

The tenth harmonic correction of magnetic field was made by intensity of the accelerated beam. As magnet field grows the orbit deviations diminish. Starting from 300-350 G fields to the acceleration end the orbit changes slightly. The orbit shape measured by electrostatic pickups on mean-level field is shown in Fig. 3.

During the investigations of particle dynamics it was found that the natural position of the operation point is not optimum. To eliminate particle loss at the initial stage of acceleration it was necessary to increase betatron oscillation frequencies at small fields to almost 9.8.

The frequency shift was made by changing the field gradient in the focusing and defocusing units. As a result, the intensity of accelerated proton beam was rasied to 10^{12} protons per pulse in October 1968. Particle losses at different stages of acceleration are given in Table 2.

Heavy losses of particles between the first revolution and the beginning of acceleration depend on the particle capture at the synchrotron acceleration regime. At present particle capture in the acceleration stable region occurs without preliminary particle bunching. Effectiveness of capture calculated for this case is 35%.

Table 2

Particle Losses

	Linac Output	First Rev.	Beginning of Acc.	End of Acc.
Particle/pulse	4.5×10^{12}	3.5×10^{12}	1.3×10^{12}	10^{12}
Loss/stage		22%	63%	23%
Total Loss		78%		

NOTE: The accuracy of the given data is about 15%.

The reasons for particle losses during the process of acceleration are not ascertained yet. Transition energy is crossed without loss. The 10^{12} protons per pulse are obtained under conditions listed in Table 3.

Table 3

Operating Conditions at 12^{12} Protons/Pulse

Intensity	10^{12} p/p
Maximum energy	70 GeV
Peak beam current of the linac	65 mA
Beam pulse length	15 µsec
Beam emittance	(2-3) cm-mrad
Momentum spread after debunching	± 0.2%
Rate of magnetic field rise at injection	4500 G/sec
Peak rf voltage per turn	380 kV
Magnetic field rise time	2.4 sec
Flat-top of the magnetic field, up to	1 sec
Duration of inverter regime	1.9 sec
Cycling frequency	$(7\text{-}8)\ \frac{1}{\text{min}}$

The value of the maximum magnetic field with the flat-top may change over a wide range without disrupting acceleration conditions. The acceleration conditions for final proton energies from 20 GeV to 70 GeV were obtained. The final energy was reduced by reducing the magnetic field rise time. It should be noted that the magnetic field topography changed at small levels. It affected mainly the initial frequencies of the betatron oscillations. When the final proton energy was lowered to 20 GeV, betatron osciilation frequencies approached the 9.5 parametrical resonance. The frequencies were corrected by changing field gradients. The adjustment of the accelerator is also given in reference 4.

Secondary Beams

A complex of secondary beam channels is under construction at the proton synchrotron. The secondary beams will provide a wide program of physical investigations by the application of various methods. The beam channel of 60-GeV negative particles was put in operation first. The channel is designed in such a way that at the energy of the accelerated protons of 70 GeV the channel can be tuned at any momentum of secondary particles within the range of 40-60 GeV/c. With the decrease of the accelerating energy the momentum value of the secondaries that enter the channel also decreases. The lower limit for the momentum of the secondaries corresponds to the energy of 20-GeV accelerated proton beam and equals about 11.5 GeV/c. The secondary beam can be deflected in three directions. The beam channel for tuning the physical apparatus is also in operation. The positive secondaries with the momentum of 6 GeV/c produced at the internal target, are extracted into this beam channel. The deflecting magnet and the collimators create six lines of the secondaries. Thus, it is possible to accommodate at least six physical setups.

In the near future a beam channel for producing negative particle beams with momenta from 25 to 40 GeV/c at the accelerated protons energy of 70 GeV will be adjusted. The beam will also be distributed in three directions. Further, it is supposed to eject the K°-meson beam, and to produce separated beams of K-mesons and antiprotons with momenta up to 40 GeV/c.

The secondary beams are produced in the internal targets. The application of the targets with the electromechanic gear permits the use of the targets at the desired moment during the accelerating cycle. Moreover these targets can be interposed in any part of the operation region of the chamber. Radial and vertical positions of the target may be fixed with an accuracy ±0.1 mm. The targets with 1-mm diameter and 20-mm length along the azimuth are made of aluminum. There are three targets for every channel to provide the maximum intensity of the particles with different momenta. The location of the targets inside the magnet units makes it possible to extract the particles into the channel at the minimum production angle. The radial position of the target must be adjustable ±5 cm with respect to the axis of the magnet. Deflection of the beam onto the target by changing the relationship of the rf accelerating frequency with respect to the magnetic field cannot be applied because the frequency dependence of the betatron oscillations results in instability of the beam. We make use of the local distortion of the orbit, which is obtained by producing additional field in several blocks. This makes it possible to decrease the shift of the betatron oscillations during the spill of the beam. Additional windings are used to produce the pulsed magnetic field in the blocks. The current pulses are fed into the winding during the flat-top of the guide magnetic field. While the current increases in the windings, the beam is being deflected to the target, and then the current is controlled with the feedback signal from a unit that detects the intensity of the ejected secondaries. A stable and constant beam spill was obtained on the target for up to 500 msec by using feedback, improving the stability of the basic field flat top to $5. \times 10^{-4}$, and by suppressing the dominant harmonic amplitudes at 50 and 150 cps to 10^{-5}. An oscillogram of the secondary particle beam is shown in Fig. 4.

During one accelerating cycle the secondary beam can be ejected into different channels. It allows several physical experiments to be carried out simultaneously.

The extraction of the beam in channel 2 is achieved through local distortions of the orbit. Targeting of the beam in channel 6 is achieved by changing the law of dependence between the acceleration voltage and the magnetic field.

Figure 5 represents the layout of the beam lines in the experimental hall. The section of the accelerator that passes through the hall has enough shielding to provide safety conditions for the work in the area of the physical apparatus.

The dimensions of the experimental hall are 90 x 156 m.

A gallery that will extend the experimental possibilities in the direction of channels 7 and 9 is 350 m in length and 24 m in width. It is under construction now. In this building the equipment for production of pure K-meson and antiproton beam of 40 GeV/c momenta will be located, in addition the production of the neutrino beam is proposed. A two-meter hydrogen chamber of the Institute for Nuclear Research, the French liquid hydrogen chamber "MIRABEL" and the propane-freon chamber SKAT of IHEP will be located in the gallery.

Rf separator and the equipment for the fast ejection system for channel 7 are now being developed at CERN.

On Physical Experiments

Such scientific institutions as the Institute for Theoretical and Experimental Physics, Physical Institute after Lebedev, Institute of Atomic Energy after Kurchatov, etc., take part in the physical experiments.

A wide research program is considered by the Joint Institute for Nuclear Research (Dubna). In accordance with the agreements that were signed between the State Committee for Utilization of Atomic Energy and the Commisariat of Atomic Energy of France, and CERN, French and CERN scientists will participate in the experimental work at the accelerator.

Nowadays several experiments are being carried out and the first results have been obtained. The energetic spectrum of π-mesons and K-mesons and antiprotons, produced on collision between the accelerated protons and the nuclei of an aluminum internal target is investigated by the CERN-IHEP group in channel 2. The results have been obtained for the proton energy of 20, 43, and 70 GeV. The data are being processed now. Proton-proton scattering at small angles in the region of the Coulomb interference is studied by Dubna Institute in the internal beam of accelerated protons. The intersection of the proton beam with a thin target happens during the accelerating cycle, starting from the energy of 12 GeV.

In the branch of channel 2Г the physicists of IHEP are looking for the particles with fractional charges of 1/3 and 2/3 that can be produced in the internal target of the accelerator by 70 GeV protons. The first part of the quark experiment was carried out in the 50 GeV/c negative particle beam. The particles were ejected at 0° angle. 10^9 π-mesons were passed and the measurement devices registered not a single event of the particles with the fractional charge. The following value of upper limits were obtained for the differential cross-section of the quark production:

$$q = 2/3\,e; \quad \frac{d^2\sigma}{dp\,d\Omega} \leq 7 \div 9 \cdot 10^{-36}\ \mathrm{cm}^2/\mathrm{ster.}\ \mathrm{GeV}/c$$

$$q = 1/3\,e; \quad \frac{d^2\sigma}{dp\,d\Omega} \leq 1{,}3 \div 1{,}6 \cdot 10^{-35}\ \mathrm{cm}^2/\mathrm{ster}\ \mathrm{GeV}/c$$

Confidence level 90%

Total cross section of the quark production with $q = 2/3\ e$ and mass of $4{,}5 \leq M_Q \leq 5$ GeV/c^2 does not exceed 4.10^{-37} cm^2 (confidence level 90%).

At present the measurements are being made in a special channel tuned at momenta of 80 GeV/c (no-background beam). In comparison with the first experiment the upper limits of the differential cross sections of the quark production may be considerably lowered.

Such experiments as the search of the Dirac monopole (Dubna, IAE) are planned. The experiments will be made on the internal proton beam. Elastic scattering of π-mesons, K-mesons, and antiprotons on protons will be studied in channel 2B. The processes will be studied with the help of a hodoscope system of scintillation counters that is connected with the computer (IHEP, Dubna).

The investigation of the π-meson-proton interactions with large momenta transfer will be carried out in channel 4B (ITEP). Channel 4A will be used for studying the processes of π-meson-proton charge exchange (IHEP). In the neutrino channel the processes of K-meson regeneration will be studied.

Thus, it will be possible to obtain data on the cross section difference between the particle and antiparticle interactions at high energies and on the electromagnetic form-factor of K°mesons (Dubna).

It is also planned to study the processes of formation of different resonant states at high energies and search for new resonance. Investigations of resonance quantum numbers, their decay, etc., are also included into this program.

The applied methods use scintillation counters, magnetic spectrometers with spark chambers, and liquid hydrogen, propane, and freon-propane bubble chambers.

References

1. V. V. Vladimersky and others, "70-GeV Proton Synchrotron," Proceedings of the International Conference on High Energy Accelerators, Dubna, M. Atomizdat, 1964.

2. I. M. Kapchinsky and others, "On the Project of the Injector for the 70-GeV Proton Synchrotron," ibid.

3. A. M. Minz, "Linear Accelerator Injector," Serpukhov 70-GeV Proton Synchrotron, issue of the Academy of Sciences of the USSR, N. 8, 1968.

4. A. A. Naumov, "Start-Up and Adjustment of the Accelerator," ibid.

5. R. M. Suljaev, "Program for Experimental Researches at the New Accelerator," ibid.

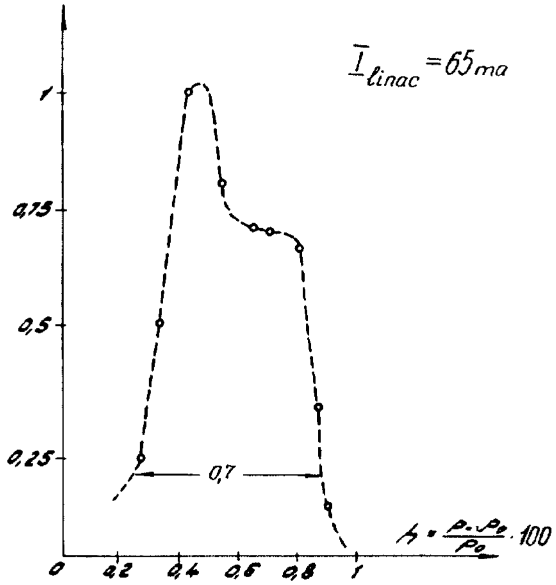

Figure 1 - Integral proton spectrum at the linac output. ρ_0 - fixed momentum of the equilibrium proton; ρ - proton momentum.

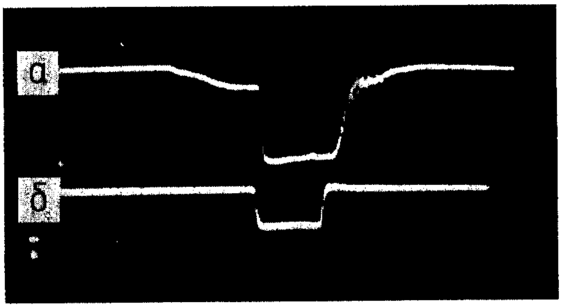

Figure 2 - Oscillograms of the linac beam current pulses: (a) at the preinjector output after a blocking condenser; (b) at the linac output; pulse duration - 15 μsec.

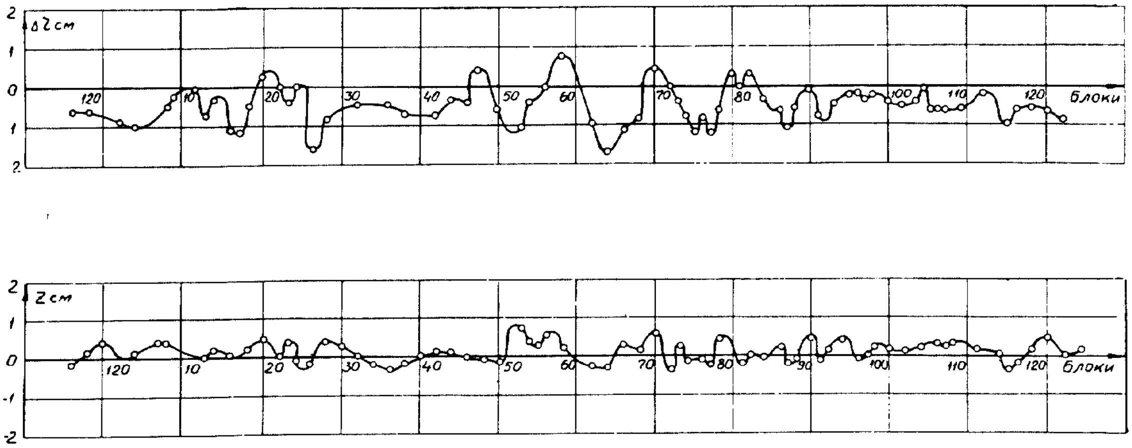

Figure 3 - The orbit shape in radial and axial directions on the average levels of field.

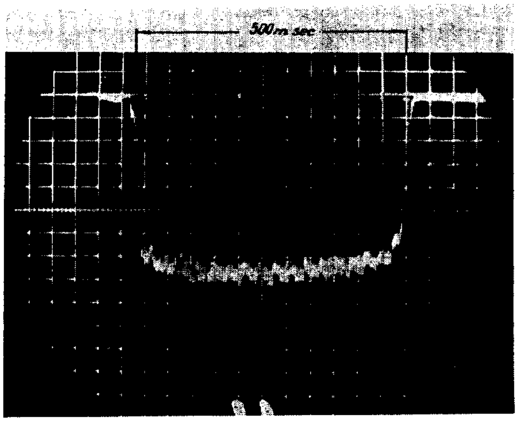

Figure 4 - The oscillogram of the secondary beam. Pulse duration - 500 μsec.

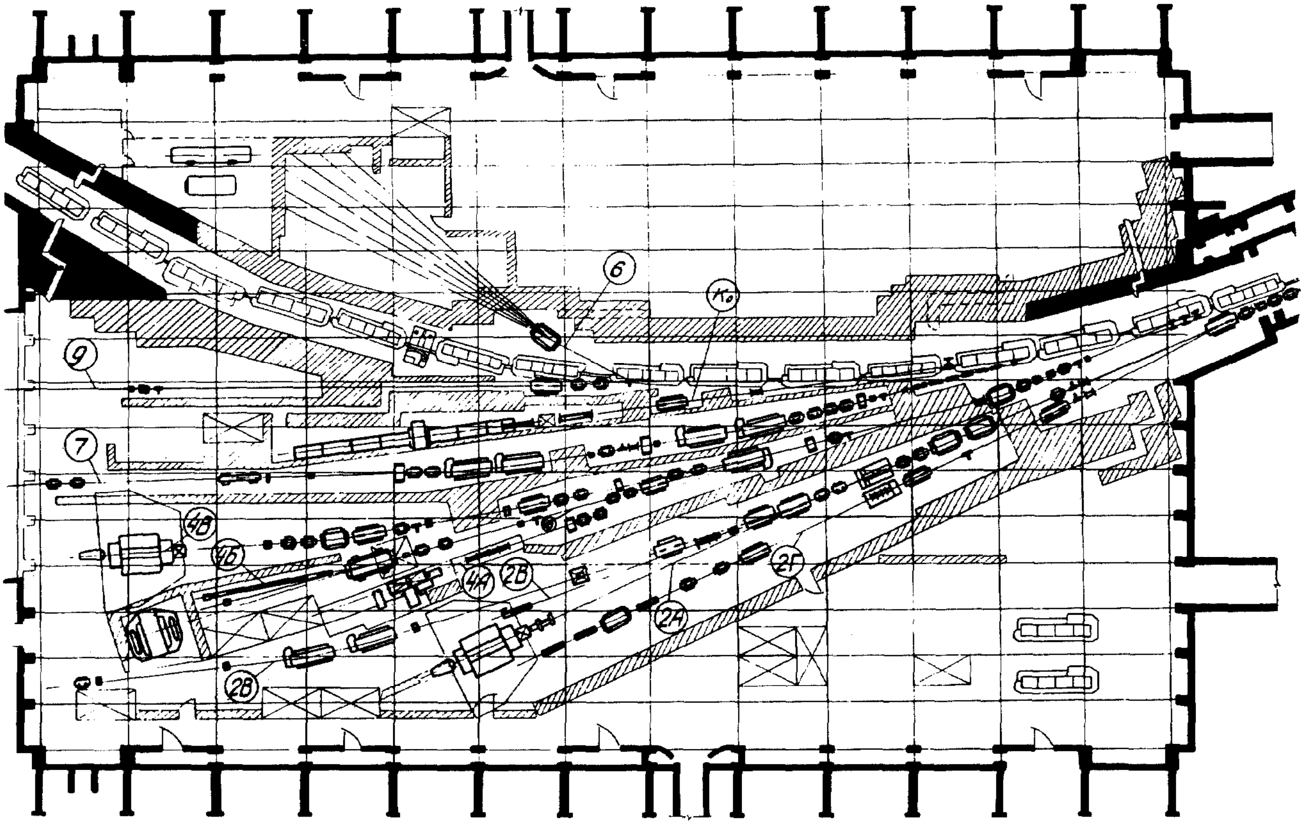

Figure 5 - Layout of the beam channels in the experiment area.

2 (A, Б , B, Г) - a negative particle beam with momentum from 40 to 70 GeV/c proton energy 70 GeV
4 (A, Б , B) - a negative particle beam with the momentum from 25 to 40 GeV/c, proton energy 70 GeV
6 - a positive particle beam with the momentum of approximately 6 GeV/c for adjusting work
7 - a channel for production of separated beams with the momentum from 35 to 40 GeV/c
9 - a negative particle beam with the momentum from 30 to 40 GeV/c, proton energy 70 GeV

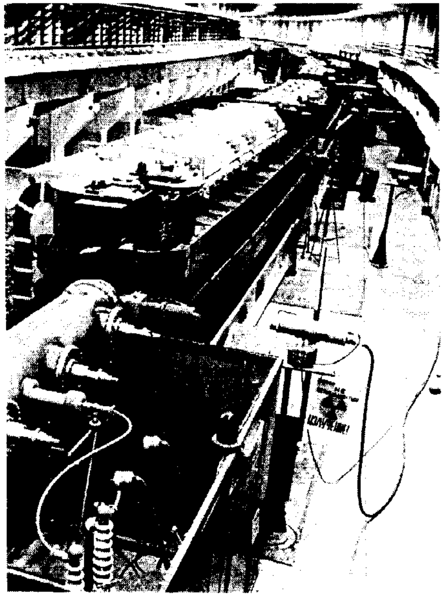

Figure 6 - The internal view on the accelerator in the region of particle injection.

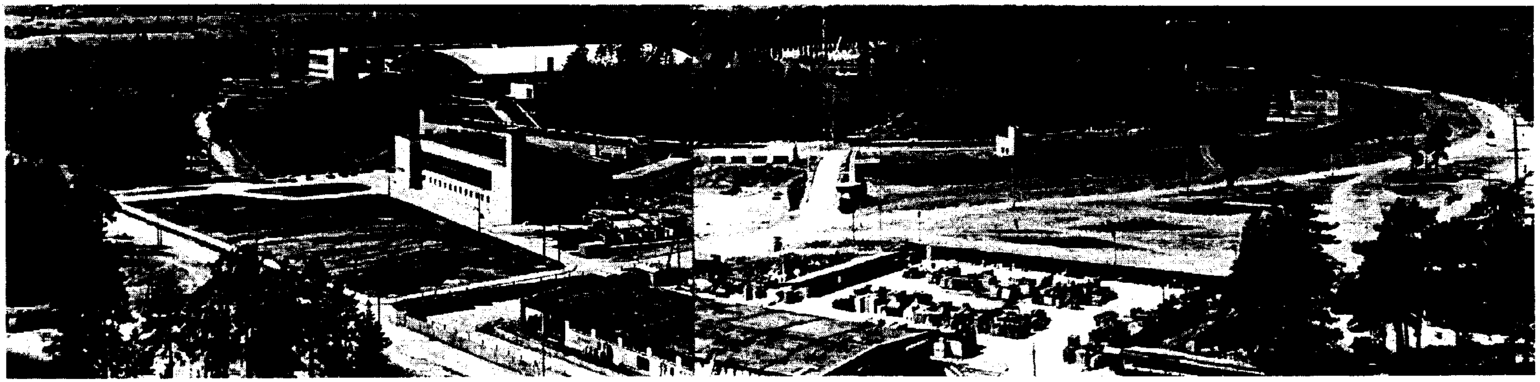

Figure 7 - Panarama of the 70-GeV proton synchrotron; injector building in the foreground.