THE STATUS REPORT OF THE LNPI 1 GeV SYNCHROCYCLOTRON

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In this paper I represent the big group of people from Leningrad who had constructed the biggest synchrocyclotron. The accelerator is located at Gatchina, 45 km from Leningrad in the Nuclear Physics Institute Academy of Sciences USSR. The first beam was obtained in November 1967. After that we had many troubles with one RF system, and 1 GeV synchrocyclotron came into operation in April 1970. The machine schedule now has 120 hours of operation per week in average for an experimental program with beams. As distinct from the other synchrocyclotrons the machine has the highest efficiency of an extraction system (25 - 30%) which allows to have intensity of proton beam about 10^{12} p/s and to minimize induced radioactivity problems inside the accelerator itself because internal accelerated beam intensity is $\sim 0.5\ \mu A$.

RF system represents 1/2 wave line with a variable rotating capacitor which consists of two sections.

Schematic diagram of the acceleration system is shown in Fig. 1:

1. Plan of the connection between the Dee and variators.
2. Cross section of the variator.
3. Equivalent diagram of the variator, where:

   C_1 - Dee variable plate;

   C_2 - inductivity variable plate;

   C_3 - ground capacitor of rotor;

   C_p - coupling capacitor.

   $L_1L_2L_3$ elements are connected with C_2 on series, they permit to increase effective capacity of the variator in the lower part of frequency band.

In the upper part of RF band C_1 and C_2 are near "zero" and L_1L_2 permit to increase the upper frequency limit.

In Fig. 2 there is an equivalent circuit of the oscillator. The feedback to the cathode is taken from the inductance connected between the L_3 and earth through the coaxial line—3.5 m long on parallel from each variator.

Anodes of tubes are connected with the resonant system by means of two coaxial lines. The choice of this symmetrical type of feed and feedback permits to expel the cross-mode of oscillating and other types of parasitic resonances, which are shown in Fig. 3.

f_2 - the second higher frequency program;

$f_1^1 f_2^1$ - cross modes of oscillating;

$f^{0Б}$ - volume oscillating.

On the right there are shown three types of parasitic resonances of the variator.

df/dt of the frequency program gradually decreases and the Dee voltage varies from 10 kV at the top frequency to 4 kV near the minimum frequency. For this reason we have a possibility to drive by the beam stretching system on the small voltage (1.5 kV).

The beam stretching system has been designed for the 1 GeV LNPI synchrocyclotron both for stretching of internal and external beams and for fast kicking of a beam to an internal target which is mounted upper or lower of a median plane. For stretching of the beam a principle of the slow acceleration by means of Cee-electrode is used. The fast kicking of the beam is made by means of a vertical deflection of protons by applying a fast voltage pulse to upper and lower plate of the Cee-electrode.

The power supply system can operate thus, that one pulse of the accelerating beam may stretch and the other kick to the neutron target.

The main feature of the stretching system is a comparatively high efficiency of a beam capture into an acceleration regime by Cee-electrode and at the same time a sufficiently high duty factor. This is made by means of phase and frequency synchronization between the main acceleration system and the oscillator of Cee-electrode. The shape of a beam macropulse is almost rectangular by owing to proper choice of the Cee-electrode frequency program. A power consumption is very small because we use a narrow band power amplifier with synchronous tuning of a frequency.

In Fig. 4, we can see how the intensity of the outside stretching beam is decreased with the increase of the beam stretching time. We had not understood this fact. We did the following experiment. The main RF system was switched off and the beam was caught by RF Cee at constant frequency for a time (10 - 100 ms). After we changed frequency Cee, we saw the same picture. Thus Cee can accelerate full beam, but when the beam is extracted the external beam intensity decreases if the duty factor increases. Figure 5 shows how efficiency depends upon phase synchronization.

The shape of the stretching beam is shown in Fig. 6.

Now let us consider general features of the nonlinear regenerative system of the proton beam extraction. The great number of particle trajectories has been calculated. In this case the spectrum of the amplitudes of the betatron oscillations has been taken into account. This calculation has been shown that in order to magnify the extraction efficiency it is necessary to increase the dip angle of the channel entrance with respect to the final circular orbit and to broaden the magnetic channel and regenerator effective apertures.

Focusing gradients in the magnetic channel section have been chosen from the condition of the optimization of all beam tract including the magnetic channel, stray field, additional focusing section outside the chamber and triplet of quadrupoles.

General data of synchrocyclotron parameters are summarized in the Table.

The experimental program includes: particle physics (proton-proton scattering and pion-proton interaction), nuclear physics (scattering off nuclei, production of light nuclei), fission, radio-chemistry and medical research (proton therapy).

Some interesting physics experiments are finished now. The group of Dr. Vorobjev finished small angle p-p scattering in the region of 1 GeV and less, where there was a big difference between theory and experiment. But the main advantage of our accelerator is that it is located near Leningrad — a beautiful tourist center of Russia. Go to our accelerator and you can see Leningrad. Thank you.

Principal Parameters 1 GeV Synchrocyclotron

Maximum Energy	1000 MeV
Internal Beam Intensity	0.5 μA
Extracted Proton Beam	$\sim 10^{12}$ p/s
Duty Cycle in Stretched Pulse Operation	70% (Maximum)
Repetition Rate	40 - 50 Hz
Radius at Maximum Energy	3.165 M
Dee RF Voltage	10 - 4 kV
Initial Frequency	29 MHz
Final Frequency	13.1 MHz
Initial Frequency Change	3 MHz/MS
Final Frequency Change	0.5 MHz/MS
Cee Voltage	1.5 kV
Frequency Range Cee	13.27 - 13.47 MHz
Flux Density, Center	1.9 WB/M^2
Flux Density, at R = 3.18 M	1.79 WB/M^2

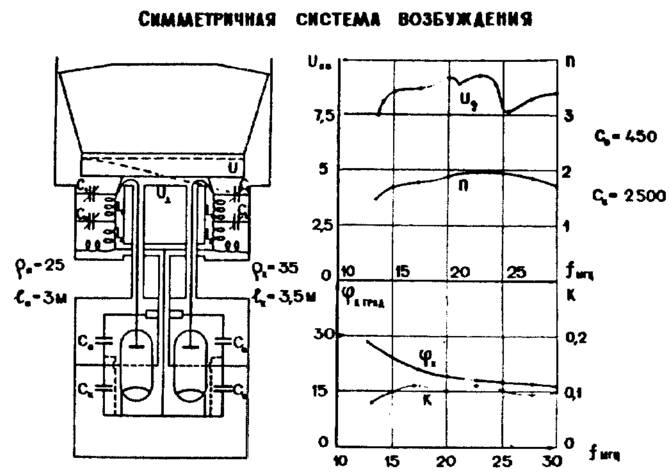

FIG. 2--Symmetrical oscillator system.

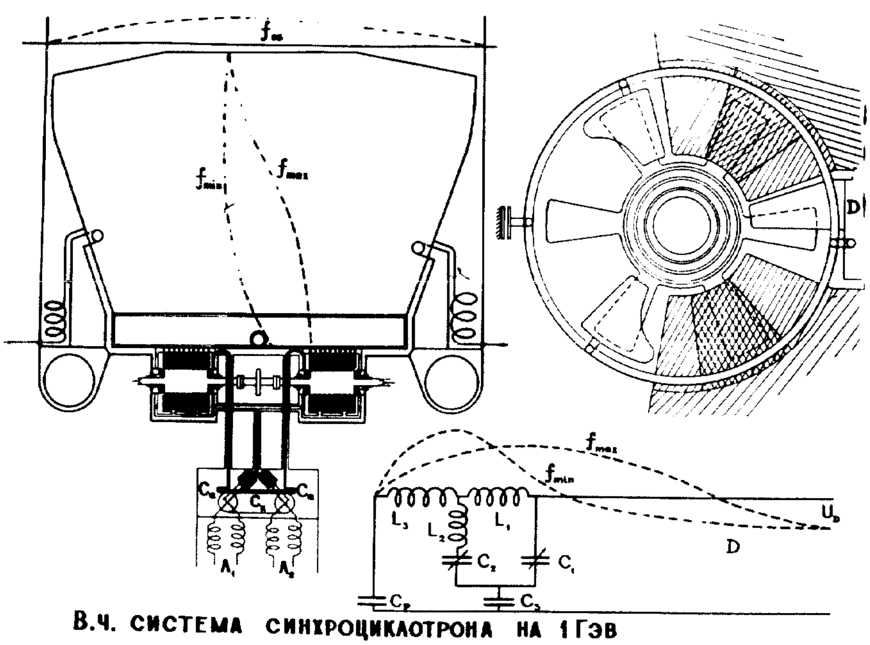

FIG. 1--RF system of the 1 GeV synchrocyclotron.

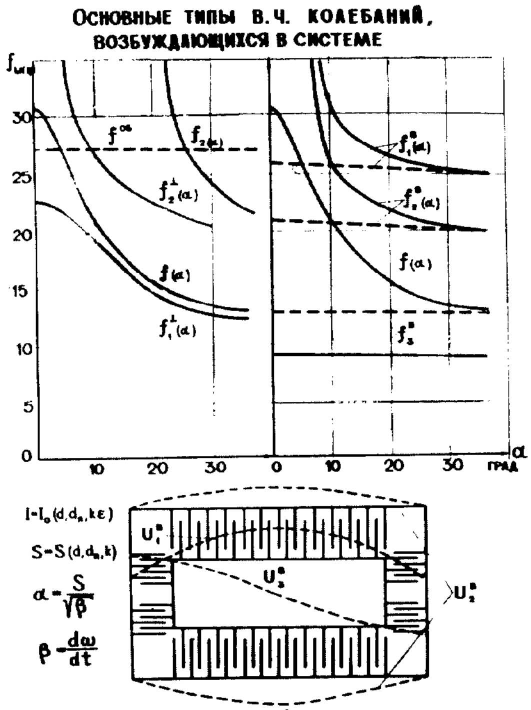

FIG. 3--Principle types of RF oscillations excited in the system.

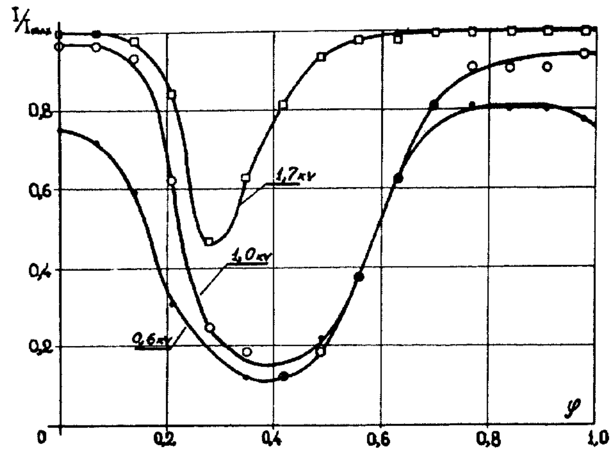

FIG. 5--Dependence of storage efficiency on phase synchronization.

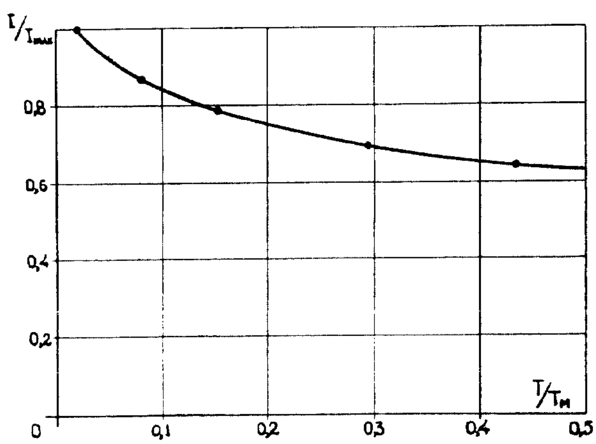

FIG. 4--Dependence of intensity on beam stretching time.

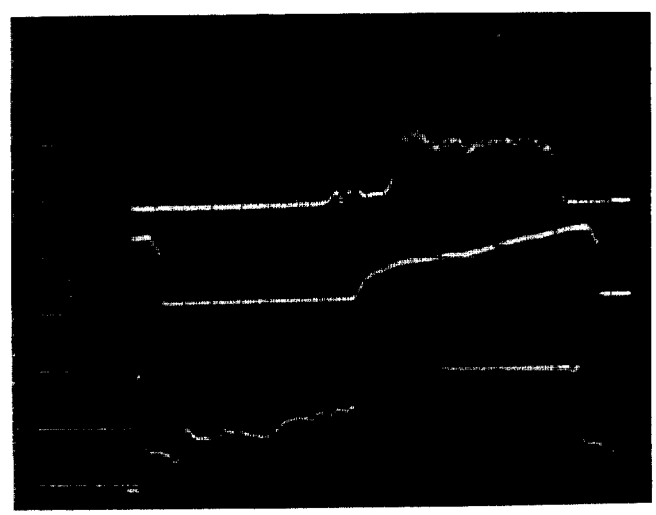

FIG. 6--Pulse shape of the stretched beam.