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ENERGY SPREAD FOR THE BEAM INJECTED INTO THE B-3M SYNCHROTRON

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НОВОСИБИРСК

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into B3-M Synchrotron

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ABSTRACT

There is described the method of energy spread production for the beam injected into soft focusing synchrotron B3-M (INP). A 10 cm wavelength cavity is used excited with a magnetron. A 30% gain in the captured current was obtained with the help of the produced spread.

INTRODUCTION

The VEPP-2M storage ring was put into operation in 1972 [1]. Until our days it has a record luminosity up to 2×700 MeV region, allowed to measure the masses of Φ, *K* and ω mesons with the highest accuracy [2, 3].

The VEPP-2 and VEPP-2M rings (Fig. 1) used a 250 MeV B3-M synchrotron as injector. The B3-M has used a 2.5 MeV linear accelerator ILU as injector since 1965. The ILU is a vacuumed RF a quarter wave circuit, operated at 2.5 MHz [4].

Table 1

The Main Parameters of ILU B-3M Complex

Pulsed Linear Accelerator ILU:	
Frequency of ILU resonator	2.5 MHz.
Accelerating voltage, normally, *U*	2.2 MeV.
Extracted current	30 A.
Duration of extracted current	30 ns.
Electron synchrotron B-3M:	
Radius of curvature of bending magnet *R*	1.03 m.
Circumference Π	8.1 m.
Maximal energy *E*	250 MeV.
Betatron tunes ν_z, ν_x	.87, .77.
Momentum compaction factor $\alpha \cong 1/\nu_x^2$	2.
Acceptance of energy ΔE/E	$\cong 2.0\ 10^{-2}$.
Extracted current	$\cong 1$ A($1.6\ 10^{11}$).
Injection occurs in vertical plane	
Repetition rate.	1 Hz.

The Luminosity of the VEPP-2M storage ring is determined by the rate of positron storing i.e. by the current extracted from B-3M.

The efficiency of conversion of electrons into positrons about $\cong 10^{-4}$ determined the luminosity level $L = 5\ 10^{30}\ cm^{-2}\ s^{-1}$ when a 1 A current ($1.6\ 10^{11}$ particles per pulse) was extracted from B-3M.

BEAM INSTABILITIES

The number of electrons extracted from ILU and injected into B-3M is about 10^{12} (5 - 6 A) in 27 ns, but after 10 - 20 turns the only 2 - 3 A remain in B-3M ("microsecond lost", Fig. 2). The further gain of injected current provides a reduction of the captured current in B-3M (Fig. 3).

It was shown experimentally that the maximal current captured into B-3M is proportional to the duration of injected current, i.e. linear density [4].

The linear density limit due to the transverse instability is described [5] as follows:

$$j_\perp = \frac{N}{2\pi \bar{R}} = \frac{\nu |\Delta\nu| \beta^2\gamma^3}{r_0 \bar{R}^2} \frac{b(a+b)}{2} BF ,$$

where $r_0 = e^2/mc^2$, ν, $\Delta\nu$ - the betatron tune and betatron tune shift, $\bar{R}$ - the mean radius of accelerator, $2a$, $2b$ - the radial and vertical size of the beam respectively, B - part of the circumference, occupied by the beam (bunching coefficient, $B \cong 0.75$), $F \cong 1$ vacuum chamber factor, $\gamma = (1 - \beta^2)^{-1/2}$ In B-3M synchrotron for $\Delta\nu = 0.1$, $F \cong 0.6$ and $\gamma = 5.3$

$$j_\perp \cong 2.4 \cdot 10^9\ 1/cm ,$$

which corresponds to 12.5 A of the circulating current.

The longitudinal fields in soft focusing synchrotron provides the negative mass instability (NMI). The very first

calculations were made in [7] and experimentally observed in the B-2 synchrotron at the INP (Novosibirsk) [6] and in the experimental model of ring fasotron of MURA group [7].

Condition for NMI is that the fields provided by the density fluctuation in the longitudinal direction are increasing. The necessary condition for that is $\partial\omega/\partial E < 0$.

These fields accelerate the particles fore of and decelerate the back ones, so if the beam has no spread over the revolution frequency it is unstable for NMI. In a real situation, the NMI has a threshold due to the spread over frequency (Landau dumping) [8, 9].

The threshold linear density is [9]

$$J = \frac{N}{2\pi \bar{R} B} = \frac{\beta^2\gamma^3}{r_0 g \eta} (\Delta\omega/\omega)^2 = \frac{\beta^2\gamma^3\eta}{r_0 g} (\Delta E/E)^2 \qquad (1)$$

where ω_0 is the revolution frequency, $g = 1 + 2 \ln \frac{A}{a}$ $2A$, $2a$ are the transverse dimensions of the chamber and the beam, respectively. The $\eta = \frac{\partial \ln \omega}{\partial \ln E} = 1/\gamma^2 - \alpha$ is equal to -2 for the B-3M synchrotron.

As it has been mentioned, the 10^{12} particles are injected into B-3M, which corresponds to $j_0 = 1.5 \cdot 10^9$ 1/cm.

For NMI, the necessary spread for stabilization must be at least

$$\Delta E/E \geq 2.5 \cdot 10^{-3} .$$

On *Fig.* 4 there is shown the dependence of the linear threshold density on the energy spread for B-3M synchrotron. Here also is shown the maximal experimentally achieved density and transverse Coulomb limit. It is clear that the NMI defines the maximal linear density if the energy spread is less than $2.5 \cdot 10^{-3}$.

The local energy spread of the beam, injected into B-3M from ILU is small and defined by thermal spread of velocities near the gun cathode of the ILU.

The full energy spread in ILU is due to the modulation over energy, i.e. particles, which goes over the accelerating gap at different moments t (Fig. 5) has a different accelerated voltage. The modulated law is $\cos(2\pi t/T)$, where T is an RF period of ILU (400 ns). Such kind of the energy spread of the beam extracted from ILU for particles with duration Δt in t, ns can be written, Fig. 5:

$$\Delta E/E \cong (2\pi/T)^2\, t\, \Delta t \cong 2.5\cdot 10^{-4} \Delta t\, t, \qquad \Delta t < t \ll T .$$

For linear density, we have an estimation

$$J_1 \cong 10^{-8} \Delta t\, t \quad 1/\mathrm{cm}$$

For example, if $J_1 = 1.5\cdot 10^9$ 1/cm, $t = 5$ ns, then $\Delta t = 3$ ns, which corresponds to ≅10 harmonic of revolution frequency.

So, in our case higher harmonics have a low threshold due to a specific decrease of $\Delta E/E$ in addition to the decrease for a high harmonic number.

The NMI increment for a monochromatic beam can be written as follows [9]

$$\xi_n = (|\Omega^2_n|)^{1/2} \;;\; |\Omega^2_n| > (n\, \Delta\omega)^2 \qquad (2)$$

here $\Omega^2_n = n^2\omega_0^2 \dfrac{J_0 r_0 \eta g}{\gamma^3}$ is the square of the coherent shift according to the impedance $(-i\; Z_n/n) = g/(\beta c \gamma^2)$. A formal estimation gives for $n = 100$

$$\xi_{100} \cong \omega_0 .$$

Formulas (1) and (2) are fair in a long wave and an adiabatic assumption, when the size of the longitudinal inhomogeneities is more than the transverse size of a vacuum chamber and the increment is bigger than the revolution frequency.

With such an assumption the Z_n/n ratio is constant for longitudinal perturbations of the linear density with wavelengths of the order $2A$ and decreases proportionally to $1/n^2$. So it is not valid to use the adiabatic assumption when $n \cong 100$ and the current density is lager than the threshold one.

Experiments with impulse voltage chopper for injected beam in B-3M have shown, that the current accepted is proportional to the duty factor of the injected beam. It followed from this fact that the the "microsecond lost" is caused by instabilities with high numbers of n.

One more additional reason for this is that the electromagnetic ecrans, which were installed in B-3M to prevent the interaction between the beam and the laminated york of B-3M [10] did not change the beam dynamics despite the radically changed impedance of the vacuum chamber.

As a result, we supposed that the "microsecond lost" is due to self Coulomb fields on longitudinal distances of the order of 2 Å/γ, the distance of ecranization. In this case, the impedance of the vacuum chamber does not define the beam dynamics.

One more conclusion is that it is necessary to have in each azimuthal point the particles of full energy spread of synchrotron acceptance to fulfill it.

PRODUCTION OF ENERGY SPREAD IN THE BEAM

The necessary energy spread can be provide by passing the beam through a thick foil. But the growth of emittances makes this scheme unreal in our case.

In [11] there is described the method for energy spread production with the help of a recharge target.

The other way is to use a short wavelength cavity on the trajectory of the beam into a synchrotron, which provides the energy modulation on possibly short longitudinal distance.

For that, the cavity with a wavelength of 10 cm was installed in the extraction channel of ILU in 1975 (see Fig. 1). The 50 kV voltage amplitude provided the energy spread not less than $\Delta E/E \cong 10^{-2}$ including the transit time factor. The cavity exited with the help of a magnetron generator.

On Fig. 6 there are shown the cavity with a wave guide and a magnetron. Here magnetron 1 is connected with the cavity by coaxial guide 2, 3 and excited cavity 4 with loop 5. Connections are made with nuts 6.

The length of the guide was chosen in such a manner that the wave reflected from the cavity comes to magnetron in opposite phase. This allows the stable work of the magnetron itself without any additional device. The quality factor was decreased by covering the surface of the cavity by Tin. The impedance matching was made by rotation of the loop 5 and control of the reflection coefficient in the 1.1 - 1.2 range. The tune shift was made by special rood 8 and nut 7. Rood 8 shifts the bottom of cavity 9 which was made corrugated. The other bottom has a hole closed by a grid. In further, this grid was removed, and a special tube was added to close the RF in the cavity. Hole 11 was used to look for sparking in guide. The whole volume was hermetized by ribbon gaskets 12. On fig. 7 there is shown the scheme of power supply. The voltage over transformer T_1 and D_1 - D_4— C_1 - C_4 rectifier supplies the line, made from coaxial cable 130 m long. A thyratron of TGI/16 type over transformer T_5 recharges the line at the moment synchronized with the beam pass time. The magnet field for the magnetron is provided by electrically supplied magnet. Control and handling is made from separated console unit.

Operation of this cavity gains the current up to 30%. During all the time of operation since 1975 this gave a sufficient increase of the luminosity integral.

On Fig. 8 there are shown oscillograms of the current monitor with and without the magnetron operated. This direct experiment shows how the current increases when modulation occurs even with a wavelength larger than the transverse dimension.

One may hope to increase the current with a shorter wave length.

CONCLUSION

To sum up, it can be concluded that the "microsecond lost" is due to the NMI with a wavelength of the order of the transverse beam size.

A direct experiment can be made if the change the structure to obtain $\partial\omega/\partial E > 0$ will be made. It needs additional triplets in straight sections and seems difficult...

Notice here that the modulation of this kind can be useful for *proton* accelerators having $\partial\omega/\partial E < 0$.

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REFERENCES

1. *Budker G.I. e.a.*//Proc. of III All union Conference on Accelerators.-Moscow, 1972.- V.I, p.52.
2. *Dolinsky S.I. e.a.* // Overview the e^+, e^- Experiments with Neutral Detector in VEPP-2M Collider. -Novosibirsk, 1989,-(Preprint/ Inst. of Nucl. Phys.; 89-104).
3. *Shatunov Yu.M., Skrinsky A.N.* Polarized Beams in Storage Rings and High Precision Measurements of Particle Masses //Particle World-1989.-Vol.1, N 2.-P.53.
4. *Petrov V.V.* High Current Synchrotron B-3M - Injector for VEPP-2 Storage Ring: Thesis...-Novosibirsk, 1969.
5. Bruck H. Accèlèrateurs Circulaires de Particles:-Press Univer- sitaires de France, 1966.
6. Nielsen C., Sesler A. Rev.Scient. Istrum., Vol.30,-P.80-89.
7. *Samoilov I.I., Sokolov A.A.* About Azimuthal Instability of Circulating Beam //Sov. JETF.-1960.-Vol.39.-P.257.
8. *Lebedev A.N., Shal'nov A.V.* Physics and Technic Foundations for Aaccelerators:-Moscow: Energoizdat, 1982.
9. *Dikansky N.S., Pestrikov D.V.* Physics of Intense Beams in Storage Rings :-Novosibirsk: Nauka, Siberian div., 1989.
10. *Mikhailichenko A.A., Turkin V.F.* Process of field relaxation in laminated core.- Novosibirsk, 1976-(Preprint/Inst. of Nucl. Phys.; 76-51).
11. *Dimov G.I.* Method of injection into accelerators with recharge. Thesis...-Novosibirsk, 1967.

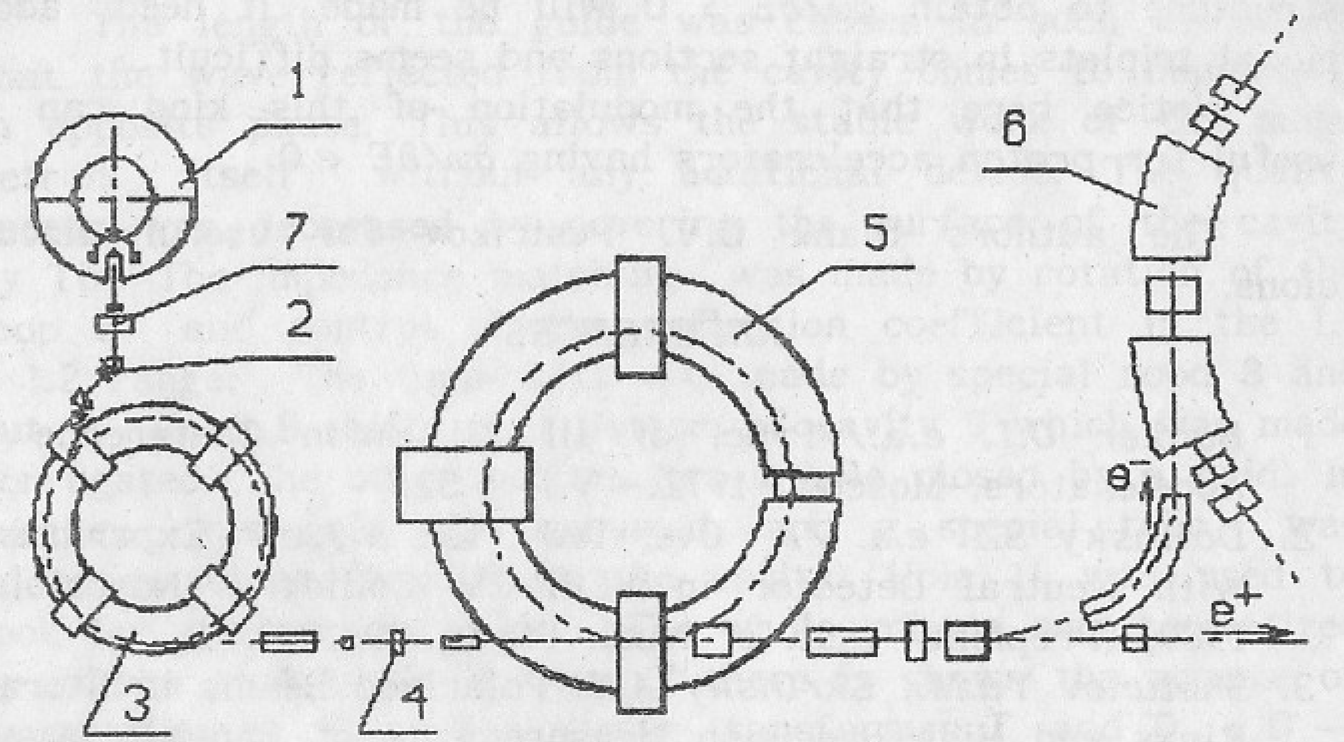

Fig. 1. VEPP-2M complex:.

1-linear accelerator ILU, *2*-beam line, *3*-impulse B-3M synchrotron, *4*-converter, *5*-VEPP-2 buster, *6*-VEPP-2M storage ring, 7-10 cm wavelength cavity for modulation of energy.

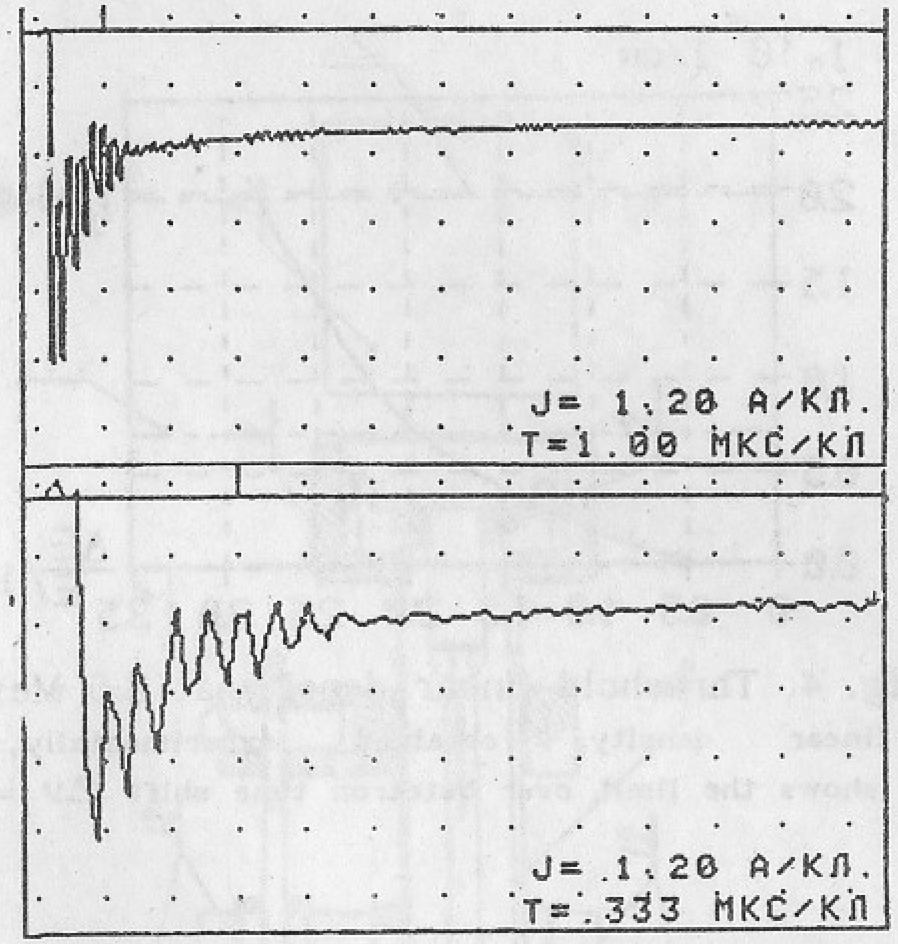

Fig. 2. Oscillograms of current with different time scaling.

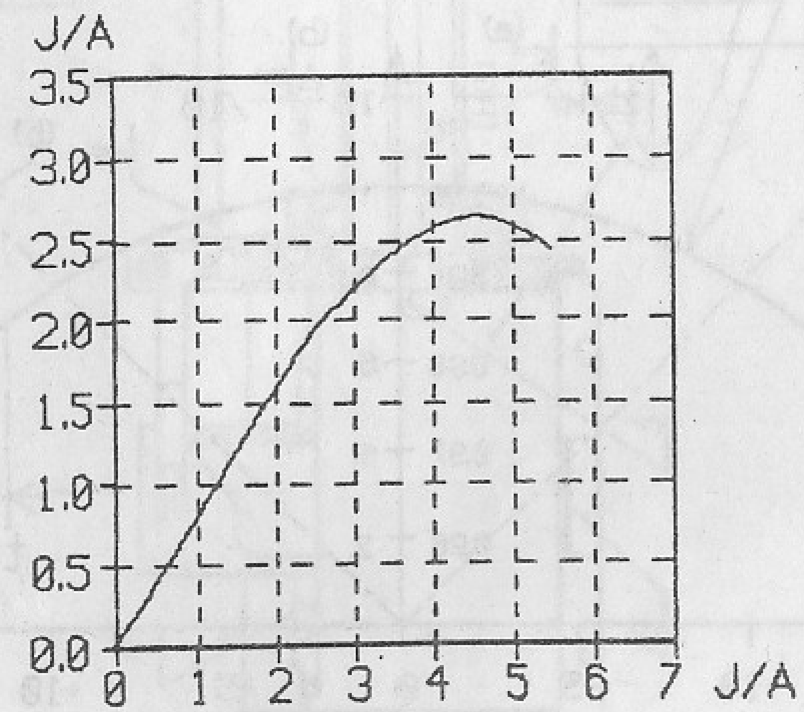

Fig. 3. Captured current dependence over injected current.

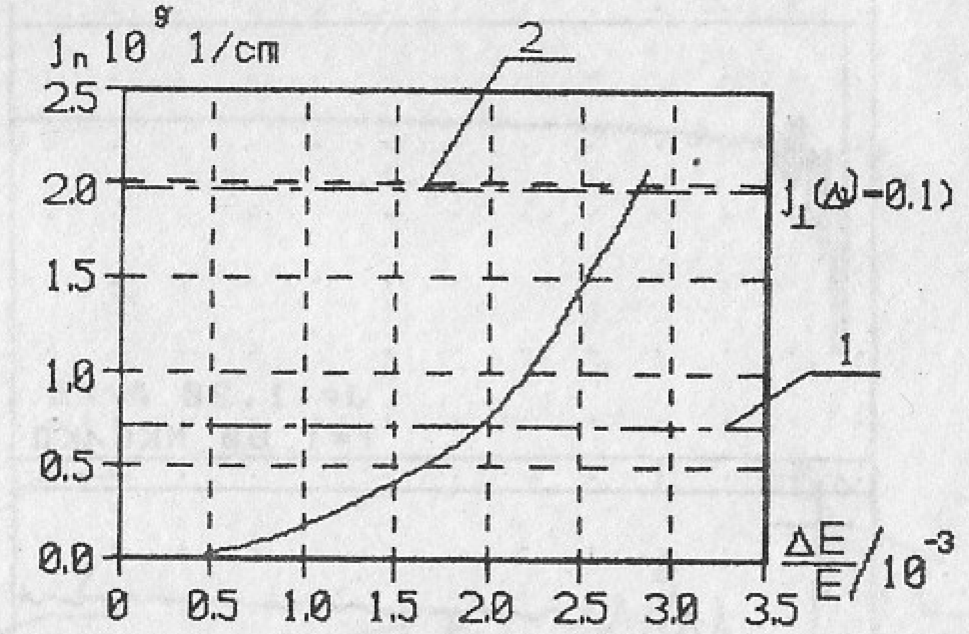

Fig. 4. Threshold linear density at 2.5 MeV:
1-maximal linear density, obtained experimentally, *2*-dotted curve shows the limit over betatron tune shift ($\Delta\nu$ = 0.1).

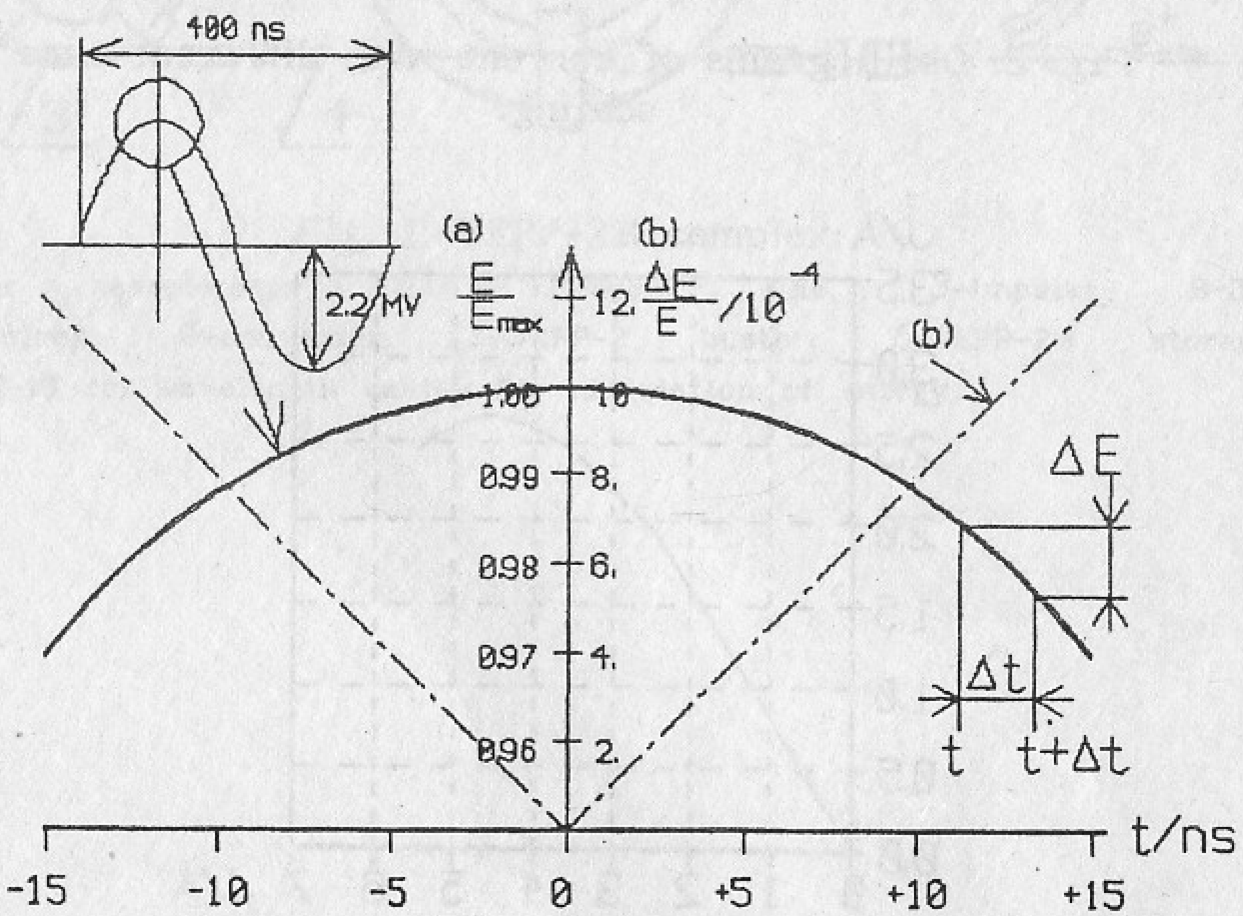

Fig. 5. *a*-energy spread of extracted beam from ILU,
b-$\Delta E/E$ for beam of Δt=.333 ns in time *t*.

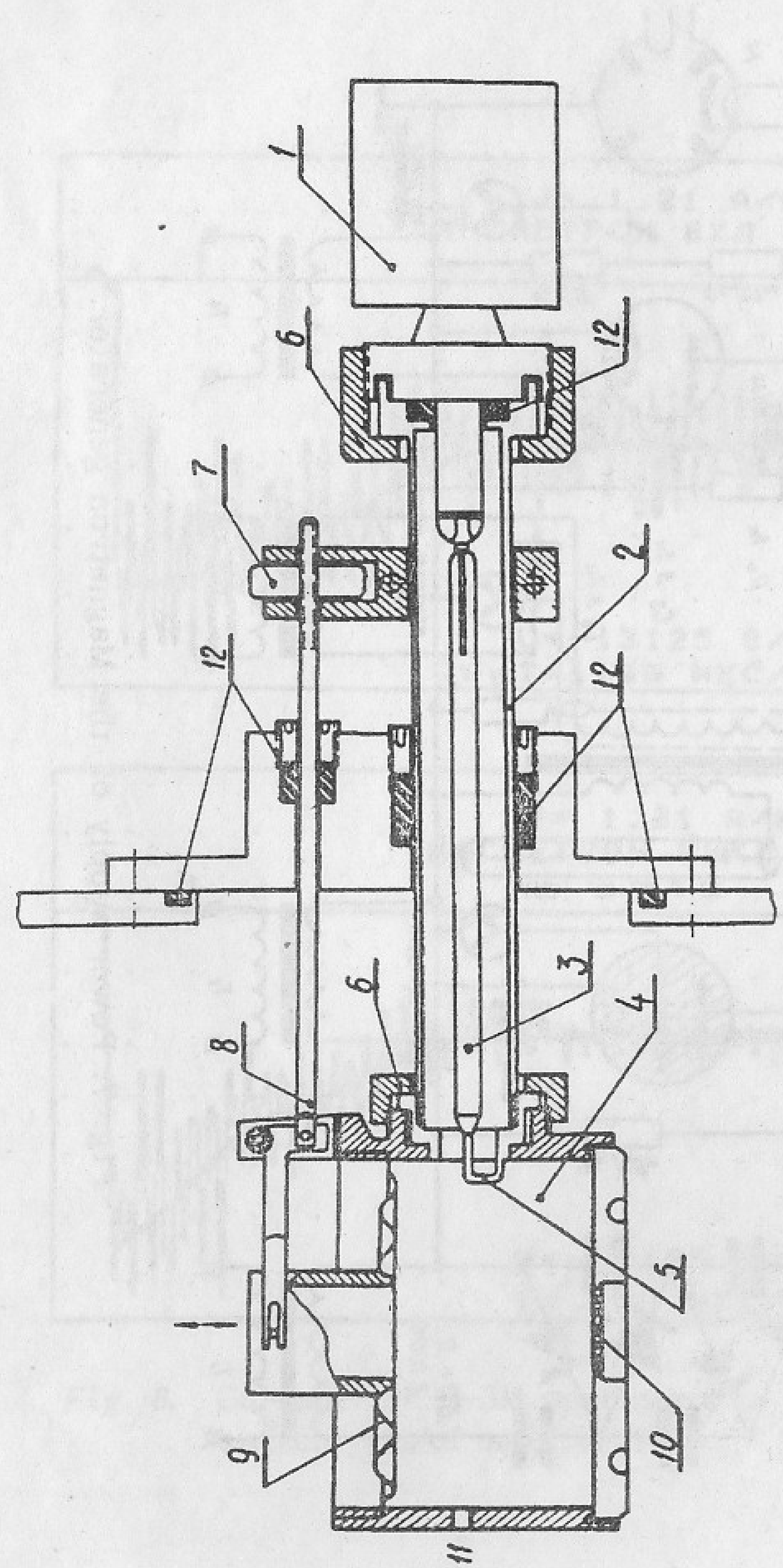

Fig. 6. Modulated cavity with wavegude and magnetron. Comments are in the text.

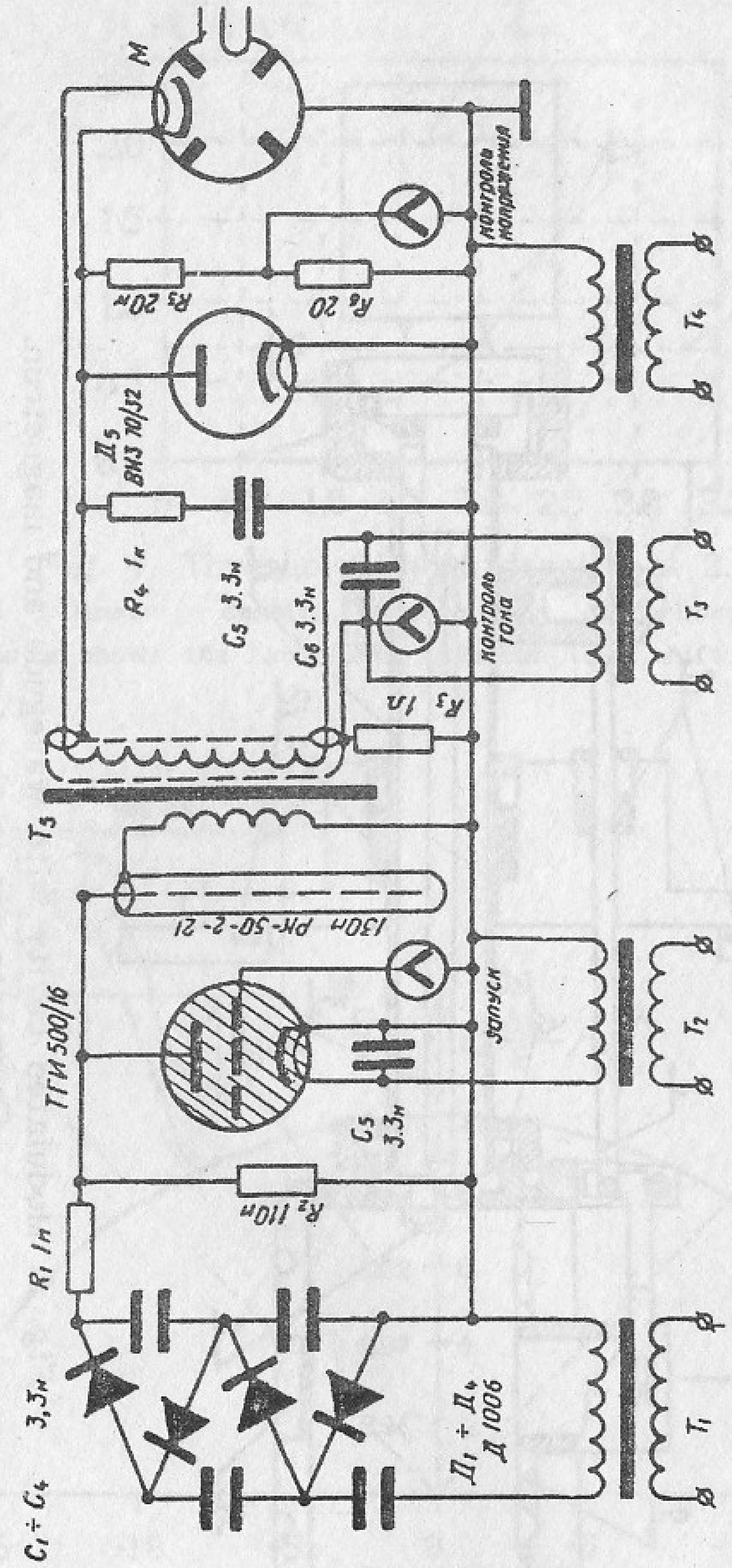

Fig. 7. Power supply of the Magnetron generator.

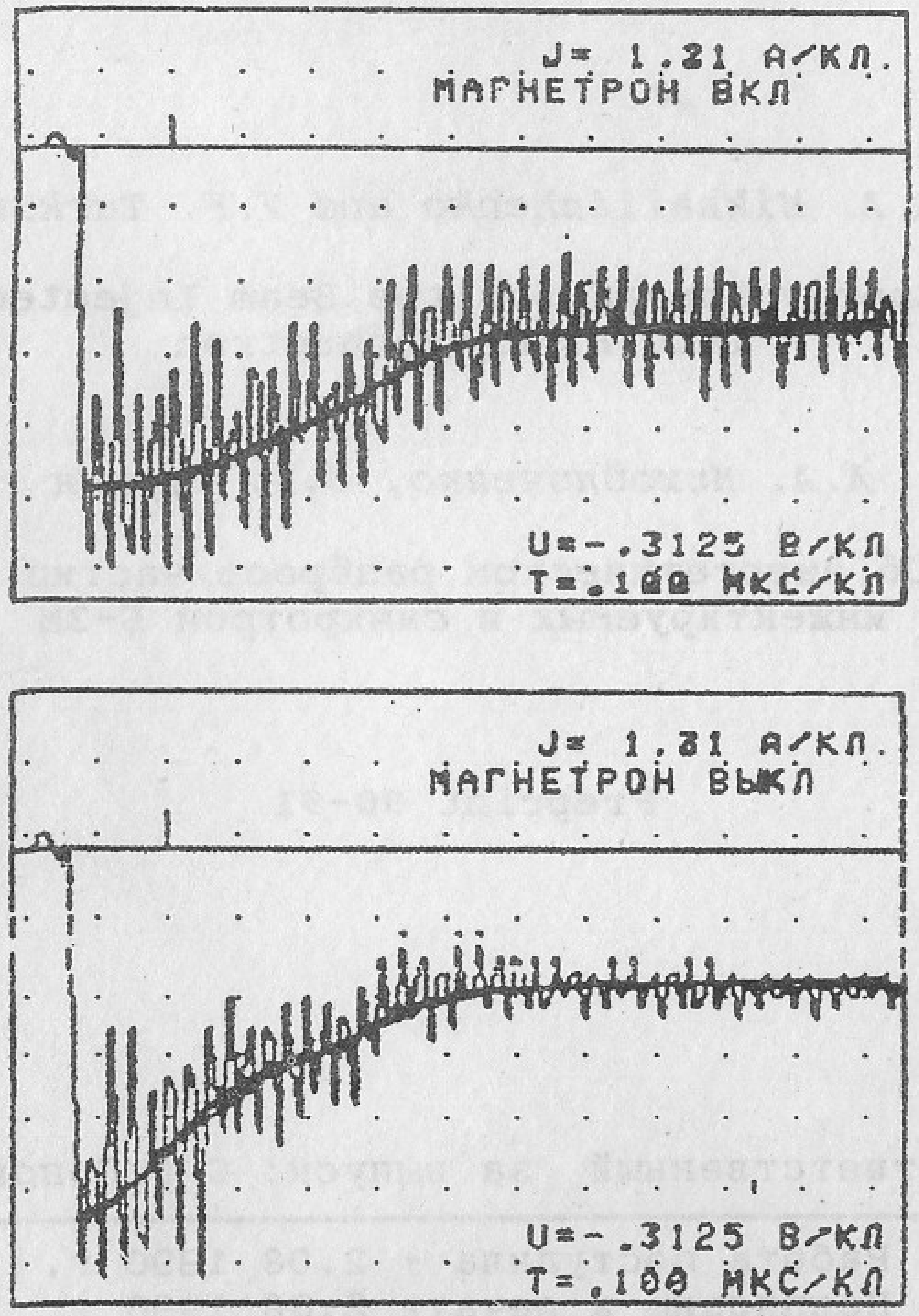

Fig. 8. Current in B-3M accelerator with switch on/of magnetron.

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Об энергетическом разбросе частиц, инжектируемых в синхротрон Б-3М

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