FEATURES OF THE PICKUP DIAGNOSTIC AT LOW ENERGY IN THE COOLER OF NICA BOOSTER

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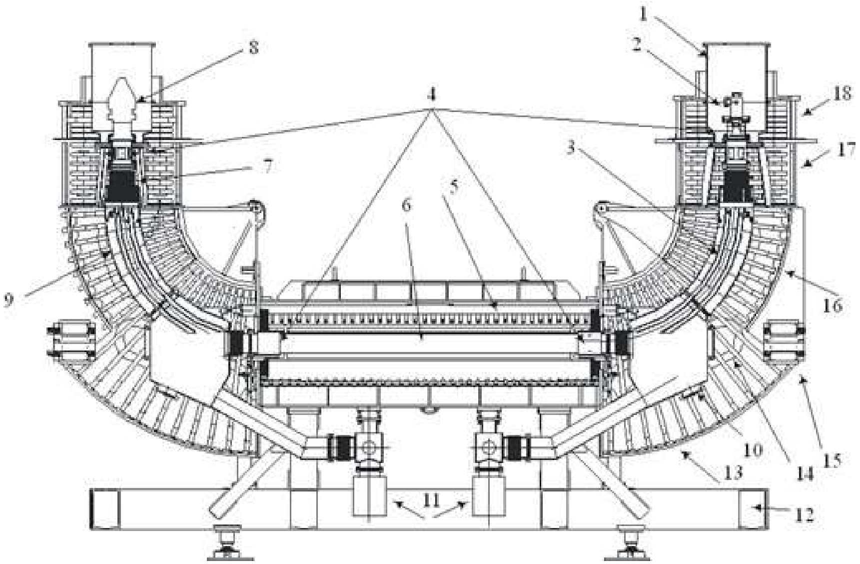
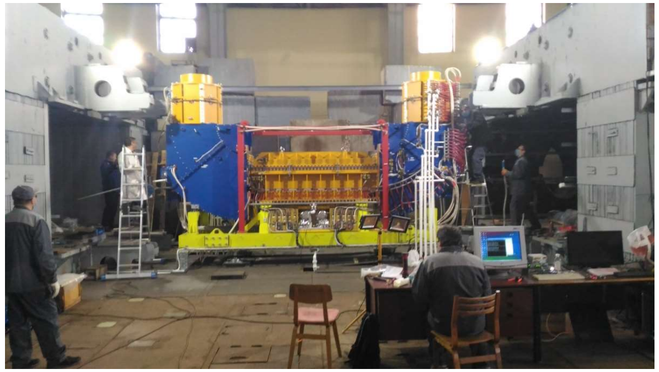


Design of electron cooler for NICA booster. The SF_6 vessel is 1, the electron gun is 2, the electrostatic plate is 3, pickups are 4, cooling section is 5, the vacuum chamber of cooling section is 6, NEG pump is 7, collector is 8, the vacuum chamber of toroid is 9, titanium pump is 10, the ion pumps are 11, the support is 12, the toroid is 13, the correction coil is 14, the corrector of ion beam is 15, the toroid solenoid is 16, the matching solenoid is 17, the gun solenoid is 18.

Parameters of operating modes were obtained for different energies.

Energy: 1.3 – 30.0 keV

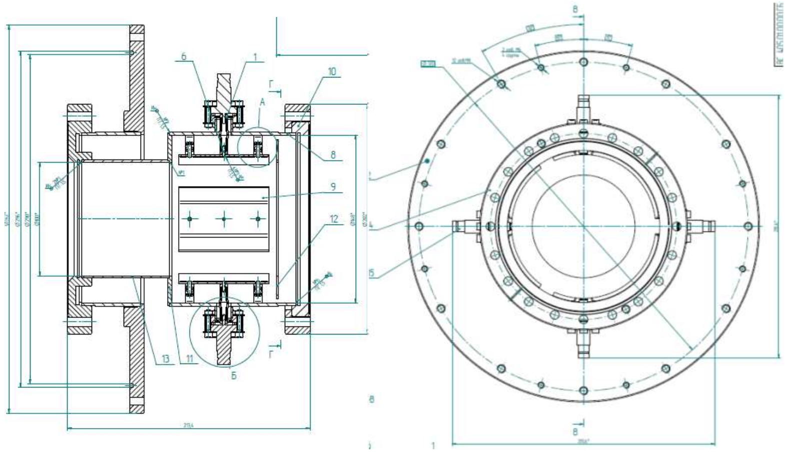
Maximum current: (not for all energy values) > 900 mA



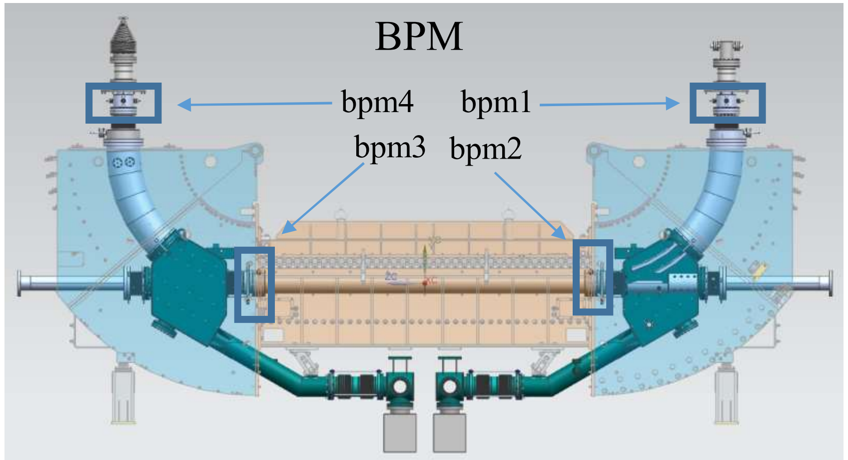
Booster electron cooling system

13th International Workshop COOL'21, November 1 - 5, 2021 in virtual mode (ZOOM), Novosibirsk, Russia

Diagnostic of Electron Beam Position

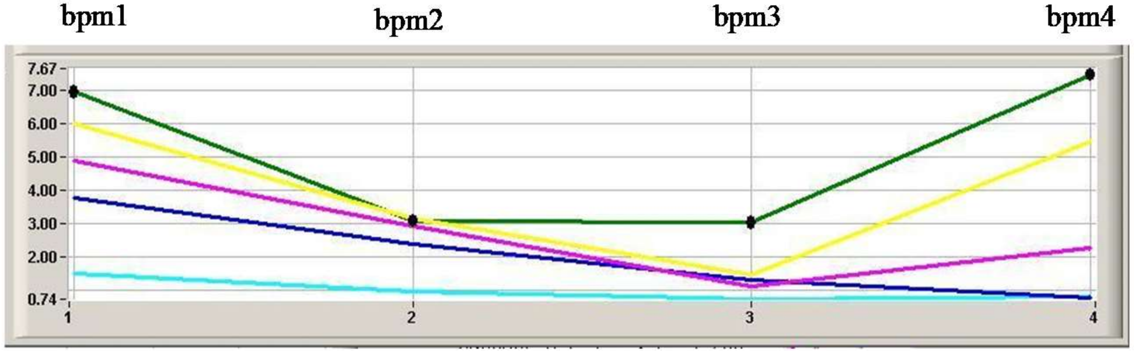


BPM design

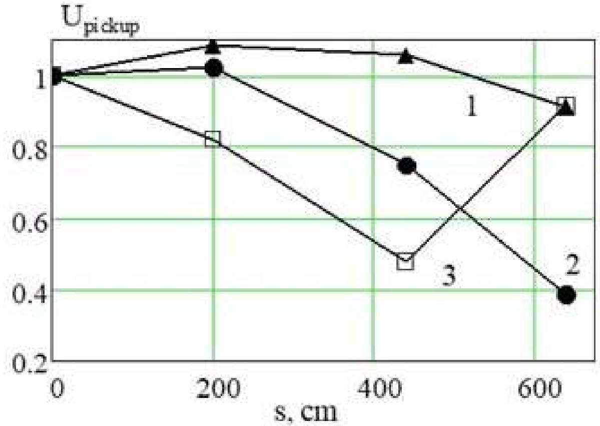


BPM position

GUN design



Amplitudes of the sum signal on 4 beam position monitors (bpm). The current values for the various curves (from bottom to top) were 100, 200, 300, 400 and 500 mA. The electron energy is 1.74 keV.



Normalized values of the sum signal along the electron beam trajectory at different electron beam currents: 42 mA (1), 167 mA (2), 440 mA (3). The signal is normalized to the amplitude of the signal in the first pickup station. The electron energy is 1.74 keV. For relative calibration between different pickup stations, signal amplitudes were used at an electron energy of 5 keV, when the influence of space-charge waves can be neglected.

Space Charge Waves

$$\frac{\partial n'}{\partial t} + div\left(n_0\overrightarrow{v'}\right) + \vec{v}_0\nabla n' = 0$$

$$m_e\left(\frac{\partial\overrightarrow{v\prime}}{\partial t} + (\vec{v}_0\nabla)\overrightarrow{v'}\right) = e\vec{E} + \frac{e}{c}\left[\overrightarrow{v'}\times\vec{B}_0\right]$$

$$\Delta\varphi = -4\pi e n'$$

$$\delta\phi(r,\theta,s,t) = \sum_{l=-\infty}^{\infty}\sum_{k_s=-\infty}^{\infty}\delta\phi_l(r,k_s)\exp[i(l\theta + k_s s - \omega t)]$$

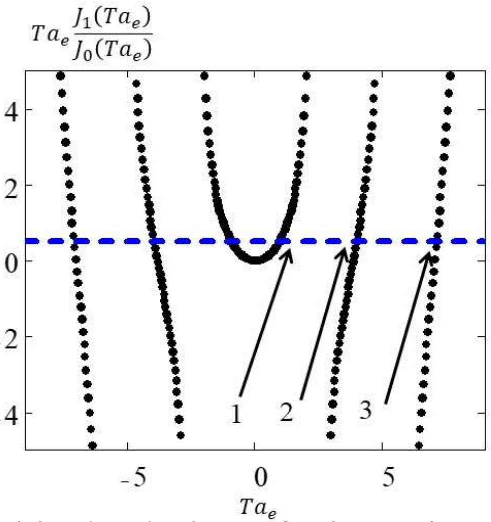
$$\frac{1}{r}\frac{\partial}{\partial r}r\frac{\partial}{\partial r}\delta\phi_l - \frac{l^2}{r^2}\delta\phi_l + T^2\delta\phi_l = 0 \qquad 0 < r < a_e \qquad \delta\phi_l = AJ_l(Tr)$$

$$\frac{1}{r}\frac{\partial}{\partial r}r\frac{\partial}{\partial r}\delta\phi_l - \frac{l^2}{r^2}\delta\phi_l - k^2\delta\phi_l = 0 \qquad a_e < r < b \qquad \delta\phi_l = B\cdot I_l(k_s r) + C\cdot K_l(k_s r)$$

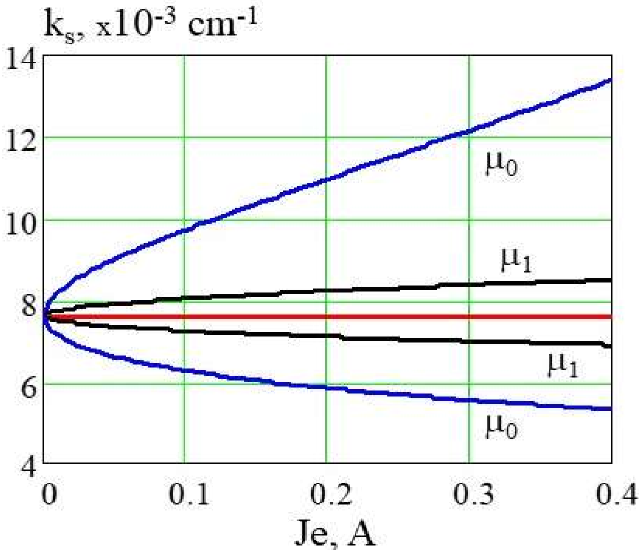
$$k_s a_e\frac{K_l(k_s b)I\prime_l(k_s a_e) - K\prime_l(k_s a_e)I_l(k_s b)}{K_l(k_s b)I_l(k_s a_e) - K_l(k_s a_e)I_l(k_s b)} - \left(1 - \frac{\omega_p^2}{\nu^2}\right)Ta_e\frac{J\prime_l(Ta_e)}{J_l(Ta_e)} = l\,\frac{\omega_p^2(\Omega + 2\omega_0)}{\nu^2(\omega - k_s u_0 - l\omega_0)}.$$

$$\nu^2 \approx -\Omega^2 \quad T^2 \approx k_s^2\frac{\omega_p^2}{(\omega - k_s u_0)^2}, \quad \omega_0 \approx -\frac{\omega_p^2}{2\Omega} \approx 0 \qquad \frac{\omega_p^2}{\nu^2} \approx 0 \quad l = 0 \quad k_s b,\, k_s a_e << 1$$

$$\boxed{\frac{1}{\ln(b/a_e)} - Ta_e\frac{J_1(Ta_e)}{J_0(Ta_e)} = 0 \qquad T^2 = k_s^2\frac{\omega_p^2}{(\omega - k_s u_0)^2}}$$

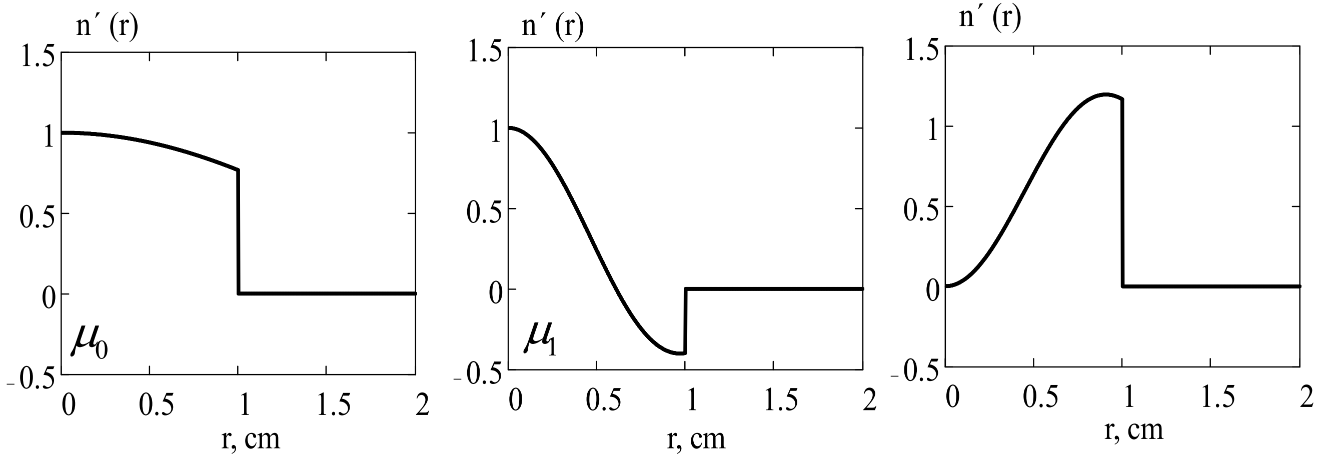


Graphical solution of Dispersion Eqiation. Point 1 corresponds to the main radial mode μ_0=0.95, points 2 and 3 correspond to additional solutions of this equation μ_1 and μ_2.

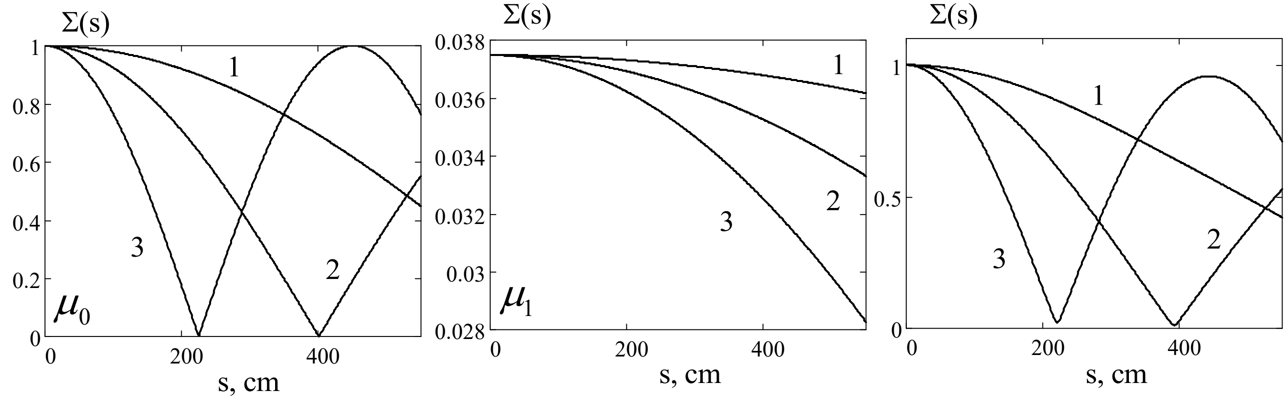


Dependence of the longitudinal component of the wave vector of the wave propagating along and opposite of the flow k_+ and k_- versus the beam current. The curves correspond to the values for the main μ_0=0.95 and the first radial mode with μ_1=3.97. Straight line (red colour) corresponds to the "dispersion equation" of particles without taking into account the space charge $k_s=\omega/u_0$.

$$(\omega - k_s u_0)^2 = \frac{1}{\mu_i^2} k_s^2 a_e^2 \omega_p^2$$



Perturbation density profiles corresponding to the excitation of an azimuthally symmetric mode with μ_0=0.95,μ_1=3.97 and their combinations.



Amplitude of the summation signal in the pickup station Σ when azimuthally symmetric modes with μ_0,μ_1 and their combinations are excited. The value Σ≈0.04 at s=0 for μ_1 reflects the contribution of the first radial mode to the current modulation perturbation. The digits 1, 2, 3 correspond to the values of the electron beam current 50, 150 and 300 mA. The initial electron energy is 1.74 keV. The amplitude of the signal in the pickup station is normalized by 1 at r=0.

Thank you for your attention

CONCLUSION

Pickup station is the main methods for obtaining information on the properties of the electron beam in electron cooling systems. The propagation of space-charge waves in a substantially intensive beam should be taken into account at analyzation of experimental data. The criterion of the influence of beam space-charge waves on signal amplitudes at pickup stations is the compatibility of space-charge wave velocity and beam velocity.

REFERENCES

[1] M. Bryzgunov, V. Parkhomchuk, V. Reva et al Proceedings of the 12th Workshop on Beam Cooling and Related Topics COOL-2019, Novosibirsk, Russia, 2019, pp. 22–25.
[2] A. Tuzikov, O. Brovko, A. Butenko et al. Proceedings of RuPAC-2016, St. Petersburg, Russia, November 21–25, 2016, Paper FRCAMH05, pp. 160–162.
[3] L. S. Bogdankevich and A. A. Rukhadze., Sov. Phys. Usp. 14, 163 (1971)
[4] A. V. Burov, V. I. Kudelainen, V. A. Lebedev et al. Preprint BINP No. 89-116.
[5] R. C. Davidson, Theory of Nonneutral Plasmas (W. A. Benjamin, Reading, MA, 1974).
[6] M. I. Bryzgunov, V. V. Parkhomchuk and V. B. Reva. Physics of Particles and Nuclei Letters, 2021, Vol. 18, No. 4, pp. 472–480.