Acoustic Experimental Studies of High Power Modes in Accelerating Structure of Kurchatov SR Source

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I. INTRODUCTION

The acoustic effects in metal constructions of accelerator electrodynamics structures permit to realize the undisturbing methods for determining of the electrodynamics characteristics of structures at nominal work conditions (at high RF-power level, for real temperature and vacuum distributions, with intense beam). These effects are registered reliably by acoustic pickups installed on external surfaces of structures.

II. MECHANISMS OF ULTRASOUND EXCITATION IN METAL WALLS OF ELECTRODYNAMICS STRUCTURES (ES).

Three main mechanisms of ultrasound excitation can be distinguished here: the ponderomotive mechanism [1], the thermoelastic mechanism by field [2] and the thermoelastic mechanism by electrons.

Thermoelastic mechanism of ultrasound excitation by field is caused by dissipation of energy of electromagnetic field penetrating in metal. Non stationary temperature distribution in pulse RF-field generates the stress wave traveling deep into metal. The stress wave amplitude σ_t can be estimated by solving the boundary problem of the thermoelasticity [2]:

$$\sigma_t = \frac{1+\mu}{1-\mu} \cdot \frac{\alpha v_\varepsilon}{c_{p\cdot}} \cdot P \qquad (1)$$

where: heat capacity c_p, Puasson modules μ , linear heat expending factor α and sound speed ν_s .

The relative contribution of ponderomotive mechanism is increasing with metal conductivity and decreasing with field frequency.

Thermoelastic mechanism of ultrasound excitation by electrons is caused by RF-field energy take-off by electrons moving in vacuum, where their free path length is large enough, and transfer of this energy to surface layer of metal as a result of structure walls electron bombardment. Numerically this effect can be estimated by relation (1), where instead of P the electron power density P_e must be substituted:

$$P_e = \frac{n_e mc^3}{\pi}\left(\varepsilon - arctg\varepsilon\right) \quad (2)$$

where n_e-free electron density in vacuum and $\varepsilon = (eE)/(2\pi fmc)$- perpendicular to metal surface RF-field electrical component amplitude E, charge and mass of electron e and m , speed of light c .

The relation (2) represents the additional to surface currents in metal walls mechanism of RF-field damping in ES - loading of RF-field by free electrons in vacuum. Free electron density is determined by RF-field rest gas ionization in structure volume and electron emission processes at surface of structure. First of all the acoustic effect of free electrons has been found in experiments at gas filled and vacuum sections of feeding wave guide at linear accelerator-injector of Kurchatov Synchrotron Radiation Source.

System of distributed along structure acoustic pickups allows to determine the time and region of discharge origins and to measure the intensity distribution of emission processes on internal surfaces of structure.

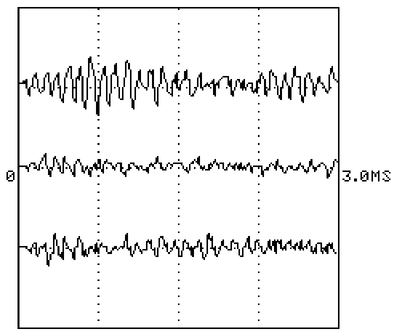
III. ACOUSTIC LOCATION OF RF-BREAKDOWNS IN LINAC ES STRUCTURES

The RF-breakdown acoustic effect in metal walls of ES is caused by non stationary heat evolution in breakdown region. After breakdown initiation the acoustic perturbation in breakdown region propagates along whole construction of the ES and can be registered by acoustic monitors. The propagation time of acoustic perturbation front determines the distance breakdown region from monitor position.

Characteristic for KSRS linac, where the lengths of accelerating structure and RF-power supply waveguide are much greater than their cross section dimensions, the problem of breakdown region location can be solved by use of three acoustic monitors. If the ES is longitudinally uniform, the signals of three monitors, distributed along structure with known positions, define all three unknowns: the moment and region of breakdown initiation, the speed of perturbation front. It is important to note, that RF-breakdowns can excite in structure walls different initial acoustic perturbations, which can propagate along the structure with different group speeds. That is why, the procedure of complete self-consistent calculations, based on signals of all three monitors, is necessary for location of every concrete RF-breakdown. For the pulsed RF regimes the problem of breakdown location

At the KSRS linac two acoustic monitors are installed at the edges of long uniform sections of monitored electrodynamics structures. The third, middle monitor is movable and can be displaced into breakdown region the accuracy of breakdown location 1 cm can bee achieved. The RF-breakdown monitoring system is synchronized by synchropulses of linac.

The acoustic RF-breakdown monitoring system operational regime on real time, is illustrated in Fig.1.



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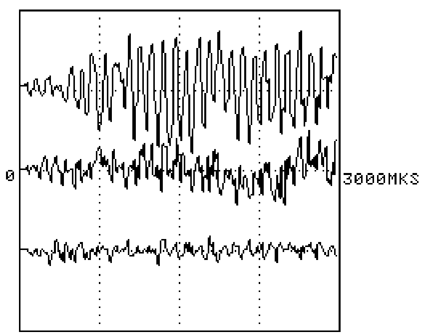

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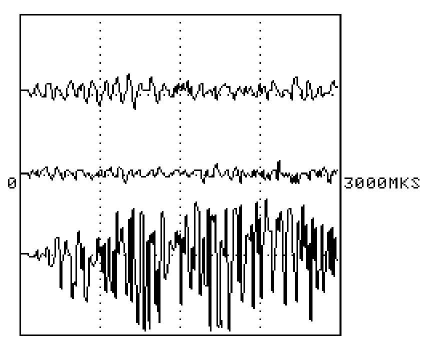

c

Figure 1 (a, b, c): Signals of the three aoustic pick-up on the accelerating structure

Every digital oscilloscope screen copy represents here the signals of three monitors placed in the beginning of the structure (upper curve), in the middle of the first half of the structure (middle curve) and in the middle of the structure (down curve). Signals in Fig.1a are the stable response of the acoustic system on RF-pulses in accelerating structure without breakdowns. Signals in Fig.1b and Fig.1c locate the breakdowns, accordingly, in the beginning of the structure (0,4 m away from the edge) and near to the RF-power input in the middle of the structure.

IV. EXPERIMENTAL STUDIES OF DISK-AND-WASHER (DAW) ACCELERATING STRUCTURE UNDER HIGH RF-POWER OPERATING CONDITIONS

Electrodynamics characteristics of accelerating structures under high RF-power operating conditions can essentially differ from those, which are experimentally investigated and tested at low RF-power levels, because of real temperature and vacuum non uniform distributions, electron emission, residual gas ionization, low energy particle flows and dark currents. Acoustic monitors installed at external surfaces of accelerating structure provide the detailed information on RF-field and physical processes inside the closed volume of accelerating structure.

One of the vital problems, which must be solved in acoustic study of structure, is the problem of local measurements. It is necessary to measure the intensity of ultrasound, excited in structure metal wall only in the vicinity of the external acoustic monitor position. Local measurements allow to investigate the distributions of acoustic effects along the internal surfaces of structure walls and, hence, the distributions of RF-field, electron emission, low energy particle flows and accelerated particles losses in accelerating structure.

The local measurements method, based on the fact, that the speed of sound is finite, was developed and used for experimental studies of electrodynamics characteristics of the traveling wave accelerating structure with slow varied along longitudinal axis geometry at high RF-power operating conditions.

The accelerating structure of KSRS linac is the standing wave DAW 6 m long structure at 2,8 GHz with RF-power input in the middle. The only control coupling loop is installed near the power input.

TheDAW structures containing the massive disks determine in constructions the existence of the acoustic oscillation modes corresponding to the own acoustic oscillations of disks. In some specified sense, a structure construction can be considered as a chain of coupled high Q identical acoustic oscillators. A short pulse acoustic excitation of any disk is attenuated on propagation along a structure strongly because of resonant energy dissipation by near-by identical disks.

These specific strongly attenuated acoustic excitations in a DAW structure construction can be observed experimentally, for example, after short puls RF-breakdowns in a structure (the duration of an RF-breakdown is limited by the duration of RF-pulses in structure). The typical situation after the RF-breakdown at disks is shown in Fig.2c. The first to the RF-power input acoustic monitor registers the breakdown (down curve). This breakdown is not registered by the next monitor (middle curve), while the next monitor is 0,8 m distant from the first one only. The signal of the next monitor is reduced in comparison with the situation without breakdown in Fig.2a because of RF-field degradation in structure. At the same time, the arbitrary acoustic perturbations excited by the vibrator at external surface of the structure propagate with slow attenuation a few meters along the structure.

The existence of the acoustic modes corresponding to the own acoustic oscillations of disks in DAW structure constructions allows for pulse RF-field regimes to formulate the spectral approach to the local acoustic measurements at structure: in spectrum of registered short pulse acoustic excitation, the intensities of lines at the own acoustic frequencies of disks are determined by the acoustic effects at a few disks near the acoustic monitor position only. In addition, the proportions of these lines intensities in spectrum characterize the type of the pulse mechanical stress on disks. Spectral local measurements are very sensitive and noise protected.

The own acoustic disk oscillations in a separate cell of KSRS linac accelerating structure have been investigated at the stand. The cell was placed in permanent external magnetic field with magnitudes up to 0,2 T, the acoustic oscillations were excited by 12 A pulses of current in disk. Measurements in different configurations of magnetic field have allowed to distinguish a few and electron emission. In this case, the slope of the straight line corresponding to the cold structure electrodynamics characteristics is given in Fig.2 by two successive experimental points for rapid RF-power level increasing in structure.

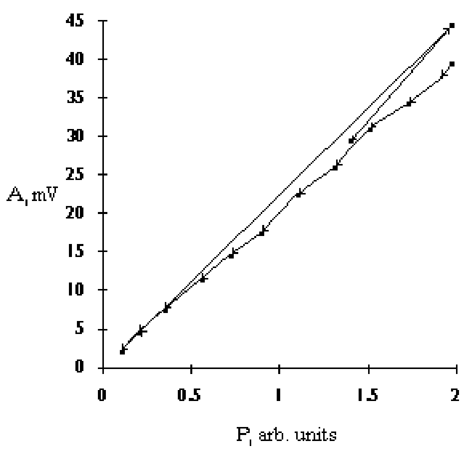

Figure 2: Dependence of acoustic spectrum on the control coupling loop signal squared.

At high power level, the heat transfer, ionization and emission processes in structure are reaching the steady state and the acoustic signal is reducing.

In Fig.3, the control loop signal squared and the signal of acoustic monitor installed 1 m distant along the structure from the control loop are presented as functions of RF-field frequency.

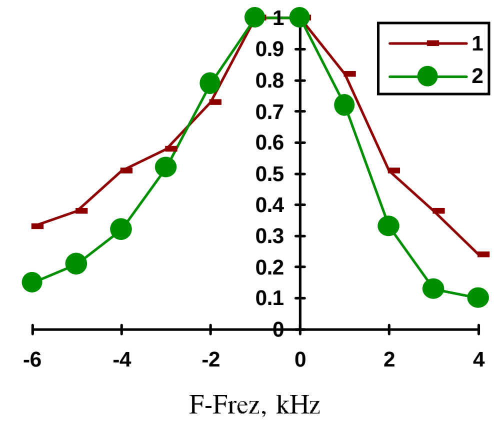

Figure 3: The control loop signal squared and the signal of acoustic monitor.

Experimental data are normalized in Fig.3 to own disk frequencies in the range 60-120 kHz.

At present the developed spectral method of acoustic local measurements is used at KSRS linac accelerating structure. In the Fig.2 is shown the dependence of the acoustic spectrum 98.8 kHz line intensity on the control coupling loop signal sguared. The sequence of measurements is indicated by arrowed lines, the time intervals between every two successive measurements is less than 4 min. In the operating pulse mode with pulse duration 8 mks and pulse repetition rate 1 Hz, the peak RF-power level is varied in the range up to 7 MW.

The observed hysteresis in Fig.2 can be explained, if the RF-field amplitude distribution along the structure depends on the RF-power level in structure. This dependence may be caused by non uniform temperature distributions in structure construction elements (60 % of RF-field power is dissipated at disks installed in vacuum) or RF-field loading by free electrons maxima at resonance.

V. REFERENCES

[1] Yu.V. Kaprin, V. I. Moiseev, V. V. Petrenko. Acoustic effects of pulsed electromagnetic RF-field
-Atomnaja energija, 1987, v. 63, n. 6. p.p. 400-402

[2] V. I. Moiseev, V. V. Petrenko.
Comparative characteristics of aconstic excitation mechanisms by pulsed RF-field.
-VANT, 1990, n. 11(19), p.p. 135-136