ACOUSTIC MEASUREMENTS AT DAW ACCELERATING STRUCTURES UNDER OPERATING HIGH RF POWER CONDITIONS

V.Moisseev, V.Petrenko, SSSPI
A.Kadnikov, Yu.Krylov, S.Kuznetsov, V.Ushkov, V.Valentinov, Yu.Yupinov, KSRS
Russian Research Centre "Kurchatov Institute", 123182 Moscow, Russia

Abstract

The acoustic method for measurements of disk-and-washer (DAW) structures real electrodynamic characteristics under operating high RF power conditions (nonuniform temperature distributions, plasma, electron emission and charged particle flows) and for diagnostics of the beam acceleration process in DAW structures has been developed on the Kurchatov SR source linear accelerator. The RF field and charged particle acoustic effects in the structure metal construction are registered by a set of acoustic monitors installed on external surfaces of the structure. In the DAW structures, a short pulse acoustic excitation of any washer is attenuated on propagation along a structure strongly because of the resonant energy dissipation by near-by identical washers. This acoustic property of the DAW structure construction enables the local acoustic measurements at the eigenfrequencies of the washers. The RF field amplitude and beam losses distributions along the structure can be measured, the field loading by electron emission and the situations before break-downs can be observed by the external acoustic monitors. The instrumentation used for acoustic measurements and the recent experimental results are described.

1 INTRODUCTION

Electrodynamic 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 nonuniform distributions, residual gas ionization, electron emission, 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.

For pulsed RF field, three main mechanisms of ultrasound excitation in metal walls of structure can be distinguished: the ponderomotive mechanism [1], the thermoelastic mechanism by field [2] and the thermoelastic mechanism by electrons [3]. The ponderomotive mechanism is the interaction of space charge and currents in skin with penetrating RF field in metal. The relative contribution of ponderomotive mechanism is increasing with metal conductivity and decreasing with field frequency. The 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 can be estimated by solving the boundary problem of the thermoelasticity [2]. The 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.

The intensities of ponderomotive and thermoelastic by field mechanisms are proportional to the field amplitude squared only and hence can be used for direct measurements of the field distribution along a structure. The thermoelastic mechanism by electrons represents the field loading by free electrons and RF discharges, the electron emission from the walls and the behavior of the low energy particle flows in a structure. The situations before RF breakdowns can be searched by a system of external acoustic monitors.

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.

2 ACOUSTIC LOCATION OF RF-BREAKDOWNS

The RF-breakdown acoustic effect in metal walls of a structure 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 structure and can be registered by acoustic monitors. The propagation time of acoustic perturbation front determines the distance breakdown region from monitor position.

For KSRS linac, where the length of accelerating structure is much greater than its cross section dimensions, the problem of breakdown region location can be solved by use of three acoustic monitors. If the structure is longitudinally uniform, the signals of three monitors, distributed along the 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.

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 be 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.

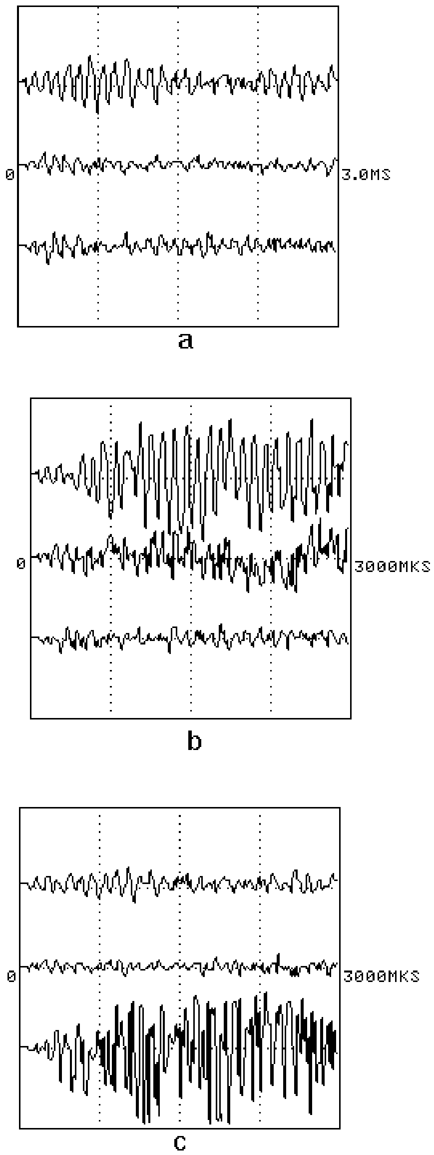

Figure 1. Signals of the three acoustic monitors on the DAW accelerating structure [3].

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.

3 EXPERIMENTAL STUDIES OF DAW STRUCTURES

3.1 Local Measurements

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.

Construction details of DAW structures containing the massive washers determine in constructions the existence of the acoustic oscillation modes corresponding to the own acoustic oscillations of washers. 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 washer is attenuated on propagation along a structure strongly because of resonant energy dissipation by near-by identical washers.

These specific strongly attenuated acoustic excitations in a DAW structure construction can be observed experimentally, for example, after short pulse 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 washer 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 washers 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 washers are determined by the acoustic effects at a few washers 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 washers. Spectral local measurements are very sensitive and noise protected. The own acoustic washer oscillations in a separate cell of KSRS linac accelerating structure have been investigated at the stand.

The potentialities of local measurements are illustrated in Fig.2, where the dependence of acoustic spectrum 98,8 kHz line intensity on the control coupling loop signal squared is shown. The acoustic monitor is 1 m distant along the structure from the control loop. The sequence of measurements is indicated by arrowhead lines, the time intervals between every two successive measurements are 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 hysteresis loop seen clearly characterizes in the structure the situation, which differs essentially from the simple one, when the RF field distribution along the structure is independent on the RF power level and the ultrasound excited by RF field directly is registered only.

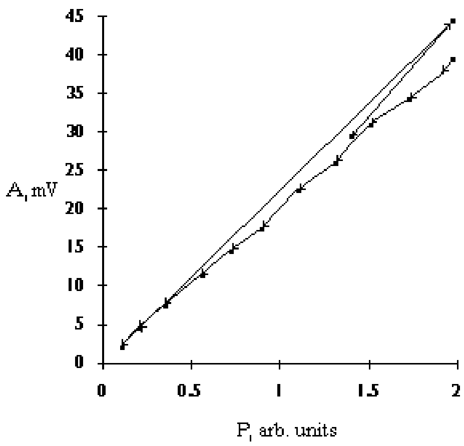

Figure 2. Dependence of acoustic spectrum 98.8 kHz line intensity on the control coupling loop signal squared.

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. Experimental data are normalized to maximum at resonance.

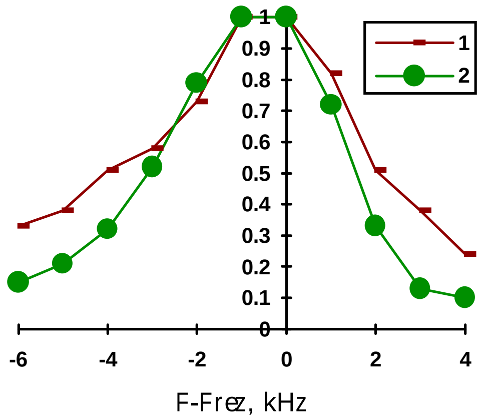

Figure 3. The control loop signal squared and the signal of acoustic monitor.

3.2 Beam loading and particle losses

The duration of the beam pulse in KSRS linac structure (15 ns) is much less than duration of the RF field pulse (15 mks) and the particle losses at the apertures of washers excite effectively the vibrations of washers at the high frequency modes. The RF field loading by beam and the particle losses are registered by acoustic monitors in the frequency range 200-400 kHz (at the 360 kHz and 385 kHz acoustic lines, for example).

3.3 Instrumentation

The sensitivity of acoustic monitors used is 50 mV/Pa in the wide frequency range up to 1000 kHz. The resonant sensitivity is much better. The precise devices are introduced for research: the spectrum analyzer (0.1-600 kHz, from 50 mkV) and the selective microvoltmeter (0.15-30 MHz, from 3 mkV).

4 REFERENCES

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

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

[3] V.Moisseev, V.Petrenko, V.Ushkov et al. Acoustic experimental studies of high power modes in accelerating structure of Kurchatov SR source. -1995 PAC and ICHEA, Dallas, 1-5 May 1995.