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## DISLOCATION AVALANCHES AND STRAIN BURSTS IN THE BOARDS OF RADIO-ENGINEERING EQUIPMENT

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*The aim of this work is to investigate the influence of vibrations on the material of the board. For that purpose a cascade of navigation devices boards was installed on the vibrational stand. Experiments were performed in the 0,5–10 Hz vibrational diapason range; 0–3 V voltage range; 0 – +45 °C allowed temperature range. Amplitude method was applied to determine the coordinates of localized sources of acoustic emission. The results indicate the initial increase in tension and relative deformation and further their decrement. Growth rate reduction of mechanical stress  $d\sigma/de$  is due to destruction of material structure. The receiving piezo converter based on ЦТС-19 ceramics and a waveguide that was in acoustic contact with the sample were used during experiments. The acquired experimental data on acoustic emission reflect the formation of microdefects and the instability of mechanical tension, its avalanche and explosive tendency in the material when the microvolumes of material are torn.*

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**Key words:** vibration, navigation devices, acoustic emission.

### Introduction

Constant mechanical stresses at the mounting points of most of the radio-engineering electronic products increases due to exploitation and depends on the work environmental conditions and materials the board is made from, usually composite materials and plastics. During installation of the board and exploitation either in normal or extreme conditions the board is subjected to vibration, temperature and pressure changes resulting in the occurrence of plastic deformations due to movement of lattice dislocations. In microcrystals that were plastically deformed inner dislocation avalanches influence the occurrence of mechanical stress spike (bursts). However in macroscopic samples plasticity is a smooth process. The distribution of mechanical stress during dislocation avalanches and its dependence on microcrystal size were presented in the (Figure 1). The authors of research work [1] determined this distribution by combining the three-dimensional simulations of the dynamics of interacting dislocations with statistical analysis of corresponding behavior. Several specific dislocations become geometrically unattached during the

same case, which demonstrates the importance of long elastic interactions in the initiation of mechanical stress burst.

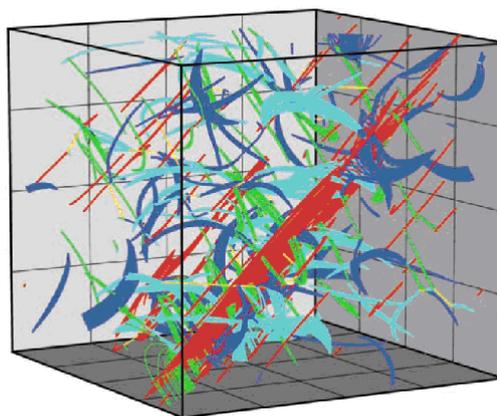


Figure 1 – Progress of large dislocation avalanche in [010] and symmetric multiple slip of dislocations in microvolume of the material of the board (the specimen size  $L = 0,5 \mu\text{m}$ )

The avalanche has a strongly anisotropic shape with more than 60 % of the deformation occurring on one of the four equivalent sets of slip planes. Although a part of the deformation is taking place

outside a single slip plane. The statistical analysis of the avalanche distribution suggests that the fractal dimension of the avalanches is close to two, indicating an effective lamellar shape [2]. Simulation graphics of time step during burst of mechanical stress [1]. Where red, green, blue and cyan colors represent dislocations on the four {111} set of crystal planes; yellow represents the static of Lomer locks created through dislocation reactions.

**Methods and specimens**

The results of published researches demonstrate the possibility of controlling the form of

dislocations before the microcracks occur in the material of the board during exploitation. Therefore the vibrations in antiphase to suppress the primary external mechanical action were investigated in this work. The polymeric composite materials with epoxy matrix are used for navigation devices boards, which work in conditions of radiation and vibration. For this purpose a cascade of navigation devices boards was assembled on the vibration stand (Figure 2). The increase of mechanical stresses determined using the methodology [4, 5] of smoothing of mechanical stress accumulation in the microlayers (Figure 3).

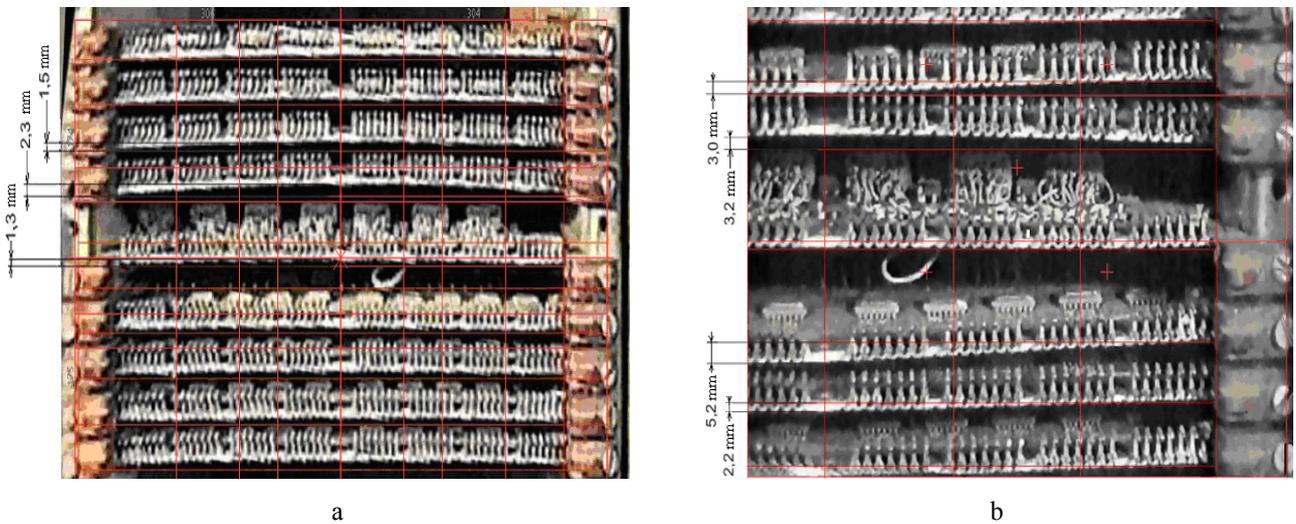


Figure 2 – Cascade of boards on the vibration stand (stills of speed filming with the grid applied (micrometer scale) for the determination of deflection and the amplitude of oscillation of the boards): a – smoothing of the deflections due to the antiphase vibration; b – maximum deflection of the boards and their collision [3]

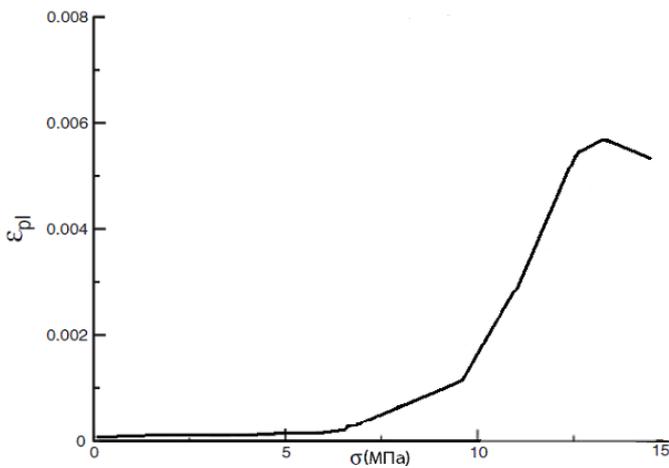


Figure 3 – The diagram of increase of mechanical stresses in the microlayers of material

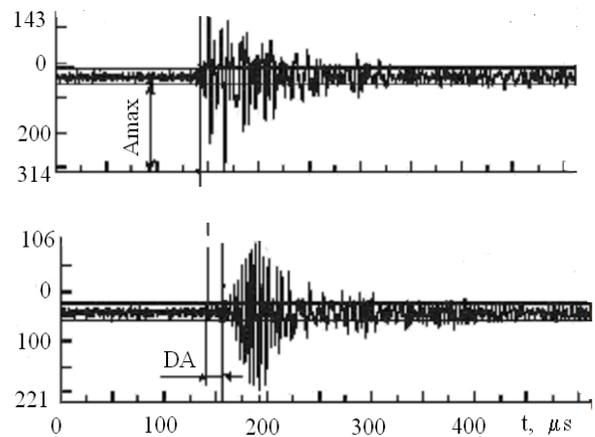


Figure 4 – Registration of AE and determination of signal parameters: DA – the difference in the arrival time of signals and its subsequent self-smoothing due to piezoeffects

The signals and noises of different origin can be occurred during local plastic deformation (signals of the friction between the board and mounting points on the stand, the intrinsic noise of the test stand, etc.). These factors make the acquisition of data more difficult. This is especially important for devices, which are sensitive to acoustic emission (AE). Therefore for discrete signals various filtering methods are used: like discrimination of sources according to location [6], spectral composition [7] or the frequency of vibration. In this work experiments were performed in the 0,5–10 Hz vibrations diapason range; 0–3 V voltage range; 0 – +45 °C allowed temperature range. The phenomenon of AE occurs when the restructuring of deformed structures at different scale levels happens [6, 7]. During mechanical stress relaxation elastic energy in the deformed regions of material is being emitted in the form of AE waves of different frequency and amplitude. This is can be detected by diagnostic equipment. In addition, the acoustic

signal can provoke changes in material structure and influence the self-organization of defects. The amplitude method was used for determination of the coordinates of localized AE sources. This method is based on the dependence of the attenuation of acoustic wave on the distance between the AE source and the acoustic transducer (Figure 4). The accuracy of about 3–5 % for determining the coordinates of AE sources was achieved [7] in this work for microsize objects.

Structural block diagrams include: sensor for conversion of acoustic vibrations of the specimen into voltage change (FH1); filter for filtration of the acoustic wave signal from the noise and external activity of the environment (FH2); block for sensor connection to the computer and summation (FH3); amplifier of the acoustic wave signal to the 1–3 V level (FH4). Various circuits were implemented by replacing different types of chips, which have the same function. For FH1 realization these variants were used (Figure 5).

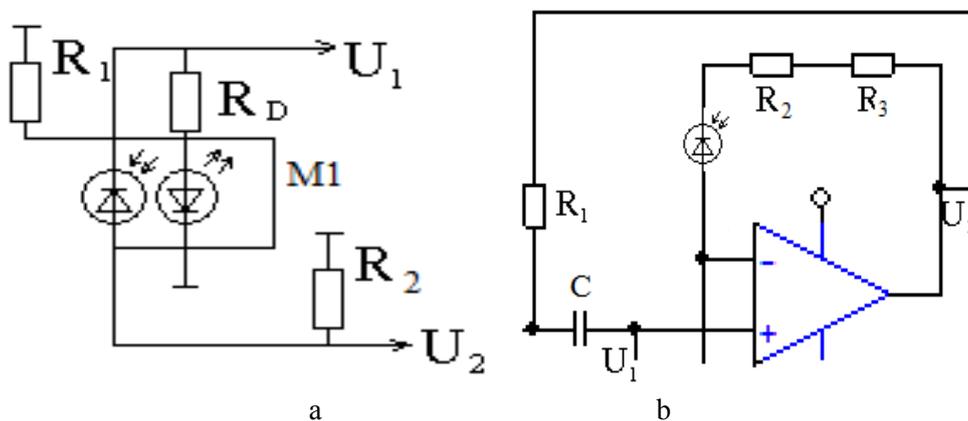


Figure 5 – Sensors: a – acoustic sensor; b – optical sensor

For FH2 realization these variants were used (Figure 6).

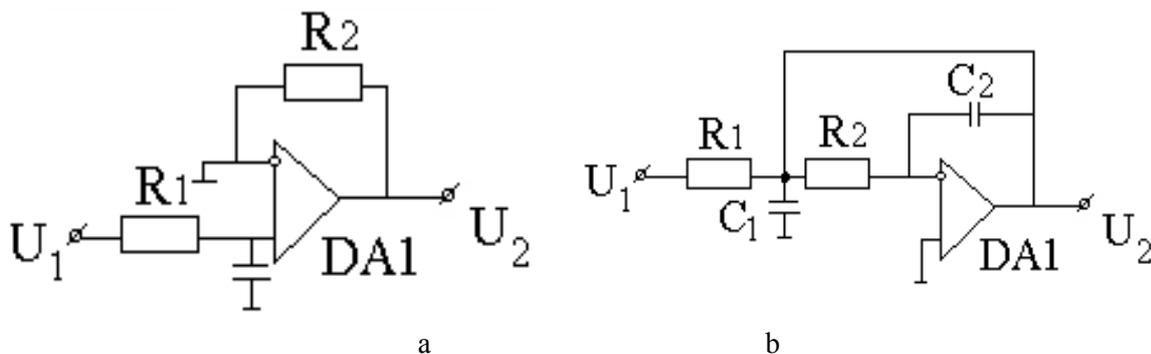


Figure 6 – Low-pass filters (LPF): a – first order active LPF; b – second order active LPF

For FH3 realization these variants were used (Figure 7).

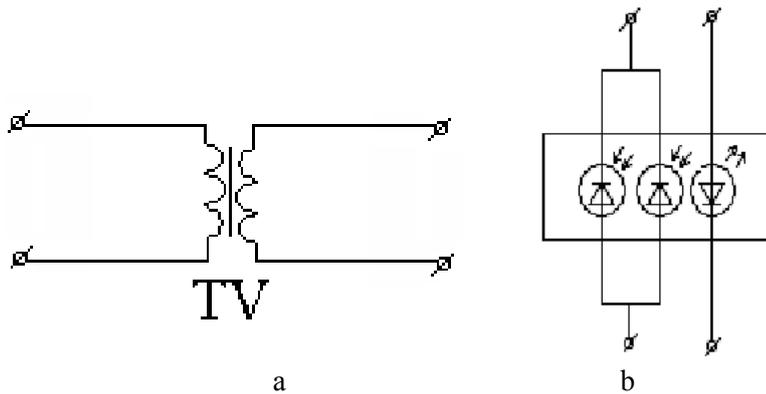


Figure 7 – Galvanic interchanges: a – galvanic interchange based on the output transformer; b – galvanic interchange based on optocouple

For FH4 realization these variants were used (Figure 8).

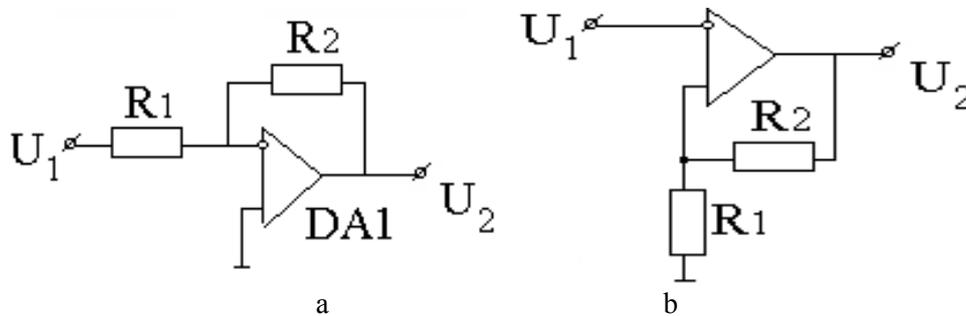


Figure 8 – Amplifiers: a – amplifier with isolated input; b – amplifier with current input

**Results and discussions**

Results of «smoothed» acoustic spectra of local plastic deformation in different temperature are shown in Figure 9. The tensile testing machine IR 5057-50 and samples for axial compression were used for investigation of mechanical stresses in the local points of boards from polymeric composite materials with epoxy matrix. Mechanical stress and relative deformation of investigated samples are shown in Figure 10.

The results indicate the initial increase of mechanical stress and relative deformation and further their decrement. In the region  $\sigma \in [0; 57]$  MPa mechanical tension is practically linear and depends on the relative deformation. The limit of proportionality  $\sigma_p = 20$  MPa (correspond to the relative deformation value of  $\varepsilon_p = 6 \cdot 10^{-4}$ ) is achieved when time value  $t = 1,2$  min. Reduction of growth rate of mechanical stress  $d\sigma/d\varepsilon$  when  $\sigma \geq \sigma_p$  is due to destruction of material structure.

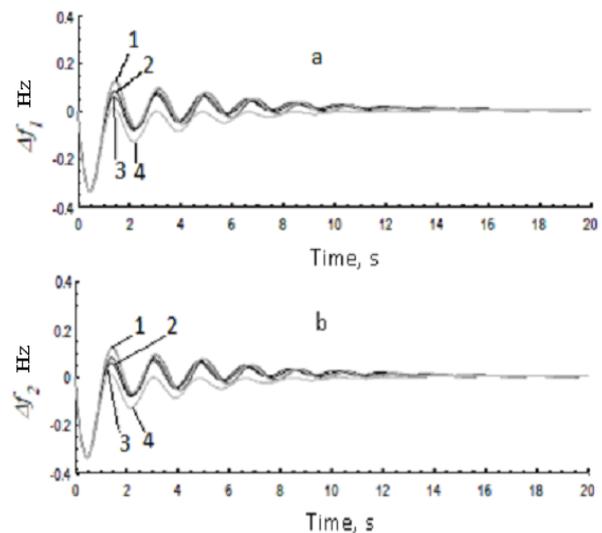


Figure 9 – Acoustic spectra of microsensors on local points on the board: a – «smoothing»; b – reduction in avalanche formation and stabilization of difference of acoustic emission (after 10 s); 1 – +45 °C; 2 – +20 °C; 3 – +8 °C; 4 – 0 °C

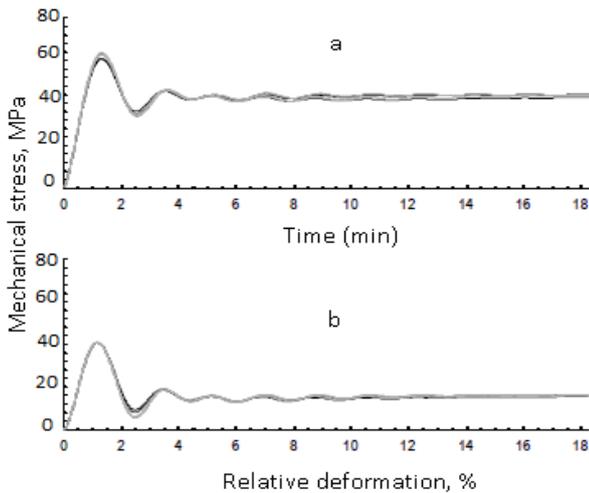


Figure 10 – Mechanical stress and deformation curves: a – stress in the material of the board; b – the compression diagram. Curves correspond to the temperature values on Figure 9

The receiving piezo converter based on ИТС-19 ceramics and a waveguide that was in acoustic contact with the sample were used during experiments. The data was stored in the memory of personal computer and is shown in Figure 11.

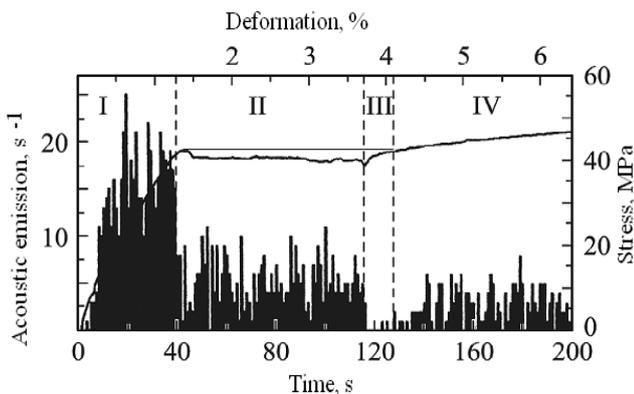


Figure 11 – AE activity when sample is being deformed (Dashed lines mark characteristic stages: I – elastic, II – yield plateau, III – «silence zone», IV – stage of parabolic hardening)

From Figure 11 it can be seen, that when the plastic deformation at the yield plateau is realized by oncoming movement from piezoeffect of two Chernov–Luders bands, the localization of AE sources exhibits same characteristics as found in [6] for samples of low-carbon steel. The data acquired in this work differ only by the order of mechanical stress, but doesn't negate the established pattern of the acoustic emission signals occurring when local points are subjected to deformation. In

this case, the motion of the first Chernov–Luders line corresponds to the spatial distribution of AE sources. The second Chernov–Luders line is moving towards the first and the velocity of lines movement is dropped to zero (complete lack of resistance due to complete destruction of the material in the local point, where it was a microcrack filled with air developed). This is confirmed by the fall of AE pulses. Then destruction of the neighboring local points begins, which can be observed in Figure 11 after 120 s from the beginning of tension-compression of the sample. In conclusion it can be added, that the kinetics of the burst and avalanche-like increase of boards microdefects is similar to the disruption of the latent period of the phase formation in polycrystals under vibration (wave oscillations) of different frequencies and piezoelectric effects in local points [8]. Herewith in one microlayer a positive charge is formed and a negative charge in the neighboring layer, which are self-balancing and reduce the amplitude of the forming avalanche.

### Conclusion

The acquired experimental data on acoustic emission reflect the formation of microdefects (microcracks) and the instability of mechanical tension, its avalanche and explosive tendency in the material when the microvolumes of material are torn. The phenomenology of these bursts of mechanical stress closely resembles the phenomenology of macroscopic instability of plastics: mechanical stress curves are ascending jagged steps (Figure 3). Time disruptions are associated with spatial localization because each burst of mechanical stress corresponds to the formation of a narrow slip line or slip band as it is discussed in work [9]. Time-spatial localization of deformation is associated with instability of plastics and has negative affect on the formation characteristics. A classic example is the Portevin – Le Chatelier (PLC) effect – the bursts of mechanical stress that result because of the interaction between dislocations and distribution solutions [10]. The instability during the microdefects (microcracks) formation in the polymeric composite boards can be avoided if the right path of the process is selected. The temperatures and mechanical stress values when dislocations and the velocity of their spreading are of the same order of magnitude must be avoided in such case. Apart from that, larger mechanical stress fluctuations can disturb the controlling of the

resulting shape during the plastics forming process. Burst-like deformation of microcrystals represents a much more fundamental instability of plastic flow, which could cause plastic formation problems from crystals of micrometric size. Bursts of mechanical stress in microcrystals are the result of avalanche movement of dislocations. Dislocations are given the ability to mutually trap each other in a clamped configuration. Further interactions between dislocations make the destruction of such clamped configurations similar to collective – avalanche-like process. Dislocation avalanches – is a unique feature that does not depend on the specific properties of material and it cannot be avoided by controlling the path of deformation like in PLC effect or other crackling noise phenomena [11], such as Barkhausen noise, that is emitted along the hysteresis loop in ferromagnets [12, 13] or metalelectrics [14], acoustic emission during fracture [15]. The existence of unstable bursts in the plastics due to mechanical stress was already known [16, 17]. However the statistical properties of AE were identified only recently. The majority of simulations involve the single axis tension/compression of cubic samples. In these cases the deformation is stimulated and monitored by control of displacement or slowly increasing the strains. In monocrystals the largest dislocation avalanches cover the entire cross-section of the sample. Its expansion limited only by the volume of samples. The stochastic nature of their appearance may make it impossible to control the forms resulting from deformation. Furthermore the dislocation avalanches in the polycrystals are limited by the grain boundaries. This can lead to a noticeable smoothing of deformation and improve the control of deformation processes.

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### **Лавины дислокаций и выбросы напряжения в платах радиоинженерного оборудования**

Приведены результаты исследования влияния вибраций на материал электронных плат. Исследования проводились на вибрационном стенде с установленным на нем каскадом из плат навигационных приборов. Эксперименты проводились в колебательном диапазоне 0,5–10 Гц; диапазоне напряжений 0–3 В; разрешенном температурном диапазоне 0 – +45 °С. Для определения координат локализованных источников акустической эмиссии применен метод амплитуд. Установлено, что изначально напряжение и относительная деформация возрастают, а далее снижаются. Уменьшение показателей роста механического напряжения  $d\sigma/d\varepsilon$  происходит вследствие разрушения структуры материала. Во время эксперимента использовались получающий сигнал пьезопреобразователь на основе керамики ЦТС-19 и волновод, который находился в акустическом контакте с прототипом. Установлено, что при вибрации образуются микродефекты за счет разрыва микрообъемов материала плат.  
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**Ключевые слова:** вибрация, навигационные приборы, акустическая эмиссия.

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