Anomalous Excess Noise in Inhomogeneous Elastic and Piezoelastic Solids

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Abstract: It is shown that few different kinds of excess noise exist in piezoelectric materials. They are related with ordinary current noise, which can be abnormally large in inhomogeneous conductors [1, 2], mechanical excess noise [3, 4] and crosscorrelated noise caused by both electrical and mechanical fluctuations. It is found that the measurements of correlation of these noises will give specific additional information about internal structure of inhomogeneous solids.

Many physical and technical problems reduce to the necessity of defining the relation between the internal structure of an inhomogeneous solid and its response to an external action. This applies to problems of the description of the macroscopic behavior of a microinhomogeneous material and to those of the determination of the internal structure of a material from its response to external action.

As a rule, the internal structure of an inhomogeneous medium is adequately described by a set of effective material constants that are determined by the moments of distribution for various fields after averaging over the volume. These constants can be found by measuring just a limited number of macroscopic parameters. So we can avoid the hard and unstable procedure of solving the inverse problem (as one must do for a detailed study of the internal structure).

The constants related to the second moments of the fields are the simplest to determine. This will be the work of deformation and heat generation for an elastic field and an electric current, respectively. Additional information about the material can be deduced from the higher moments of the corresponding field. These higher moments are most important in cases of a field with a highly nonuniform spatial dependence (e.g., when there are large peaks on a smooth background). In certain cases, the magnitude distributions of such peaks can provide nearly all the information about the structure of the material.

A simple method for determining the high distribution moments of a field is based on measurements of the excess noise arising from fluctuations in material constants such as conductivity, elasticity moduli, components of piezoelastic tensor, etc. This statement was demonstrated in [1, 2] for excess fluctuations of the total electric current through an inhomogeneous conductor. It was shown that some geometric peculiarities of heterogeneous structure of a sample can lead to the sharp changes of excess noise, even in the case when heterogeneities themselves are not of large magnitude. Some composition rules for local two-point and two-time correlations were derived: These rules express "external" two-time correlator of total current fluctuations \( K_2(t_1 - t_2) \) in terms of local two-time, two-point correlator \( k_2(t_1, r_1, t_2, r_2) \) of conductivities. For the case of \( \delta \)-correlation in space

\[
k_2(t_1, r_1, t_2, r_2) = k\left(\frac{r_1 + r_2}{2}\right)\delta(r_1 - r_2), \tag{1}
\]

here \( \tau = t_1 - t_2 \). These rules are very simple

\[
K_2(t_1 - t_2) = \frac{\int q^2(\tau)k(\tau^2, \tau)dV}{(\int q dV)^2} \tag{2}
\]

\( q \) is the Joule dissipation density \( q \sim E^2 \). This means that regions where the field strength is higher have stronger effect on the noise intensity than the other ones. It is remarkable that the current correlator contains the weight functions \( q^2 \propto E^4 \).
In [3, 4] the approach developed in [1, 2] was generalized to elastic phenomena in heterogeneous solids. The statement of problem is to relate the fluctuations of elastic moduli to those of the strains. To characterize these fluctuations, we will use just one quantity, namely, fluctuation of the work of deformation $\delta A$:

$$\delta A = \frac{1}{2} \int p \delta u dS, \quad (3)$$

where $\delta u$ are the fluctuations of the the surface displacements caused by those of the elastic moduli.

Fluctuation of the deformation work $\delta A$ can be found as a variation with respect to the fluctuations of the elastic moduli $\delta A_{ijkl}$:

$$\delta A = -\delta \Pi = -\frac{1}{2} \int \delta A_{ijkl} \epsilon_{ij} \epsilon_{kl} dV, \quad (4)$$

where strain $\epsilon_{ij}$ (the subscripts are omitted below) is the unperturbed value.

We assume that fluctuations of the elastic moduli are $\delta$-correlated:

$$\langle \delta A_{ijkl}(t,r) \delta A_{mnop}(t_1,r_1) \rangle = K(t,t_1,r-r_1),$$

where $K$ is obviously a tensor of the eight rank. Then,

$$\langle \delta A(t) \delta A(t_1) \rangle = \frac{1}{4} \int K(t,t_1,r) \epsilon \epsilon \epsilon \epsilon dV, \quad (5)$$

where the tensors are contracted over all indices. Now, it is evident, that the correlator of the work fluctuations is determined by the fourth moments of the strain distribution.

If we take into account the piezoelectricity, the phenomenon of excess noise becomes more complicated and at the same time more colorful. Namely, besides of noises caused by fluctuations of conductivity (current noises), dielectric permeability (electrical noises), and elastic moduli (mechanical noises) we can observe also cross-correlated electromechanical fluctuations. The measurement of such correlations permits us to investigate mutual influence of local inhomogeneities of mechanical stress and electrical fields.

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References