# STRUCTURAL-INFORMATION PARAMETERS OF DISSIPATIVE STRUCTURES ON DILIS-M SYSTEM SURFACE

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In the present paper there are considered problems concerning analysis of stability of dissipative structures with viscous friction, i.e. dielectric liquid metal electrode (DILIS-M). Theory of kinetic energy changes through free surface of DILIS-M system for the case of liquid potential movement taking into account dissipative mechanism of viscosity is formulated. Stability regions for dynamic model of dissipative structures are constructed by numerical-analytical method of investigation.

## 1. Introduction

One of the most important problems in development of models of dissipative structures used for description of physical regularities of optic information record on photothermoplastic carriers (PTPC) is the problem of stability of these models. Processes of spontaneous ordering, appearance of temporal or functional structures take place in open nonlinear systems. Nonlinearity means irreversibility and multiplicity of evolution, possibility of unexpected changes of rate and direction of process proceeding, availability of bifurcation points, i.e. points of evolution way branching. There exists a number of approaches in study of model of nonequilibrium processes (I. Prigozhin's theory of dissipative structures). General models in the theory of dissipative structures lead to considering of separate subsystems. In this aspect DILIS-M system gives wide possibilities, since in them besides usual isotropic liquid of subsystem (model) of continuous medium (thermoplastics - TP) elastic properties and electric subsystem using semiconductor and liquid dielectric models are important.

## 2. Investigation methods

Closed systems with disturbed equilibrium tend to return to the equilibrium state. However open systems DILIS-M being in strongly nonequilibrium conditions in the corona discharge field may transit from disorder, heat chaos, to the order. Openness of the system means availability in it of sources for exchange of substance and energy with the surroundings. Far from equilibrium in open systems new types of structures may spontaneously appear. This class of nonequilibrium systems, nonlinear ones are called dissipative systems. In order to emphasize singularity of this view, one of the founders of self-organization system I. Prigozhin has called order appearing in open nonlinear systems being far from equilibrium, connected with scattering of energy, substance or information, dissipative structures (DS) [1,2].

Operative and reliable estimation of DS characteristics in the process of its exploitation is the most important task for analysis of technical state of the PTPC system. On the basis of modern information technologies this problem may be successfully solved by statistical treatment of results of measurements of free oscillations of DILIS-M dissipative system proposed by the author in [3]. At the convective movement of the liquid the leading parameter of

DS development is the temperature gradient (of Bernar's cell). However in the present experiment conditions *the governing parameter is viscosity gradient*. Experimental investigation of this problem is a necessary condition for successful solution of the problem.

### 2.1. Experimental confirmation of memory effect theory for DILIS-M

Solution of basic equations of viscous liquid hydrodynamics may be found only for extreme cases - for very small Reynolds numbers **Re** corresponding to high *viscosity* and for very large **Re** corresponding to flowing of liquids with low *viscosity*. This behaviour is unusual because usually viscosity suppresses movement and stabilizes it. Therefore in the given case we should give a theoretical explanation what is the source of *destabilizing influence of high viscosity* $\eta$, *if there is no instability without taking* $\eta$ *into account* (the Rayleigh theory) [4]. Paradox of stability of the DILIS-M surface is the following: how at constant electric potential of the electrode do the liquid surface deviations from the state of rest appear? How may $\eta$ provoke instability in open DILIS-M systems?

The reason of this behaviour is the memory effect appearing in viscous liquid. Let us consider the element of liquid of DILIS-M surface undergoing shift due to its equilibrium position. The memory effect on DILIS-M surface is shown in the form of pseudoturbulent movement of liquid or development of retarded deformation - protocrater [3]. This takes place due to breaking of fluctuation array existing before deformation of TP liquid layer and beginning of new structure formation in the direction of stretching of TP macromolecules [3]. This phenomenon is called *forced elasticity* because at photothermoplastic record (PTPR) highly elastic deformations appear under influence of high stresses. Due to viscosity, local flows caused by shift of the liquid surface gradually attenuate. However this does not occur in a moment, this means that the flows have time to influence future movement of the surface, deviations of the latter do not attenuate in the corona discharge field.

Experiment carried out in natural conditions confirms the phenomenon of retarding of viscosity influence on movement of the DILIS-M surface, and it is proposed in [5]. Thus, formation of fundamental deformation (type) of the dissipative structure of crater-like kind depends on time of development of prototype - protocrater determined by local shift of the DILIS-M system surface from the state of rest at a distance $\leq 25$ μm [5].

Development of the prototype (perturbations having viscous nature) of the dissipative structure is caused by local shift of the DILIS-M system surface. It smears the strict boundary between glassy state, instantaneous high-elasticity state *and forced elasticity*. Due to chaotic state of the process of energy transfer from the liquid surface movement in the process of development of the prototype (protocrater) to the less scale movement - the dissipative structure formation, let us consider below the mechanism of energy dissipation [5].

### 2.2. Estimation of energy dissipation scales in DILIS-M systems

In nonequilibrium DILIS-M systems new types of structures and transition from the chaotic deformation to the ordered one may spontaneously appear. Scale of the energy transformation mechanism (Fig.1) caused by the local shift of the DILIS-M system surface is divided into the following:

1. Long-wave interval of the liquid surface shift from the equilibrium state; it corresponds to large-scale pseudoturbulent movement of liquid $D \geq 10\text{-}12$ μm containing information on the flow prehistory (the memory effect). Non-Gauss distribution of the liquid surface shift.

2. Inertial interval; local character of the liquid surface shift from the equilibrium state ≤6-10 μm. The prototype of DS (perturbations having viscous nature) or *forced elasticity deformation* develop.
3. Dissipation interval; short-wave range of the kinetic energy dissipation. Corresponding shifts of the liquid surface from the equilibrium state have complex statistical structure, the movement coordinate is $d\approx$1-2 μm.

The dissipation interval contains *a small part of full energy* of the liquid surface movement. So the problem of the viscosity dissipative mechanism will be simplified by the proof that the velocity $\partial E/\partial t$ of decreasing (dissipation) of the kinetic energy $E_t$ is proportional to viscosity η:

$$E_t = \frac{\rho}{2}\int_V \tilde{u}^2 dV \tag{1}$$

Velocity of movement of incompressible liquid $\tilde{u}$ at infinity is equal to zero and its $E_t$ is finite. For calculation of $\partial E/\partial t$ let us differentiate $\partial u/\partial t$ by time, let us use under integral the Navier-Stokes equation:

$$\frac{\partial \tilde{u}_i}{\partial t} = -\tilde{u}_k \frac{\partial}{\partial x_k}\tilde{u}_i - \frac{1}{\rho}\frac{\partial}{\partial x_i}\tilde{p} + \frac{\eta}{\rho}\frac{\partial^2}{\partial x_k \partial x_k}\tilde{u}_{ik} \tag{2}$$

and condition of incompressibility $\partial \tilde{u}_i / \partial x_i = 0$ at infinity, symmetry of tensor of viscous stresses

$$\sigma_{ij} = \frac{\eta}{\rho}\left(\frac{\partial \tilde{u}_i}{\partial x_j} + \frac{\partial \tilde{u}_j}{\partial x_i}\right) \text{ and } \frac{\partial p}{\partial x_i} = -\frac{\partial p}{\partial x_k} + \frac{\eta}{\rho}\frac{\partial \tilde{u}_i \sigma_{ik}}{\partial x^2}. \tag{3}$$

The kinetic energy dissipation has the form:

$$\frac{\partial E_t}{\partial t} = -\frac{1}{2}\int_V \sigma_{ik}\frac{\partial \tilde{u}_i}{\partial x_k} dV. \tag{4}$$

Let us further distinguish the divergent member from (2). Let us note for this that $\tilde{u} = {dz}/{dt} = D\omega$, where $\omega = grad\tilde{u}$ is the deformation development increment. Then the turbulent movement of the liquid layer of thickness $h$ is described by the ratio $grad\omega = {\omega}/{h}$ and

$$\frac{\partial \tilde{u}}{\partial x} = grad\tilde{u} = Dgrad\omega = \frac{D}{h}\omega.$$

In the present experiment conditions the coordinate $D$ of the long-wave scale of the liquid turbulent movement is $D>>h$. But at infinity the liquid movement velocity decreases down to $\tilde{u} = 0$. Then the liquid flow is potential, because it is limited by the area ***S*** of the contact surface of the DILIS-M. For the potential flow we use the identity:

$$\frac{\partial \tilde{u}_i}{\partial x_k} = \frac{\partial \tilde{u}_k}{\partial x_i}.$$

The energy dissipation velocity $\frac{\partial}{\partial t}E_t = -\eta\frac{D}{h}\omega\oint\frac{\partial \tilde{u}_i}{\partial x_k}dS = -\eta\oint_S \nabla^2 \tilde{u} dS$ (5)

determines not just the viscosity dissipation mechanism, but the fact that at dissipation the viscosity coefficient becomes negative -η. Availability of the negative coefficient in liquid movement equation (2) means deviation of the DILIS-M system surface from the state of rest. i.e. instability development.

## 3. Discussion of results

Dissipation equation (5) does not depend on the liquid volume, and the integral will be always positive. The result indicates at single conclusion: the more viscosity the higher velocity of dissipation of the total kinetic energy. From equation (5) let us find the dissipation character by substitution of $\frac{\partial \tilde{u}}{\partial x} = \frac{D}{h}\omega$:

$$\frac{\partial}{\partial t}E_t = -\eta\left(\frac{D}{h}\right)^2 \omega^2 S\,. \tag{6}$$

The second conclusion following from equations (5), (6) is that high viscosity does not stabilize the contact surface stability position under action of constant force in the DILIS-M dissipative system, on the contrary it disturbs equilibrium. As it is seen from equation (6) the energy dissipation in the DILIS-M system depends also on the ratio of coordinates of the liquid flow scale *D/d*.

Since the ratio $D/h \approx \mathrm{Re}^n$ is a dimensionless value, where $0<n\leq 1$, the liquid flowability ($1/\eta$) will be similar to the ratio of the coordinate $D_{max}$ of the long-wave range of the liquid surface shift to the coordinate of the dissipation interval (the short-wave range) $d\sim h$. For example, $\left(D/d\right)^{1/n} \approx \mathrm{Re}$, for $D=h\sim d$ number $\mathrm{Re}\approx 1$.

The third conclusion following from equation (6) is necessity of development of the resonance wave vector or spatial frequency $1/d\approx k_\eta$. Below we will prove that development of the wave vector $k_\eta$ on the liquid surface is condition of the energy dissipation mechanism. Since the liquid viscosity is expressed as:

$$\eta \cong \alpha\frac{\pi}{D}\cdot\frac{1}{\omega}, \tag{7}$$

equation (6) is reduced to the form:

$$k_{\max}\frac{\partial}{\partial t}W_t \approx -\alpha\omega\left(k_\eta\right)^2 \tag{8}$$

Here the following denominations were used: $W$ is the energy density; $\alpha$ is the coefficient of surface tension; $k_{max}\approx 1/D$ is the long-wave vector of the dissipative structure prototype; $k_\eta^2 = \pi/hd$ is the short-wave dissipation vector, when the developed dimensions of the fundamental deformation have cylindrical form $d\sim h$.

The physical sense of equation (8) is the following: member $k_{max}$ ($\partial W/\partial t$) characterizes the energy of the DS prototype with the wave vector $k_{max}$, which begins dissipation. The member $-\alpha\omega\left(k_\eta\right)^2$ corresponds to the velocity $\partial W/\partial t$ of the kinetic energy dissipation on the coordinate $k_\eta$, where viscous forces act. From (6) and (8) the following dependence is obvious:

$$\omega^2 \approx k_{\max}\frac{\partial}{\partial t}W_t\ . \tag{9}$$

The obtained results are attractive for experimental investigation of the DILIS-M dissipative systems. For the first time the ratio between the coordinates of temporal scale $\omega$ of the DS prototype development and coordinates of the flowability scale $D/d \approx \mathrm{Re}^n$ is found and $\mathrm{Re} \cong \Delta t\omega$.

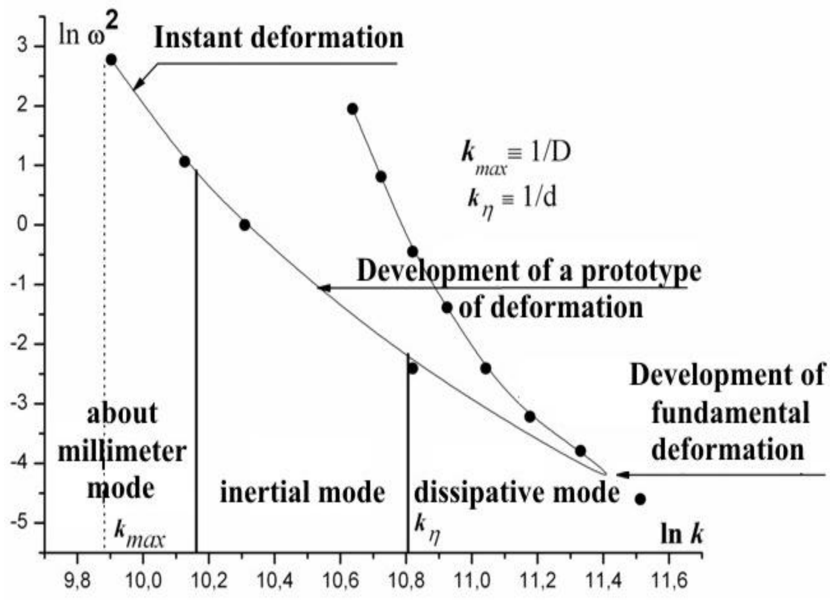


Fig.1. Curves of the liquid flowability.

Equation (6) is important because it is possible to determine scale of the coordinates $k_{max}$ and $k_\eta$, or critical values of number $\boldsymbol{Re}_{cr}$ whereat the dissipation mechanism starts working, and negative value of viscosity -η. Thus, viscosity forces destabilize the liquid surface due to the law of retarding of inertia force action in strongly viscous media. Influence of the viscosity dissipative mechanism on DS formation is shown in Fig.1.

It follows from Fig.1 that precisely for coordinates of flow $d \ll h$ nanometric shifts of molecules are amortized (Re→∞). In this case the ideal liquid model is applied to the viscous liquid flow. Fig.2 shows localization of fundamental deformation for the case of the liquid flowability (Fig.1). Curve 1 in Fig.2 corresponds to the deviation of the liquid surface from the state of rest - instantaneous deformation caused by molecule shift in intermolecular space. Curve 2 corresponds to the development of *forced elasticity* under action of the inertia forces or to the development of DS prototype. For the DILIS-M system of the DS prototype this is *development of a protocrater* [5, 6]. Curve 3 corresponds to the *development of the DS type* or *fundamental deformation*.

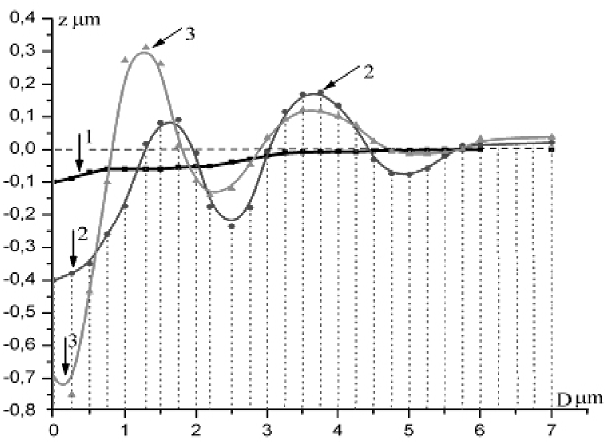


Fig.2.

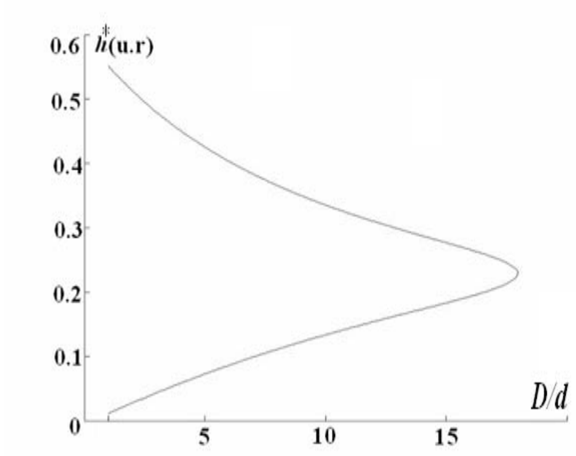


Fig.3.

Fig.2. Crater prototype at real development of the attractor on the DILIS-M surface.
Fig.3. Dependence of the chromaticity parameter on character of the liquid flowability.

Investigation of the curve of dependence of chromaticity parameter $h^*$ on flowability scale ($D/d$) has revealed the bifurcation point in Fig.3 - transition from the forced deformation to the **DS** formation. The parameter $h^*$ =1(ur) corresponds to the thickness $h$ =2 μm [7-10].

### 3.1. Concerning paradox of stationary states of DILIS-M dissipative system

Let us compare the equation for the viscosity coefficient η deduced from the theory of the kinetic energy change for the case of potential movement of liquid (6):

$$\eta^* = -\left(\frac{h}{D}\right)^2 \frac{1}{\omega^2}\frac{\partial}{\partial t}W_t \quad (10)$$

with the equation for the viscosity coefficient η deduced from the Navier-Stokes equation (2).

Since the term $\omega^2 \geq 0$ and $0 < \left(h/D\right)^2 \leq 1$, the liquid viscosity during the dissipative structure development has the value $\eta \leq 0$. At high values of the interval of the electric potential action $\Delta t$ (small scale $h \approx D$) and high interval of time of deformation development ($\omega \approx 0$), the energy dissipation will correspond to the total viscosity with the value:

$$\eta_{tot} = \eta + \eta^* \leq 0 \quad (11)$$

Here η is the Newton viscosity, $\eta^*$ is the structural viscosity of liquid.

The numerical calculation confirms the dependence of the value of chromaticity parameter $h^*$ (pseudospatial) on the liquid flowability scale ($h/D$) shown in Fig.3 and experimentally studied in [5]. The liquid flowability curve in the value range $(h/D) \approx 10 \div 20$ suffers the phase jump in the deformation development, or as it is customary to say - the bifurcation point appears.

The parameter $h^*$ expresses the liquid surface shift from the equilibrium position [5-12]. In the present experiment conditions the liquid surface shift from the equilibrium position for $h^*_{max}$=1(u.r) corresponded to the thickness of the liquid layer $h_{max}$=2 μm.

## Conclusions

1. Development of dissipative structures is a process localized in medium, having relatively stable space-time organization. Dissipative structures (DS) in the systems being far from equilibrium of the DILIS-M type are highly ordered self-organizing formations having certain form and characteristic space-time dimensions; they are stable relative to small perturbations. The most important characteristics of dissipative structures are the following: lifetime, localization region and attractor fractal dimensionality.

2. DS differ from equilibrium structures because they require for their existence a constant energy influx from without. The deformation self-organization is connected with the exchange of energy and substance with the surroundings. Let us note general conditions resulting in DS formation:

a) DS are formed in open systems DILIS-M. Only in them the energy influx compensating losses caused by dissipation and ensuring existence of more ordered states is possible.

b) DS appear in macroscopic systems, i.e. in systems consisting of large number of elements (atoms, molecules, macromolecules). This makes possible collective interactions necessary for the system reconstruction.

3. There were carried out numerical-analytical investigations of the dependence of change of the model main parameters and regime of treatment of experimental data in the diapasons: $D/d \in (0.7; 20)$ and $\omega = (0,01;\ \pi)$.

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