Modern Status of the Parametric Excitation of Oscillations in Film Flows and Granulation for Amorphous Materials' Production

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Abstract: - The general and specific peculiarities of parametrically excited oscillations in the film flows and the new parametric effects revealed are discussed for engineering and technological applications. The main focus is placed on the film flows spreading on a solid surface or in another liquid medium with comparably high velocities when inertia forces are playing together with capillary ones and up to some extent sometimes with gravity forces. Scientific novelty of the work consists in the revealed three new phenomena of the film flow decay and created new granulation technologies for the unique amorphous materials' production.

Key-Words: - Parametric, Wave, Excitation, Suppression, Instability, Control, Film Flow, Amorphous

1 Vitality of parametric oscillations

The periodic or quasi-periodic influences are widespread in technological installations and processes: fluctuations of a field (electric, magnetic, temperature, vibration.) or such conditions under which the acyclic changes of certain parameters in a system cause oscillations of other parameters causing, in turn, parametric oscillations of system. Vitality of problem is due to intensive development of the new technologies, creation of the devices of high efficiency and profitability based on the use of parametrically controlled oscillations, as well as based on stability of a system impossible in absence of effective suppression of the oscillations.

The methods based on use of the strong (resonant) effects allowing developing the new energy- and resource-saving technologies are especially perspective. Many parametric instability phenomena in the flows complicated by phase transformations and chemical reactions are well known in magneto-hydrodynamics (MHD) and physics of plasma [1-9], thermo-hydrodynamics of the granular and underground natural systems [10-14], Biology [15-17] and others [18-21].

1.1 Statement of the research problem

Possibly the first sharp efficient intensification of technological processes due to parametric oscillations in continua was revealed more than century ago by Chernov (1879) noted positive influence of mechanical oscillations on a quality of crystallizing ingot [22]. But recommendations for a choice of parameters for external influences were often contradictory or absolutely absent. By control of crystallizing metal's structure the recommended range of fluctuations covers area of 1-250 Hz and it is known that the low-frequency mechanical, electromagnetic, thermal oscillations or their combinations most often crush the structure of metal making it smaller 2-10 times [10,23]. But the pulsing thermal field can lead to strengthening of orientation of the big size crystals.

Modulation of the parameters in continua with time influences stability of the physic-mechanical and chemical processes and can lead to stabilization of the certain instabilities [6-8,18,24,25] or, on the contrary, to excitement of instability [2,3,27-39]. Thus, the processes of excitation and suppression of oscillations in continua are closely interconnected, especially under strong non-linearity of processes and in a presence of complicating factors (heterogeneity of media, relaxation, etc.).

Intensive development of technology for generation of parametric oscillations in continua is caused by successful application in many areas: control of structure in MHD-flows [4,40,41], intensification of chemical and technological processes [42-44], localization of heating [45-49]. Considerable spreading was gained by vibration and acoustic methods in intensification of technological processes [27,50-55], which are also not completely studied in detail yet [44,57-59].

1.2 The classes of parametric oscillations

On a nature of impact on continua (technological processes), parametric oscillations may be classified as following: optimizing, intensifying, transforming and stabilizing. The first ones allow just improving the process or its some parts (acoustic granulation and centrifugation, etc.). The second class increase a speed of process or its parts (the MHD-granulation [20,59], acoustic dissolution). The third class oscillations lead to receiving essentially new regimes or processes impossible in absence of parametric action. Finally the fourth class gives a chance to carry out stable regime of process in continua (decrease in hydraulic resistance to moving bodies in a liquid by stabilization of the laminar mode of flow [60-62], ensuring running the chemical reactions with unstable parts, etc.).

The effects made by parametric oscillations in continua may be the first order (small-amplitude oscillations determined by frequency, intensity and speed of spreading in a medium) and the second order (powerful perturbations of medium causing the non-linear phenomena, violation of continuity, etc.). There are many papers on some parametrically excited (suppressed) oscillations in continua but the research of a problem of parametric excitation and suppression of oscillations on the interfaces of continua is still in an initial state due to a lot of diverse substantially different cases available. Therefore the subject of researches mainly consists in the specified problem being considered on the example of specific classes of the tasks, e.g. film flows under prevailing contribution of the inertia forces with different types of parametric actions as in our works: electromagnetic fields and vibrations. Parametric oscillations are considered mainly of the third (transforming) and the fourth (stabilizing) types (sometimes - the second type).

The parametric resonant oscillations can form a basis for creation the essentially new highly effective power- and resource-saving technologies, e.g. receiving powders and granules by means of the film MHD- and vibration type granulation machines [59,63,64]. The parametric oscillations having effect of both the first order, as well as the second order on the interfaces of continua are considered.

External action can be transferred to each point of the continua (volumetric control) or to its boundary (boundary control). And the most effective impact on the processes in continua is hardly realized: so, the alternating electromagnetic field penetrates into conductive medium just on a distance of the skin-layer thickness, the acoustic wave also fades in a medium, and so on.

Comparably easily realized is boundary control in continua, the theory of which was developed by Butkovsky with colleagues [10,66], Sirazetdinov [67,68], Ladikov [7,8], and other researchers. For electromagnetic control of the processes in continua Samoylenko proposed the linear layered and fibrous artificial media possessing high resolution (reaction of the medium to external action can be as much as close to the delta function) [69]. The theory of such systems was developed in [6,70]. This paper is mainly devoted to the problems of the second the third classes: disintegration of the film flows by parametric oscillations and stabilization of the boundaries of phase transition of thin films, with the first and the second types of influences. While in problems of parametric suppression of oscillations on the boundaries of phase transition the crucial importance belongs to an energy exchange, in contrast to that at the electromagnetic or vibration initiation of a surface's oscillations in film flows the main role is played by an impulse exchange.

In the modern continuum mechanics differing in merge to many areas of physics, penetration into various technical and biological systems with broad application of mathematical modeling and computers, the problems of the programmed open-loop control in touch with improvement of structure of ingots [23,24], vibration mixing and intensification of heat transfer, stabilization of technological processes [7,8,71], parametric wave excitation on liquid surfaces [35,72,73], stabilization of a flow in a boundary layer using suction and blow-in [43,62], and many others [21,74-79] have been considered. Many new tasks were solved during the recent decades [66,80-90].

In general the problem of parametric excitation and suppression of oscillations in continua can be formulated as follows. After schematization of the physical phenomenon, allocation of its most essential and minor parameters and creation of physical and mathematical models with the subsequent choice optimum from them (in a certain sense) it is necessary to investigate regularities of system perturbations' development in space-time.

It leads to establishment of the correlations of a type $F_n(A_j, \omega_j, \vec{k}_j; \vec{A}_j^*, \omega_*, \vec{k}_*) = 0$, where $A_j, \omega_j, \vec{k}_j$ are the amplitude, frequency and a wave vector of *j*-th perturbation, respectively, $\vec{A}_j^*$ is a vector of the perturbed parameters of the system (process) of dimension *J*. Asterisks noted parameters belong to Eigen fluctuations of a system, F_n are the sought relations of parameters (e.g. differential), $n=\overline{1,N}$, $N \geq J$ (by $N<J$ there is an uncertainty of a task).

The behavior of continua is defined by parameters of Eigen fluctuations and external influences. Therefore the problem of excitation (suppression) of parametric oscillations can be reduced to determination of physically realized parameters $A_j, \omega_j, \vec{k}_j$ providing the necessary mode, or the set type of a vector function $\vec{A}_j^*(x,y,z,t)$.

1.3 The novelty of parametric oscillations

Complex non-linear models are realized by means of numerical methods on the computer. *Validity and reliability* of the results obtained follow from validity and reliability of the initial theoretical base on parametric oscillations in continua and the models of continua applied, from strict substantiated statements of the tasks solved and the methods for their solution, experimental proof of the results and their comparison to the known limit cases. *Practical value* of the work consists in the developed physical and mathematical models of parametric excitation and suppression of oscillations on the interfaces of continua. The *new technological processes* based on the **discovered three new phenomena** of film flow decay are provided here and some patents on the invented methods and devices for materials' granulation together with the results of their implementation into industry are described.

Mathematical and physical modeling was applied to expand the areas of the studied phenomena and their comparative analysis in crossing areas, receiving data on adequacy of the constructed mathematical models and reliability of the technique applied. The results include [32-35,91-100]:

1. Theory of parametric excitation and suppression of oscillations on the film flow surfaces under action of electromagnetic fields and vibrations.
2. Theoretically revealed and experimentally proved the new phenomena of soliton-like and shock-wave decay of the film flows into drops.
3. Experimental studies and natural experiments with the processes (and facilities on their base) on parametric control for film flow waves and the new created devices and processes.

2 Scientific and engineering problems

Nowadays numerous ways of parametric excitation and suppression of oscillations in continua, in particular, in the liquids are known. For example, physics of the superficial phenomena and thin films [19,28,71,75,76].

The new directions in modern natural sciences appeared in touch with research of the non-linear processes by different physic-mechanical and chemical nature [21,36-38,53,72,83]: thermo-hydrodynamic and magneto-hydrodynamic instability, self-oscillations, etc. In recent decades it was established that an ideal way of energy transfer in non-linear systems is a soliton, which mathematical descripttion for shallow water was given by Korteveg-De-Vriz.

Steady solitary waves are formed as a result of mutual compensation of the non-linearity and dispersion and combine wonderfully properties of a particle and a wave [15,17]. Three new phenomena on parametric wave excitation have been revealed and studied by us both theoretically and experimentally [32-35,59,91-95], and then implemented into industrial practice of the new materials creation based on the high speed cooling of the small drops, which produce unique properties of the metals obtained of it [63,64,96-100].

2.1 Development of the models of continua

A number of the new interesting phenomena were found by studying thermal waves [66]. Here the non-linearity caused by dependence of physical properties of the medium on coordinates and time, in particular, heat conductivity coefficient dependent on temperature, which comes to zero at the front a thermal wave. The revealed mechanism of volumetric heat absorption [45] was used as one of possible explanations for thermal self-isolation of a fireball. The general equations of dynamics of continua by any structure may be represented as

$$\partial\rho/\partial t = -div\left(\rho\vec{v}\right), \qquad (1)$$

$$\rho\left(\partial\vec{v}/\partial t + \vec{v}\nabla\vec{v}\right) = divP + \rho\vec{F} - \sum_{j=1}^{N}\vec{v}\nabla\left(\rho_j\vec{v}_j\right), \qquad (2)$$

$$\rho\left(\partial e/\partial t + \vec{v}\nabla e\right) = div\left(\vec{q} + P\vec{v}\right) + \rho\vec{F}\vec{v} + \qquad (3)$$
$$+\sum_{j=1}^{N}\left[\rho_j\vec{F}_j\vec{v} - div\left(\rho_j e_j\vec{v}\right)\right],$$

where ρ - density of heterogeneous medium, $\vec{v}$ - velocity vector for heterogeneous medium, *t*- time, *P*- stress tensor, $\vec{F}$ - volumetric force, $\rho_j, \vec{v}_j$ - parameters of the medium's components (similar for the other parameters), *e*- specific density of energy, q - specific volumetric energy influx.

The (1)-(3) are, respectively, mass, impulse and energy conservation equations. For reversible processes the uncompensated warmth is equal to zero. Except internal energy and entropy the other functions of state and some additional thermodynamic relations are used. Here later on from the mass forces only gravitational and electromagnetic ones are mainly considered. And inflow of the external energy (the so called Joule heat) or vibration energy of action transmitted through the boundary interface is accounted. Therefore differential equation array must also include the field equations:

$$div\vec{B} = 0,\ \partial\vec{B}/\partial t = -rot\vec{E},\ \vec{j} = \partial\vec{D}/\partial t + rot\vec{H}; \qquad (4)$$

$$\rho d\vec{v}/dt = divP + \rho\vec{g} + \rho_e\vec{E} + \vec{j}\times\vec{B},\quad \rho_e = div\vec{D}; \qquad (5)$$

$$\rho de/dt = \vec{E}'\cdot\vec{j}' + \rho\vec{g}\vec{v} + \Phi + div\left(\vec{q}^{\,вш} - \vec{q}^{\,вн}\right) - pdiv\vec{v}, \qquad (6)$$

where $\vec{E}'\cdot\vec{j}'$ is the Joule heat, Φ is the dissipation function, $\vec{E}' = \vec{E} + \vec{v}\times\vec{B}$, $\vec{j}' = \vec{j} - \rho_e\vec{v}$ - vectors of electric field and current density in a coordinate system connected to the considered volume of the moving continua. The Ohm law for density of the electric current is:

$$\vec{j} = \rho_e\vec{v} + \gamma_e\left(\vec{E} + \vec{v}\times\vec{B}\right). \qquad (7)$$

The system (1)-(3) can be transformed to a divergent form that is very important for numerical simulation. For its closing, except the above-stated, there are used also some other defining correlations, as well as the empirical dependences of physical characteristics of media from the parameters of state (pressure, temperature), etc. For instance, for linear materials without polarization the constitutive relations are connecting the vectors of magnetic and electric induction with intensity vectors of electric and magnetic fields through the equations:

$$\vec{B} = \mu_m\vec{H},\quad \vec{D} = \mu_e\vec{E}. \qquad (8)$$

It is assumed that all continua considered here (homogeneous as well as heterogeneous) are two-parametric, so that their thermodynamic functions *e,p,s* are determined by two parameters of state. This allow using the Gibbs correlation and entropy for incompressible fluid:

$$de = Tds - pdV, \qquad (9)$$

$$s = c_V \ln\frac{p}{\rho^{c_{p/V}}} + const, \qquad (10)$$

therefore $de = c_V dT + const$, and for ideal gas with account of the Clausius-Clapeyron relation yields:

$$p = \rho RT,\quad c_p dT = c_V dT + d(p/\rho), \qquad (11)$$

Here c_p is, in general, function of temperature.

The non-stationary equations of non-isothermal movement of the viscous liquid (1)-(3), (4)-(6) in the Cartesian and cylindrical coordinate systems were used in modeling. And in each considered case the ratios (7)-(11) concretizing a model of the continua were used.

2.2 The boundary-value problems

Statement of the boundary-value problems for parametric oscillations in continua requires specifying the type of parametrical influence: external electromagnetic field, vibration or thermal action, etc. Vibration can be characterized by a vector of vibration acceleration and the process can be considered in a moving coordinate system connected to the vibrating surface, considering an action of vibrations as oscillating body force.

In a linear theory the progressive waves

$$\tilde{q}_j = Q_j(y,z,\omega)\exp i(kx - \omega t), \qquad (12)$$

are spreading along the axis *x* with velocity ω/k. Here Q_j is complex amplitude. Separation of the real part may be done in a final result. Derivation and substantiation of the boundary conditions is definitely an important task to which it is given more and more attention in connection with the problems of obtaining the missing conditions, and also appearing the singularities and influence of lack of boundary conditions on a nature of modeled processes [87].

The conditions replacing classical conditions of sticking on a moving contact surface are unknown; therefore it is impossible creating rather general adequate theory of parametric oscillations on the interfacial boundaries of continua. Features of thermo-hydrodynamic processes on the interfacial boundaries are defined by interaction of media in thin layer having a thickness by order of radius of molecular interaction (the nano-sizes): $a' \sim 10^{-9}$ m.

At a statement of macroscopic boundary conditions usually the phenomenological approach is used. For example, considering the volume *V* limited by the surfaces S_1 and S_2 parallel to a boundary interface S_{12} of the media it is possible to choose the coordinate system in which S_{12} is immovable. Then from the differential equation array (5), (6) the conditions on the boundary interface are:

$$\rho_1\vec{v}_1\cdot\vec{n}\vec{v}_1 = \left(p_1 - p_2\right)\vec{n} + \left(\rho_1 - \rho_2\right)\vec{g} + \left(\rho_{e1}\vec{E}_1 - \rho_{e2}\vec{E}_2\right)\cdot\vec{n} +$$
$$+\rho_2\vec{v}_2\vec{n}\cdot\vec{v}_2 + \left(\vec{j}_1\times\vec{B}_1 - \vec{j}_2\times\vec{B}_2\right)\cdot\vec{n} + p_s^{ex},\quad \rho_j\vec{v}_j\vec{n} = idem,$$
$$\vec{n}\times(\vec{E}_1 - \vec{E}_2) = 0,\quad \vec{n}\times\left(\vec{H}_1 - \vec{H}_2\right) = \vec{j}_s\times\vec{n},$$
$$\vec{n}\cdot(\vec{B}_1 - \vec{B}_2) = 0,\quad \left(\vec{D}_1 - \vec{D}_2\right)\cdot\vec{n} = \rho_{es}, \qquad (13)$$
$$\rho_1\vec{v}_1\cdot\vec{n}\left(e_1 + \frac{1}{2}\left|\vec{v}_1\right|^2\right) + \left(p_2\vec{v}_2 - p_1\vec{v}_1\right)\cdot\vec{n} + \left(\vec{q}_1^{\,ex} - \vec{q}_2^{\,ex}\right)\cdot\vec{n} = q_s^{ex} +$$
$$+\rho_2\vec{v}_2\cdot\vec{n}\left(e_2 + \frac{1}{2}\left|\vec{v}_2\right|^2\right) + \left(\vec{E}_2\times\vec{H}_2 - \vec{E}_1\times\vec{H}_1\right)\cdot\vec{n} + \left(\vec{q}_2^{\,in} - \vec{q}_1^{\,in}\right)\cdot\vec{n}.$$

Here p_s^{ex}, q_s^{ex} - the surface densities of the external forces and energy fluxes' distributions, $\vec{j}_s, \rho_{es}$ are the surface current and charges' density.

Conditions (13) represent the mass, impulse, energy conservation on the boundary separating continua and are the main by consideration of parametric oscillations on the boundaries.

3 Parametric oscillations on interfaces of the electro-conductive liquids

3.1 Features of the boundary interfaces

Behaviors of the boundary interfaces are defined by properties of media, conditions of their interaction and the nature of external influences (for example, electromagnetic - in case of the conductive media).

Because in complex heterogeneous media it is impossible to follow an evolution of each separate boundary of the phase separation, the various averaged equations and models obtained at the accounting of the media interaction on separate boundaries are used [11]. Due to the fact that the behavior of system is defined by parameters of external influences and Eigen oscillations, the task of parametric (e.g. electromagnetic) excitation (suppression) of oscillations on the interfacial boundaries is formulated as a problem of achieving the physically realized electromagnetic fields creating the requested effect: stabilization of phase transition (crystallization) against perturbations [7,8,18], excitation of oscillations of the film surface in a requested form [32-35,73,93-96] and their disintegration into the drops (spraying, dispersing) [20,27,32,59,91,94,96-100].

3.2 Boundary interfaces' parametric control

One of the first works on electromagnetic impact on a liquid metal jet with a purpose of its stabilization showed [7] that with a frequency of field satisfying the condition that a thickness of skin-layer is small comparing to capillary radius, the oscillations of a jet surface fade (steady jet).

Study of this problem was continued by many scientists. It was stimulated by need of stabilization the Rayleigh-Taylor, Kelvin-Helmholtz and Tonks-Frenkel instability. The special kind instability of thin viscous jets and films, appearing the teethes on an interface (so-called "rugosity") was investigated on the one-dimensional and two-dimensional mathematical models, which analysis led to obtaining the conditions of appearing this type of instability connected to hyperbolic properties of the equations. Stabilization of the free and surrounded liquid metal jets and films have been considered in touch with the thermonuclear technology, excitation of parametric instability, disintegration of the jet and film flows - in connection with a task of a granulation of metals [20,32,59,91,96-100].

4 Oscillations in non-conductive media

Parametric excitation and suppression of oscillations on the interfaces of non-conductive media is possible due to action in the volumes occupied by media the distributed power sources or an exchange of mass, impulse and energy on the boundaries. It allows influencing effectively the kinematic and thermodynamic properties of media: stabilize interfaces of media in case of their instability against casual or regular perturbations [18,25,53,72], excite oscillations of the required mode [33,35,73], destroy the interfacial boundaries by excitation of the oscillations growing by amplitude [12,20,21,27,32,59].

4.1 Parametric oscillations of the interfaces

Initiation of parametric fluctuations in continua requires exceeding some barrier of parameters determined by energy brought to system from the outside spent not only for a rating of fluctuations, but also for dissipation. As in the nature there are no absolutely elastic media, this lower barrier of parameters is defined by the dissipation energy.

Parametric excitation of oscillations on the boundary interfaces of continua [50,93] of infinite sequence of areas of unstable fluctuations gives the maximum width for the area of frequencies $\omega/2$ equal to a half of frequency of the compelling force (the main harmonica ω). From a set of various ways of excitation and suppression of the oscillations on boundaries of non-conductive media the acoustic ones [37,51,58], vibration and vibro-thermal [27,50], mechanical and gas-dynamic [31], are most often used, with application of the surface-active substances (SAS) [37], thermo-capillary effect [38].

4.2 Transfer of wave energy between modes

In many works it was noted that parametric excitation (suppression) of some modes can lead to excitation (suppression) of the others. Parametric stabilization of some part of harmonics by the applied external influences can lead to excitation of instability by other kind or in other part of a range of frequencies [38,69].

In a majority of works the three main types of instability and possibility of their suppression by parametric action or their strengthening for the purpose of destruction of media are investigated: dispersing, spraying. One of the most developed areas - the theory of stability and disintegration of liquid jets and films - has numerous applications in various industrial, technical and other devices [20,59,76,94]. Research of progressive the external perturbations of a jet's surface has shown that process is almost always generally defined by the first spectral mode. Complex wavy process is, as a rule, possible only by using special polyharmonic activators [63].

Resonant modes' interaction can lead to energy transfer from one mode to another. The phenomenon of generation the second harmonics called by Wilton's effect is known, for example, when as a result of interaction of the gravitational and capillary waves with parameters $k_2 = k_1, \omega_2 = \omega_1$ at the flow velocities close to the threshold value, yields the strengthening of waves by half length (transfer of wave energy).

The other surprising object of researches by parametric oscillations - film flows - differs in a hydrodynamic originality and broad practical application. It is a problem by stability and disintegration (dispersing, spraying) of the boundary interfaces and free surfaces, etc.

Attempts were made to explain the general mechanism of the non-linear saturation of instability in thin films on example of the Rayleigh-Taylor instability. It was established that in the certain range of parameters' variation the perturbation breaks off a standing film and doesn't break the moving one. The works [20,38,76,90] have been devoted to research by influence of external perturbations of unstable liquid films on dispersive structure of the drops, which are formed as a result of their disintegration. The experimental study of the compelled high-frequency impact on stability of thin liquid films showed its weak influence on increase rate of perturbations on the film surface, however influence on dispersive distribution of drops is considerable: reduction of the drops' sizes on average is 15-20%, and up to 40%.

Influence of dynamic effect of air, disintegration of films in a direct-flow gas stream, fluctuations of a film surfaces, a shaping of the breaking-up boundary separating it from the surrounding medium, dispersing characteristics of a round film have been investigated in [72,76,90] and in other works. Vibration initiation of parametric oscillations on a surface of radially spreading films was studied by Entov V.M. Two types of bending perturbations of a film surface were theoretically considered: the running concentric waves created by the vibrating disk, which on a round jet is spreading from the nozzle located over disk plane, and standing waves are formed from edges and defects on a disk.

4.3 Industrial applications

It is the relatively new science promising great opportunities in creation of the new resource and energy saving highly effective technologies and economic high-productive devices [91,96-100], which are extremely needed for a modern industry and economy.

Usually the low-intensive perturbations rather lead to some decrease in indicators (not resonant case) while at high intensity of external influences the technological process is mainly defined by a nature of the influences and practically doesn't depend on character of unperturbed state of system. The resonant effects allowing significantly increase an intensity of process or even to receive essentially new phenomenon at low power expenses are especially important for practical use [20,91,94].

Physical and mathematical models of processes for cases of vibration and thermal influences were constructed, the computer programs were created by us, computational and physical experiments for detection of regularities by earlier unexplored physical systems were made [91]: excitation of wavy processes of the stated kind and disintegration of the film flows of viscous liquids into drops (dispersing, granulation), increase of intensity by thermo-hydrodynamic processes in the presence of parameters' oscillations on interfacial boundaries in heterogeneous continua and others.

The new technological decisions, some concrete designs were provided and the information on their efficiency and practical tests has been supplied. Along with improvement of indicators by known technologies and devices, the essentially new technologies have been developed and the devices based on the beautiful, original hydrodynamic phenomena were constructed [97-100] too. For example: dispersing of the liquid films on the vibrating disk at the Euler's numbers significantly exceeding unit [63,64], use of the phenomena of electromagnetic resonant film flow decay, the soliton-like modes of the film decay, etc. Some of them are shown in Fig. 1-3 and granules – in Fig. 4.

The problem of parametric excitation and suppression of oscillations was solved by us for the development of new materials on the basis of granule technology, for which we created methods and devices by receiving particles of metals of a given size; with a high solidification rate (cooling rate of drops was reached 10^4 K/s!).

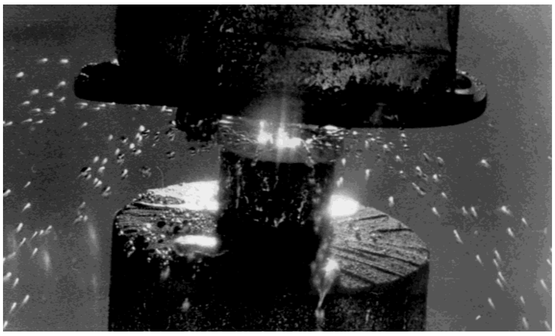

Fig. 1 Electromagnetic resonant film flow decay

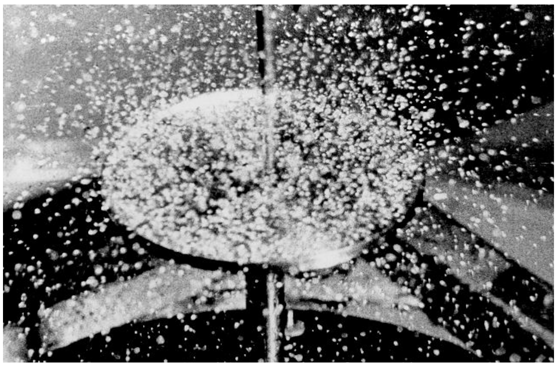

Fig. 2 Vibration soliton-like film flow decay

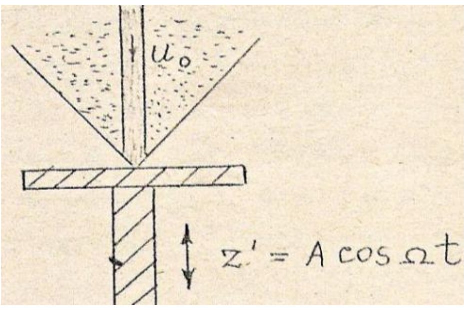

Fig. 3 Shock-wave controlled film flow decay

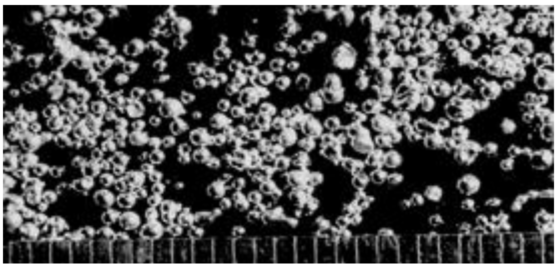

Fig. 4 Granules produced on film granulator

These are so-called amorphous metals. The idea of their creation went from an assessment of iron durability, which Academician Frenkel gave at the beginning of the last century. He estimated that theoretical iron durability differs from the real one up to 1000 times.

5 Conclusions by the results obtained

- Parametric excitation of the jet and film flows' disintegration allowed inventing and successful constructing the new highly effective granulation and other machines implemented into practice of modern material science.
- Discovered by us three new phenomena on film flow decay may be of interest for spreading technologies and other applications.
- Both analytical, as well as numerical methods were developed for solving the non-linear boundary problems, which present the new direction of control processes in continua.
- Developed experimental facilities allowed testing the revealed new phenomena and created perspective technologies and devices for granulation of liquid metals.

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