# Technologies and Devices for Granulation Method of Amorphous Materials' Production Based on Parametric Film Flow Decay

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*Abstract:* - The new technological decisions, some concrete designs are presented and discussed, and the information on their efficiency and practical tests is supplied. These granulation technologies and devices were done for amorphous materials' production in the newly created machines with parametric film flow decay and highly intensive particles' cooling methods based on the idea of particles' passing through the system of the nitrogen liquid film flows.

*Key-Words:* - Parametric, Wave, Excitation, Granulation, Control, Film Flow, Cooling, Nitrogen,Amorphous

## 1 Vitality of the problem

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, thermo-hydrodynamics of the granular and underground natural systems, biology and others. 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 [1-7], which are extremely needed for modern industry.

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 [1]: 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 [2-7] too. For example: dispersing of the liquid films on the vibrating disk at the Euler's numbers significantly exceeding unit [8,9], use of the phenomena of electromagnetic resonant film flow decay, the soliton-like modes of the film decay, etc. Some of the granulated metal particles produced by the method obtained are shown in Fig.1. And a few granulation methods are presented in Figs 2-4.

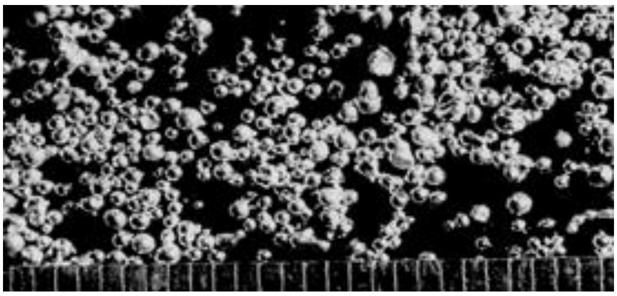

Fig.1 Granules produced on film granulator

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!). 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 [10]. He estimated that theoretical iron durability differs from the real one up to 1000 times.

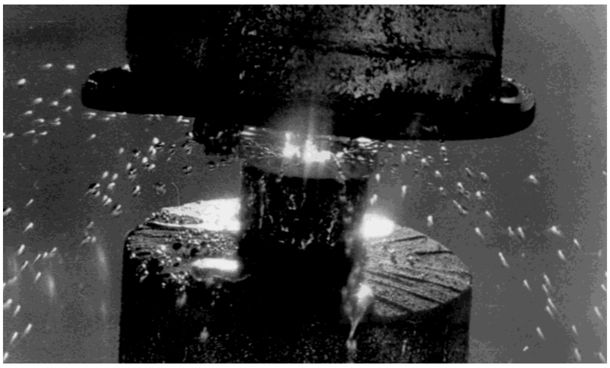

Fig.2 Electromagnetic resonant film flow decay

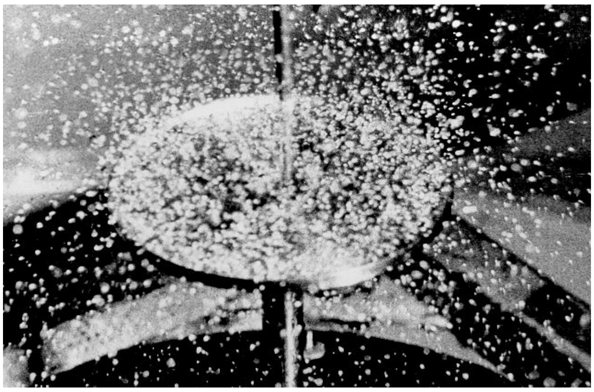

Fig.3 Vibration soliton-like film flow decay

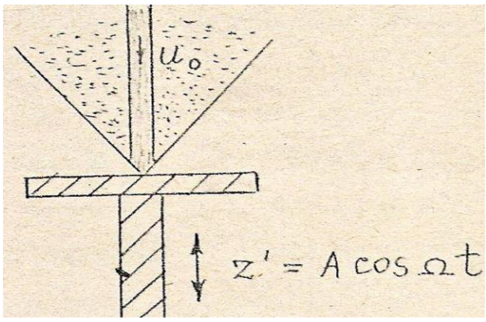


Fig.4 Shock-wave controlled film flow decay

### 1.1 The main results for implementation

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.

### 1.2 Statement of the problem

In this paper the new technologies and devices are presented, which were created [2-6] on the basis of the new phenomena obtained [1,7-9], have been tested and introduced into practice. These technologies and devices were done for amorphous materials' production in the newly created granulation machines with parametric film flow decay and highly intensive particles' cooling methods.

## 2 Experimental study of parametric controlled film flow decay

The results of theoretical researches revealed the characteristics of parametric excitation and suppression of oscillations on the film flows. Parametric influences were considered of two types: electromagnetic waves and vibrations. And the methods for intensive cooling of the drops and particles in liquid nitrogen were investigated as well

In this paper the installations for research of parametric oscillations on surface of film flows and their decay into particles of controlled size and form are described, theoretical results are confirmed and some new hydrodynamic phenomena and processes, including the ones having essential technological applications revealed.

### 2.1 Experimental facilities and methodologies for electromagnetic and electrodynamic wave excitation in conductive film flows

For establishment of adequacy of theoretical researches and detection of new regularities of initiation processes for disintegration of film flows of the electro-conductive liquids into drops (for the purpose of dispersing, liquid spraying or subsequent crystallization into granules, experimental works on physical model installations with application of gallium and other alloys as model metals have been carried out.

We state further the basic principles of physical modeling of the studied processes and give results of the corresponding modeling.

### 2.1.1 Vacuum MHD-facility for study of electromagnetic film flow decay into drops

General view of experimental installation for research of film MHD-flows, parametric oscillations of a film surfaces and processes of their disintegration into drops of controlled size is given in Fig.5. Shapers of drop flows as elements of granulators are called dispersers [1,7-9]. Dispersers of plainly and radially spreading film flows are equipped with the nozzles forming such film flows. They can be of various types as shown in Fig.6.

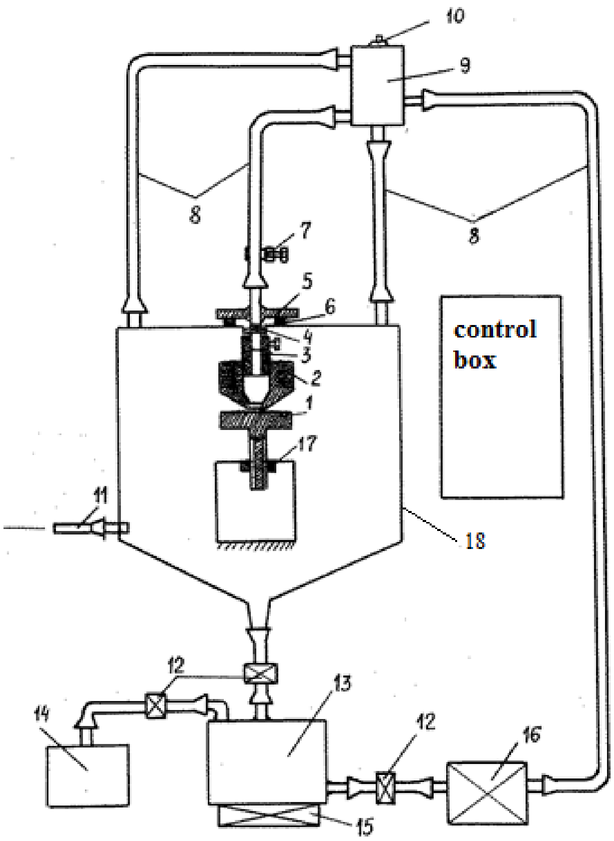


Fig.5 Vacuum MHD-facility for electromagnetic excitation of film flows of electro-conductive liquid: 1- disk, 2- inductor, 3- the insulating plug, 4- removable nozzle, 5- aligning platform, 6- sealing washer, 7- regulator of outflow from a nozzle, 8- pipeline, 9- tank of constant level of melt alloy, 10- air valve, 11- gas pipeline, 12- lock, 13- melt supplying tank, 14- forvacuum pump, 15- heater, 16- liquid metal induction pump, 17- regulator of disk space orientation, 18- hermetic box

The principle of action of the dispersers is based on transformation of a liquid flow of rectangular or round cross-section into one or two flat jets in the first case and in radially spreading jet in the second case. Both cases corresponding to application of the nozzles forming jets similar to Vitoshinsky's nozzles (providing a rectangular velocity profile on a nozzle cut) for an exception of whirlwinds in an initial jet.

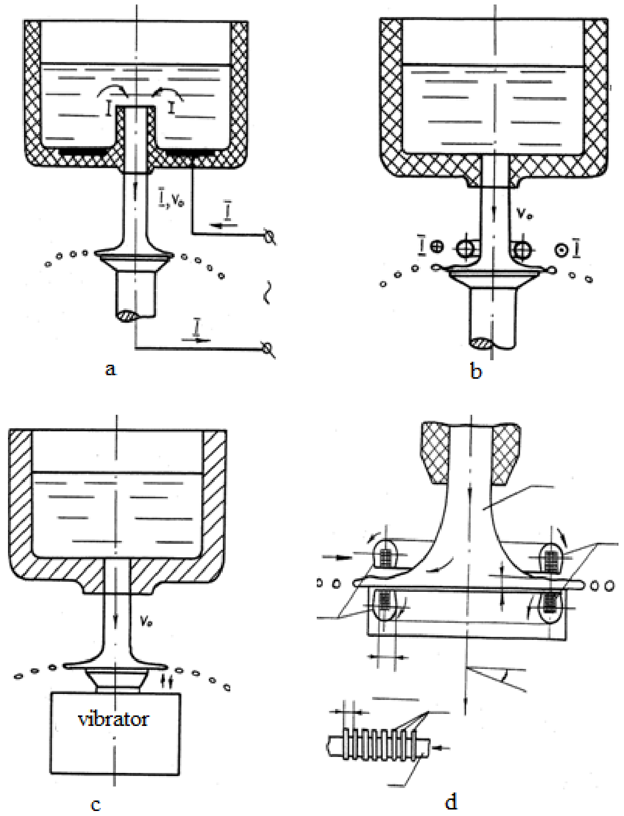


Fig 6 Systems for film flow disintegration:
a- conductive type, b- inductive, c- vibration,
d- electromagnetic inductor

Systems of initiation of film disintegration of dispersers (destroyers, sprayers of jets on drops) can be various types. The simplest type in realization consists of elements of conductive (i.e. current goes by jet, which is electro-conductive) a current supply to an initial jet (Fig.6a). The disperser is based on application of velocity modulation in a jet using the effect of magnetic pressure creation at spatial spreading of currents in a jet source and in a place of its contact with the disk-crosser forming the flat or radially spreading film. The specified magnetic pressure has the frequency doubled in relation to the frequency of current in a jet.

At use of the industrial frequency of 50 Hz it is obtained 100 Hz, respectively. In Fig.6d the electrode system of a current supply to a jet source is represented. It consists of the ring current supply and an insulating fillet, which is flowed round by current in the meridian direction. In the face section of fillet electromagnetic forces of a form

$$H_z = H_m(r)\exp i(kr + m\varphi - \omega t), \qquad (1)$$

are created that it is possible to provide placing it in a longitudinal variation magnetic field or creating vertical vibration of a disk, on which the jet is flowing, by means of electro-dynamic systems.

The cylindrical coordinate system $r\varphi z$, which axis $0z$ coincides with a symmetry axis of the round axisymmetric jet, is implemented here. $H_m(r)$ is amplitude of magnetic field strength, $k, m, \omega$ - wave numbers by coordinates $r, \varphi$ and frequency of the EM field, respectively, $t$ - time, $i = \sqrt{-1}$.

In both mentioned cases it is possible to apply the source of the poly-harmonic current feeding respectively the inductor of an axial field or vibro-system of electro-dynamic type (Fig.6c) to control the process of film disintegration.

Following the process of disintegration of liquid films can visually be made in the light of a stroboscopic source with application of photo and movie data-acquisition equipment. For many melts (aluminum, gallium, etc.) it is necessary to conduct a process in the controlled atmosphere or in vacuum in view of emergence of an oxide film on a melt film surface in the active oxidation medium. The oxide film can change radically the flow regime since capillary forces become defining and lead to randomization of all system.

### 2.1.2 Induction system

Basic element of the MHD-disperser is the induction system for creation of the alternating electromagnetic (EM) field operating disintegration of a liquid metal film into the drops of given size. One of such inductors is presented schematically in Fig.7, where on a disk-crosser 4 the vertical round jet is transformed to radially spreading film.

The scheme of experimental installation, in which this inductor was used, is represented in Fig.8. Some installations of various type, which on the ways and methods of metals' dispersing and the modeling liquids were studied, have been developed, made and experienced. Nozzle is made of a glass tube and serves for a supply of liquid metal to a disk-crosser. Disk is made of ceramics and it is equipped with the steel electrodes, which are built in a disk flush with. The arrangement of electrodes is shown in Fig.9.

Such system allows registering an instant electrodynamic and magneto-hydrodynamic picture in a liquid metal film, and then by them calculating the turning-out forces developed by a field in a film flow, and to define film destruction conditions on drops (dispersing). So, in a motionless film by current I=1A on a surface of a disk the following potentials were registered: $1'$-$2'$: 10mV, $2'$-$3'$: 5mV, $1'$-$3'$: 15mV, 1-3: 12mV, 1-4: 14mV, 1-5: 16mV, 4-5: 3mV, 3-4: 3mV, 2-3: 3mV.

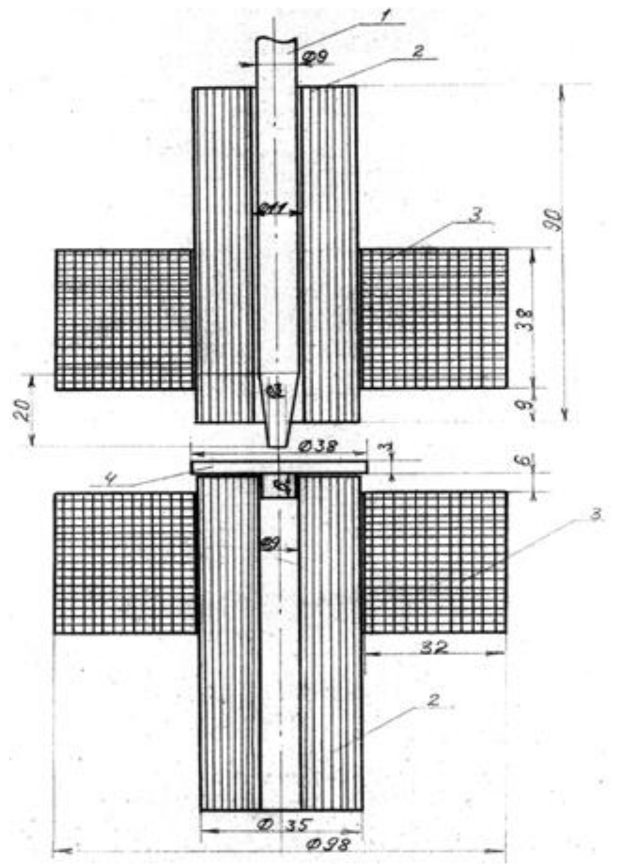


Fig.7 Scheme of electromagnetic inductor for controlled decay of film flow into drops: 1- removable nozzle, 2- blended magnetic conductor, 3- electromagnets, 4- disk transforming the vertical jet1 into radially spreading film

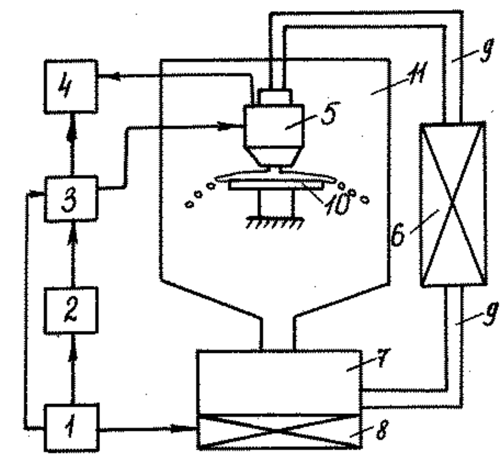


Fig.8 The scheme of device with inductor:
1 power unit, 2-setting generator, 3-pulse power unit, 4-control and measuring block, 5- inductor, 6-liquid metal pump, 7-capacity for collecting liquid metal. 8- furnace for heating of metal, 9- pipeline, 10- disk formatting liquid metal film flow, 11- hermetic camera with the inert environment

Values of potentials from current in an inductor winding (industrial frequency) at I=1, 2, 3, 4, 5A, respectively, are the following: 9, 17, 24, 30, 37 mV. Results of tests of the inductor are done in Figs10-12, where B(T) - induction of an electromagnetic field, I(A) - current in the inductor, $\omega$(Hz) - the frequency of the current feeding the inductor. So, characteristics of an electromagnetic field of a direct current at turning on only of the top coil 1 are given in Fig.10, only lower - 2 and two coils together - 3.

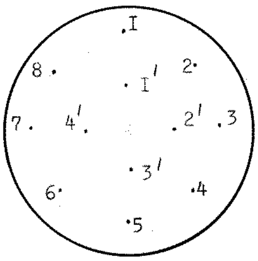


Fig.9 Displacement scheme for electrodes on a disk

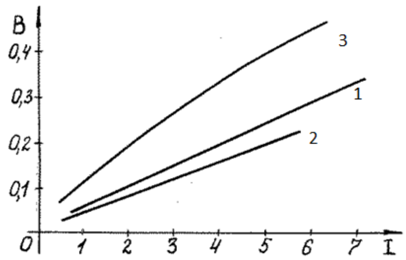


Fig.10 Value of induction of electromagnetic field for direct current in the plane of disk

Characteristics are weakly non-linear functions of current in inductor windings. In Fig.11 change of induction of an electromagnetic field in the disk plane from alternating current is shown for the frequency $\omega$=100 Hz (the 1- top coil, 2- lower). The small dispersion of points of characteristics 1 and 2 is explained by an error of measurements and different distance of a disk from the top and from the lower coils. Dependence of induction of EM field from frequency of the current feeding the inductor at common work of both coils, when current is equal in them 1A, is shown in Fig.12.

As seen from Fig.12 induction of EM field against frequency of current is practically linear function up to the current frequency $\omega$=600Hz.

The provided data show that at sufficient compactness the developed electromagnetic inductor creates a field with induction up to 1T at current in a few amperes in the working range of the frequencies of 100-800 Hz that allows carrying out reliable work of a film MHD-disperser. Thus, such inductor is suitable for work in perspective film MHD-granulators of liquid metals [4,5,8]. Results of tests of such granulators are given below.

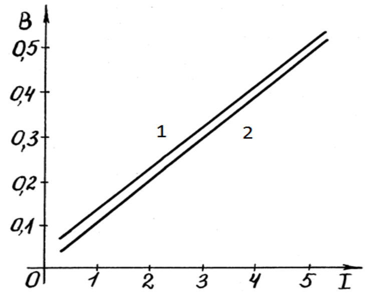


Fig.11 Value of induction of EM field of alternating current with frequency 100Hz in a disk plane

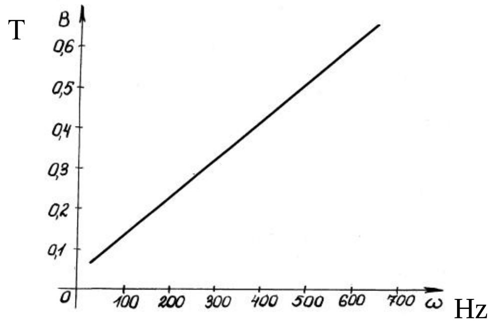


Fig.12 Dependence of induction of electromagnetic field against frequency of current feeding inductor

## 2.2 The methodology of experimentation

For research of the main modes of parametric excitation of oscillations in films of the electro-conductive liquids at diverse conditions of their disintegration on drops, the experimental studies of process in the wide range of the varied parameters were conducted. As showed analysis of the equations of process written in a dimensionless form [1,7,8] a number of the major factors defining the wave film flows and a condition of their disintegration on drops are as follows:

- Dimensionless criteria: hydrodynamic and magnetic Reynolds numbers $\mathrm{Re}$, $\mathrm{Re}_m$, Froude number $Fr$, Weber number $We$, Galileo number $Ga$, Euler numbers (conventional and magnetic) - $Eu, Eu_m$.
- Character and form of the exciting force.
- Geometric characteristics of the system.
- Simplexes – the ratio of densities, viscosities of melt and surrounding medium, etc.

In experiment in each separate case is possible to consider a set of geometrical parameters (from experiment to experiment can change), simplexes. If experiment is made on one model liquid, then it is $\nu, \nu_m = const$ at a constant temperature of the medium or its weak change. We will consider the radius of a nozzle fixed for this test with number *j*, therefore Re and $\mathrm{Re}_m$ can vary in everyone *j*-th test by regulation of flow velocity $u_0$ from a nozzle.

### 2.2.1 Planning the experimental studies

For experiment's planning it is necessary to set the variation limits for the main dimensionless criteria, to choose for them a step of a variation and after that to make the optimum organization for performing the experiment.

Having $\mathrm{Re} = u_0 r_0 / \nu$, $\mathrm{Re}_m = u_0 r_0 / \nu_m$, $We = \rho a u_0^2 / \sigma$, $Fr = u_0 / \sqrt{ga}$, $Eu_m = \mu H^2 / (\rho u_0^2)$ - the dynamic criteria, $Oh = \sqrt{We} / \mathrm{Re} = \sqrt{\rho / (\sigma r_0)} \nu$, $Ga = \sqrt{g r_0} r_0 / \nu$ - Ohnesorge and Galileo kinematic criteria, for the characteristic of disintegration process is possible to use in every *j*-th experiment only dynamic criteria. Proceeding from the stated, it is possible to conclude that physical process is generally defined by the criteria Re, Ga, Oh, Eu - for vibration impact on a film and Re,Be,Ga,Oh,$\mathrm{Eu}_m$ - for electromagnetic one. Therefore the sequence of conducting experiment can be presented the following:

- Liquid and nozzle are set, Be, Ga, Oh are known, with variation of the nozzles one can vary the criteria;
- With change of flow velocity $u_0$, the criteria Re, Eu ($\mathrm{Eu}_g$), $\mathrm{Eu}_m$ are varied.

For example, in experimental installation there are nozzles of three radiuses: $r_{01}$, $r_{02}$, $r_{03}$. We choose a step for variation of the Reynolds and Euler numbers from the conditions of change of the flow rate determined by type of the using pump, and intensity of external influence. Let $u_0 = Q / (\pi r_0^2)$, where $Q$ - a volumetric flow rate, then taking into account all stated yields:

$$\mathrm{Re} = \frac{Q}{\pi r_0^2 \nu}, \quad Eu_m = \frac{\mu_m}{\rho} \left( \frac{H}{Q} \pi r_0^2 \right)^2, \qquad (2)$$

where from follows:

$$\mathrm{Re}_{\min} = \frac{Q_{\min}}{\pi \nu (r_0)_{\max}}, \quad (Eu_m)_{\min} = \frac{\mu_m}{\rho} \left( \frac{H_{\min}}{Q_{\max}} \pi (r_0^2)_{\min} \right)^2, \quad (3)$$

$$\mathrm{Re}_{\max} = \frac{Q_{\max}}{\pi \nu (r_0)_{\min}}, \quad (Eu_m)_{\max} = \frac{\mu_m}{\rho} \left( \frac{H_{\max}}{Q_{\min}} \pi (r_0^2)_{\max} \right)^2.$$

Based on expressions (3) the limits for available values of the criteria Re, $\mathrm{Eu}_m$ are got. Let $(r_0)_{\max} / (r_0)_{\min} = 4$, then $Q_{\max} / Q_{\min} = 25$ allows varying the value Re on one model liquid for two decimal orders. In view of the limited power of the pump and physical conditions it is practically difficult to realize it: from the top there is restriction on pump power, from bottom - on physical existence of a film flow (it is necessary for existence of a film flow that inertia forces, at least, exceeded losses of a pressure on overcoming of friction forces of liquid on a disk).

Ratio of maximal and minimal magnetic Euler numbers is as follows

$$\frac{(Eu_m)_{\max}}{(Eu_m)_{\min}} = \left( \frac{H_{\max} Q_{\max} (r_0^2)_{\max}}{H_{\min} Q_{\min} (r_0^2)_{\min}} \right)^2 = \left( \frac{H_{\max} \mathrm{Re}_{\max} (r_0)_{\max}}{H_{\min} \mathrm{Re}_{\min} (r_0)_{\min}} \right)^2, \quad (4)$$

where from follows that this ratio can be substantial even by $(r_0)_{\max} \sim (r_0)_{\min}$, because even by such narrow range of variation $H_{\max} / H_{\min} = 5$, $\mathrm{Re}_{\max} / \mathrm{Re}_{\min} = 5$ there is wide range for variation of electromagnetic Euler number: $(Eu_m)_{\max} / (Eu_m)_{\min} = 625$.

### 2.2.2 Influence of the Ohnesorge and Galileo numbers

To analyze influence of the Ohnesorge and Galileo numbers on the considered physical process, it is necessary to have identical values $\mathrm{Re}, Eu_m$ in different experiments. Let suppose that there is a set nozzles with radiuses $r_{0i}$ ($i = \overline{1, I}$). We divide all range of variation Re on $N$ parts, and $Eu_m$ - on $L$ parts and we will demand that by Reynolds number in each interval $[r_{0i}, r_{0i+1}]$ on $n_i$ numbers of values Re coincided, and on $l_i$ numbers of values $Eu_m$ also coincided.

The problem of splitting an interval of the varied values of diameter of a nozzle $[(r_0)_{\min}, (r_0)_{\max}]$ and choice of corresponding steps on parameters $\mathrm{Re}, Eu_m$ ($\Delta \mathrm{Re}, \Delta Eu_m$), taking into account the set range $[(Q_0)_{\min}, (Q_0)_{\max}]$, is solved. It is a complex challenge, therefore we receive the main ratios by means of which it is possible to solve it. Analyzing the described physical situation with account of the above mentioned (to have *j* integer, we have at given $n_i, N$, $Q_{\min}, Q_{\max}$ to choose $(r_0)_{\max} = r_{0I}$) yields:

$$Q_{\min} \le r_{0i} \left[ \frac{Q_{\max}}{(r_0)_{\min}} + \frac{j}{N-1} \left( \frac{Q_{\min}}{(r_0)_{\max}} - \frac{Q_{\max}}{(r_0)_{\min}} \right) \right] \le Q_{\max}, \qquad (5)$$

where from $(r_0)_{\min} = r_{01}$, and the following expression results

$$j_{i+1,1}=l_iN_i+\frac{(l_i-1)NQ_{\min}}{Q_{\max}\prod_{i=1}^{I-1}l_i-Q_{\min}}, \qquad (6)$$

where $l_i=\left(n_{i,j}M_{i,j}\right)^{1/4}$. By the repeated indexes there is no sum. Because $l_i$ is rational number, then due to $\prod_{i=1}^{I-1}l_i=\left(r_0\right)_{\max}/\left(r_0\right)_{\min}$ is known, $l_i$ is computed from the condition

$$l_i=\frac{j_{i+1,1}\left\{(Q_{\max}/Q_{\min})\left[\left(r_0\right)_{\max}/\left(r_0\right)_{\min}\right]-1\right\}+N}{N_i\left\{(Q_{\max}/Q_{\min})\left[\left(r_0\right)_{\max}/\left(r_0\right)_{\min}\right]-1\right\}+N}. \qquad (7)$$

Thus, selecting in (7) $N_i=idem,\ \ j_{i+1,1}=idem,$ one can get $N_i=Ni/I,\ \ j_{i,1}=N(i-1)/I, j_{i+1,1}=Ni/I,\ \ l_i=1\Rightarrow\left(r_0\right)_{\max}=\left(r_0\right)_{\min}=r_0$, that means trivial case. We use expressions (5)-(7) at a choice of a way of splitting an interval. At rather big variation intervals at the same time of several parameters of experimental installation, it is very difficult to make such splitting without the offered formulas.

# 3 Control of film flow decay using the generator of poly-harmonic currents

At the operated disintegration of the jet and film flows of the electro-conductive liquid the form of the formed drops (particles, granules) depends on the variation law of controlling influences [7-9]. The magnetic pressure acting on the jet and film flows is created by interaction of the current induced in the conductive liquid with an inductor's field (for induction systems) or by interaction of the current entered into the channel with the conductive liquid and an external magnetic field (in conduction type systems). Thus the law of change of magnetic pressure is defined by the law of current change in the inductor or the current proceeding in the conductive liquid.

At the electromechanical (vibration) way of control of disintegration of jet and film flows considered further the form and the sizes of the formed drops (particles) are defined by character of a current and, in particular, by the law of the movement of the disk influencing jets and films. The law of the disk movement is defined by a type of current in a winding of an electromagnet of the vibration device VEDS-10A creating the movement of a disk (this movement was strictly vertical).

The special sources of current allowing to receive current of the set form are necessary for the process control by disintegration of the jets and films descending from a disk, as well as in case of electromagnetic action at electromechanical control. Such sources developed at the Institute of Electrodynamics of the National Academy of Sciences of Ukraine (IED NASU) [7,8] were tested on various installations providing the poly-harmonic external impacts on jets and films.

The Source of the Poly-harmonic Currents (SPC) consists of the control unit (CU) providing the set law of change of current, and the power block amplifier of the power (AP) providing the necessary level of current. CU can be executed with "rigid" logic of control, i.e. with unchangeable algorithm when one certain law of current's change is provided. But CU can also execute with reprogramming possibility when various demanded algorithms of a functioning allowing to reproduce the set laws of current's change are set.

The carrier of the program represents a replaceable operational memory (ROM) in which in the form of digital codes the algorithm is stored. Replaceable ROM as the carrier of the program is used if control algorithms are known in advance and they are comparably in small amount. The microprocessor is the logical block which is carrying out operations on processing of basic data about algorithm and development of all signals for control of SPC.

The shaper of input signals for the AP represents the digital-to-analog converter (DAC) if as a part of SPC as the AP the amplifier of continuous action is used. On input of the amplifier the signal representing approximation of a curve of the set law of change of output current of SPC is given. The type of an approximating curve is selected proceeding from the necessary accuracy of reproduction of the set law of change of current.

If as a part of SPC the key amplifier is used, the shaper has to on signals of the microprocessor create discrete signals with a certain level and temporal ratios which will be transformed to signals of an analog form by the amplifier. Among the key amplifiers in the region of formation of signals with the set law of amplifying the greatest distribution was gained by amplifiers with step-wise and pulse-code modulation, in which approximation of the amplified signal is done by step-wise function. This operation is carried out directly in the output cascade of amplifying.

Key amplifiers in comparison with amplifiers of continuous action have higher efficiency, however they possess also higher level of non-linear distortions, and owing to what at high requirements to accuracy of the set law of change of current it is preferable to use the amplifiers of continuous action. The reprogrammable SPC was developed for performing the experimental studies of the controlled disintegration of jets and films, which was also used in trial installations of electromagnetic and electromechanical dispersing of liquid metals and in other devices with minor changes.

### 3.1 Functional scheme of the SPC

Process of formation of output current I from the SPC under the set law is convenient to explain using Fig.13, considering a case when SPC has to create such curve of current, which at magneto-hydrodynamic control of jets' disintegration [7,8] gives particles of a spherical form for example. Such poly-harmonic influence is shown in Fig.14.

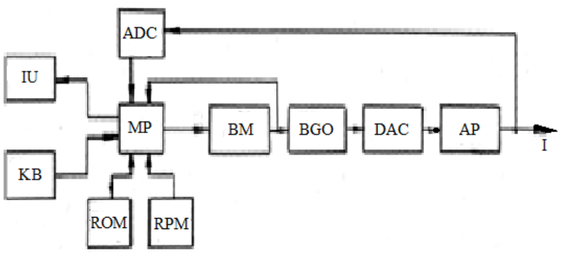


Fig.13 Functional scheme of the SPC

When forming a curve in CU of SPC the method of piece-wise linear approximation was used, according to which depending on the demanded reproduction accuracy the set curve was divided into *n* parts of duration $\Delta T_i$, each of which was approximated by a straight line, and the period of change current I was equal to $T=\sum_{i=1}^{n}\Delta T_i$. In the removable operational memory (ROM) of the microprocessor (MP) from the keyboard (KB) panel the value of current amplitudes (points $A_0 \doteq A_9$) and durations of corresponding time intervals $\Delta T_0 \doteq \Delta T_9$ are introduced at the moments of time $t_i$.

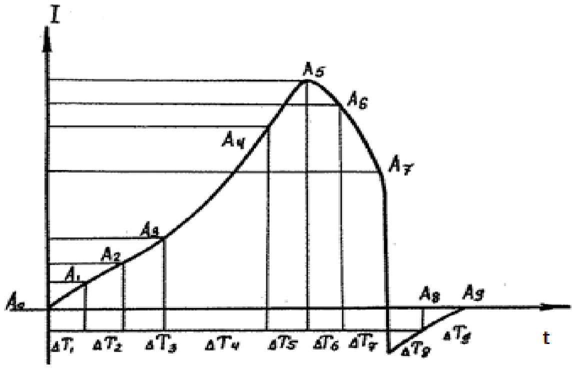


Fig.14 The form of poly-harmonic current curve

According to the program which is stored in removable permanent memory (RPM) of the MP the amplitudes of the points located on a curve through discretization intervals $\Delta T_i$ are calculated. The interval of discretization of a curve is selected depending on the demanded accuracy of curve reproduction taking into account speed of MP and DAC (digital-analog convertor), and an increment of amplitudes of points on an interval $\Delta t$ for *i*-th part is $\Delta A_i = (A_{i+1} - A_i)\Delta / \Delta T_i$. Amplitudes calculated by this formula in the corresponding digital codes correspond in the buffer memory (BM). The feedback loop covering BM allows controlling and correcting the data copied from the ROM. BM allows increasing the delivery speed of codes by ROM since we have smaller time of reading than the ROM of MP. It gives the chance to choose smaller value $\Delta T_i$. Besides, work with BM exempts MP from functions of DAC control that allows using the MP for control of a signal at SPC exit.

Existence the feedback loop through ADC covering all path of formation of output current makes the SPC such system of automatic control possessing sufficient stability to various deviations of parameters, including external (regular or casual) perturbations. For increase of noise immunity of CU the block of galvanic outcome (BGO), which is switched on between BM and DAC is entered. The conducted researches of programmable SPC confirmed efficiency of application of such poly-harmonic current sources for formation of the demanded poly-harmonic influences when carrying out the controlled jet and film flows' disintegration.

The main interactions of parameters of a film flow and electromagnetic field were theoretically investigated. Works were carried out on facility, which general view is shown in Fig.15. The block diagram of this facility is given in Fig.16.

### 3.2 Relationship, mutual influence of the parameters of film flow and electromagnetic field. Conditions for film decay on the drops

It is one of the simplest facilities, researches on it showed that the gallium film in the weakly-controlled nitric atmosphere (free replacement of air by the nitrogen supplied to the chamber, without preliminary vacuuming of the chamber) due to formation of an oxide thin film on its free surface becomes uncontrollable. Capillary forces of oxide film on the free surface of liquid metal film flow chaotically tear a film and do its disintegration process uncontrollable (Fig.16):

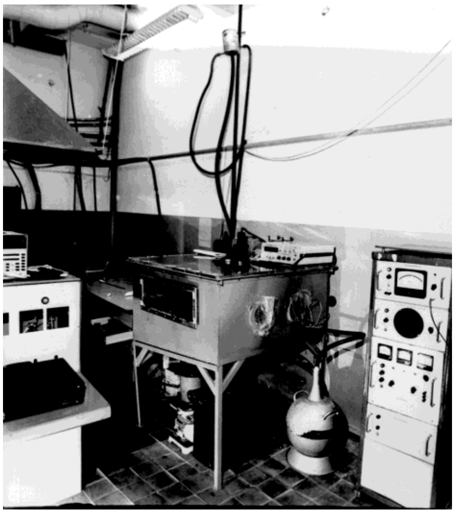

Fig.15 General view of facility with nitric atmosphere in chamber

Fig.16 Gallium film flow in weakly controlled nitric atmosphere

Even application of the powerful pulse fields received from the special generators of pulse currents (GPC) didn't allow receiving the considerable prevalence of electromagnetic forces over capillary ones owing to what disintegration of a film is chaotic and control of disintegration is possible only at very high power expenses. Application of the developed facility was possible only in systems of a special purpose. In view of the specified features the experimental researches of disintegration of films were carried out on the facilities presented in Fig.17. This facility has the vacuum working chamber, in which horizontal disk is placed under a vertical jet of the liquid metal supplied by the MHD-pump through a nozzle (for this there is a closed liquid metal loop). A nozzle arrangement over a disk is adjustable.

The induction system is placed to the cylindrical tight box with a diameter of 520 and 500 mm high (the working chamber of facility), where the vacuum up to 0,1 Pa is reached, is put on a nozzle (in working state there were on average 0,4 Pa). Facility is supplied with the closed liquid metal loop, pressure at the exit from the pump developed about 160 kPa, thus the speed of the expiration made to 5 m/s. Nozzles were of diverse caliber, easily replaced, with diameters of 2-7 mm.

Fig.17 General view of the vacuum liquid metal facility: film flow decay under action of electromagnetic field is observed through the windows

The research of electromagnetic excitation of oscillations and disintegration of film flows of Gallium on drops carried out on the described vacuum facility showed good operability of facility and possibility of effective MHD-control of the film flow disintegration. In view of considerable difficulties, the development of precise measuring equipment appeared a subject of big independent work. And in this work the research was carried mainly in a generally qualitative character.

Reliable measurement of local change of the fields of speeds, forces, etc. in a film flows was still impossible so far. Difficulties, in particular, are connected with problems of an exception of different noises and reliability of contact at the movement of a film (the most suitable were steel electrodes, the copper ones were quickly washed away by Gallium).

## 3.3 Device with nitric atmosphere and crystallizer

For verification of the technological and constructive decisions laid in the base for the project of the semi-industrial film granulator for the low-melting alloys with liquid nitric crystallizer [8] (Fig.18), the electrodynamic device was developed and created. This device allowed determining the main consistent patterns of films' disintegration in dispersers with electrodynamic excitation, in particular, it was succeeded to receive data on influence of melt flow velocity, level of a disk vibration accelerations and other factors at a size and uniformity of the produced drops (granules).

Model liquid or melted metal is supplied by the warmed thermo-insulated channel 1 and calibrated replaceable nozzle 2 forming a cylindrical jet is coming on a disk 3. The last is connected by a rod 4 to the resounding membrane 5 (there is a set of membranes of different thickness) of the VEDS (the vibration electro-dynamic stand), which is installed on a regular little table of the vibrator 6.

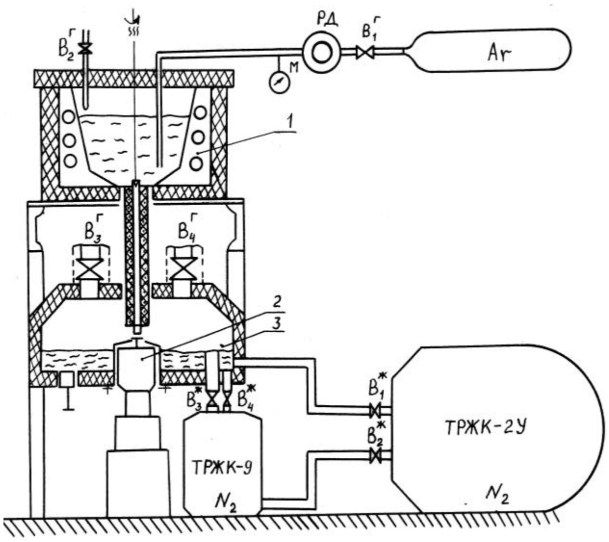


Fig.18 The project of semi-industrial film granulator for low-melting alloys with liquid nitric crystallizer

The granulator has refrigerating conditions and crystallization of drops and granules at which their adhesion is excluded. These conditions are defined by the corresponding choice of coolant level (liquid nitrogen) in a crystallizer and its continuous circulation. Besides, creation of the film ring veil of coolant improves conditions for crystallization of drops and promoting growing crystallization rate. Intensive cooling was achieved due to avoiding the crisis phenomenon of heat exchange thanks to movement (falling down in a chamber) of the drops and solidified particles. It was got $10^4$ K/s, which the record for the moment for particles. Such cooling rate allows getting amorphous materials for the unique new materials' production.

# 5 Conclusions by the results obtained

The developed new principles of granulation allowed constructing the film MHD- and electrodynamic granulators differing significantly in bigger productivity (on one-two decimal orders) comparing to the known jet granulation machines, which don't have analogs in world practice, considerable wider range of the produced mono-granules, simplicity of a design and low energy consumption. One of the semi-industrial granulators of this kind, FGA-1 (the film granulator for aluminum alloys, model 1), was successfully tested in vitro and at the enterprise [11]. Works in this direction are perspective for many technologies.

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