REVISTA ESPACIOS

Increasing geometric homogeneity of dispersed particles of plastic materials produced by vibration assisted micro-cutting

Aumento de la homogeneidad geométrica de las partículas dispersadas de materiales plásticos producidos por el micro-corte asistido por vibración

Yuriy SERGEEV 1; Sergey SERGEEV 2; Alexander D'YAKONOV 3

Content

ABSTRACT:

This article substantiates a new concept of dimensional mechanical dispersion of viscous plastic materials in condensed media by cutting. It is about increasing geometric homogeneity and forming a required shape and size of dispersed particles by forcibly introducing a specified controlled vibration action into the area of material destruction. This approach will allow us to move from the traditional (chaotic) to the new highly organized and controlled process of destructing viscous condensed media of various structures. Achieved results make it possible to produce dispersed powder and fiber particles of required quality without changing the physicochemical characteristics. They will also contribute to the processes of developing vibration-assisted cutting technologies and designing high-technology energy efficient dispersing machines.

RESUMEN:

Este artículo sustenta un nuevo concepto de dispersión mecánica dimensional de materiales plásticos viscosos en medios condensados por corte. Se trata de aumentar la homogeneidad geométrica y formar una forma requerida y el tamaño de las partículas dispersadas mediante la introducción forzada de una determinada acción de vibración controlada en el área de destrucción del material. Este enfoque nos permitirá pasar del proceso tradicional (caótico) al nuevo proceso altamente organizado y controlado de destrucción de medios condensados viscosos de varias estructuras. Los resultados obtenidos permiten producir partículas dispersas de polvo y fibra de la calidad requerida sin cambiar las características fisicoquímicas. También contribuirán a los procesos de desarrollo de tecnologías de corte asistido por vibración y diseño de máquinas

1. Introduction

A high level of requirements for modern high-tech products has necessitated the production of a wide range of composite materials with specified physical and mechanical properties. At the same time, we are able not only to control the performance properties of composites by varying the composition, ratio, orientation of filler particles different in shape and size (Chumanov et al., 2010; 2012), but also to create new ones (Chumanov et al., 2015; 2017).

The prospects for materials science development are conditioned by the demand for new materials with unique properties and efficient manufacturing technology, as the requirements for their properties are constantly changing. Powders, fibers, granules and light metal pastes are widely used in various fields of engineering: metallurgy (Gordeev, Sergeev & Chumanov, 2010), chemistry (Sergeev & Gordeev, 2009), medicine (Salernitano & Migliaresi, 2003), energy (Sandalov & Sergeev, 2012), building and construction (Lakirev et al., 2003), nuclear (Sergeev, 2011), space, military technology (Balaykin, Smelov & Chempinskiy, 2012) and other industries, as they have new (in comparison with compact materials) properties, based on specific surface properties of dispersed materials (Sergeev & Gordeev, 2010) (various metal and non-metal composite materials). They are produced by reducing metal oxides or metal salts to metal, by electrolytic deposition, by plasma spraying, by electrospark dispersion, and by mechanical methods: cutting, grinding, abrasion, and etc. The technological features of these processes determine their scope of implementation and economic feasibility. Such a variety is based on different requirements to physical, chemical, mechanical and performance properties of dispersed materials. However, all these processes are being improved to increase productivity while maintaining the physicochemical properties of materials and, mainly, producing particles of desired shape and size in stable dispersion. Therefore, all manufacturers producing components for composite materials face an acute problem of providing the required particle geometry and particle uniformity that largely determine the performance properties of a product.

Physicochemical and mechanical dispersion methods used in industry have the following drawbacks. Physicochemical dispersion of metals and plastics involves physicochemical feedstock transformations. As a result, produced material is chemically or physically different in comparison with the feedstock. Mechanical granulating methods transform the feedstock into granular-like chips, fibers and even into powder without a noticeable change in its chemical composition. There are such widely used methods as granulating through cutting (shredding machines), abrasion and grinding (ball, vortex and hammer grinders), but the last two methods are advisable to use only for treating brittle materials. The process of grinding viscous and plastic materials (zinc, aluminum, copper, great part of thermoplastics) is difficult, since they are mainly flattened, not destructed. On the contrary, the process of granulating through cutting allows treating these viscous materials. Treated metal must be granulated into chips and have, at the same time, stable size and shape, since non-uniform particle-size distribution (PSD) of granulated metal entails defects (chipping, swelling, excessive or uneven porosity) and, as a consequence, deterioration of physical-mechanical properties of the final product. At the same time, the process of granulating through cutting does not allow making a desired shape and providing a desired PSD of dispersed material while the existing granulating methods are physically highly demanding. Therefore, high cost of manufacturing powder, especially metal powder, holds the producers from wider distribution of products made of composite materials. There is a need to produce granule like chips while treating wastes, for example – metallurgical slags (Sergeev, Sergeev & Karpov, 2016) and plastics (Sergeev & Gordeev, 2010), for the second time. Meanwhile, up to 50% of secondary raw materials can be added to the

feedstock while manufacturing products based on thermoplastics, and up to 20% –while sintering products made of thermoset material if the last meets the specified PSD. In treating thermoplastics, non-uniform size of the cut-off material and its significant deviations from a desired shape lead to a number of defects in products obtained of it (non-melts, burnings, cracks, etc.). In terms of injection molding machines, there are always requirements for the size and shape of used thermoplastic granules, while the allowed deviation of the final particle size from the required should not be more than 15%. In sintering products made of thermosetting plastics, it is recommended to add secondary powder materials, which degree of dispersion should be 0.02 … 0.05 mm. The latter cannot be obtained with existing cutting mills.

Summarizing the above, we should note that the considered methods have certain requirements for the granulate particle size and particle shape. In plant operating conditions, granulate particles with specified sizes and shapes are produced irregularly while grinding raw materials and waste. High dimensional heterogeneity and existing deviations from the specified shape of the cut-off segments lead to a number of defects in products obtained of it. This problem is particularly urgent when waste is being dispersed by milling, since such method is widely used because it is simple to implement and works fine with various engineering materials combining elastic and viscous properties. These difficulties are explained by insufficient knowledge of how the chips separate while the segments are being cut. There are also no substantiated recommendations how to control the process of shaping final particles. In this regard, there is an urgent task to improve the process of forming a cut-off segment while dispersing materials.

2. Methods

Physical phenomena occurring during mechanical dispersion are peculiar, as it has not been possible (until now) to build a unified physical theory of such processes that would explain the whole set of empirically well-known facts and predict new effects and phenomena. The problems in mechanics associated with the penetration and motion of solids in the continuous (solid) media are the least studied part of mechanics. Moreover, issues related to rotating instruments, namely their rotation motion in solid media, are not considered as problems of mechanics. Thus, no one seriously studies them be means of mathematical modeling. Since the issues of modeling the movement of multiple-cutting-edge tools in a metal workpiece and the movement of a grinding tool on the surface of formation are attached to the applied branches of science, the level of knowledge of such processes is immeasurably behind the level of knowledge of mechanical motion in other media. This situation is further aggravated by the fact that modern production technologies are based more on the experience of engineering practice, rather than on scientific research. In this regard, increasing efficiency of a particular development is largely based on the knowledge of the physical nature of related processes. Numerous attempts to attract professional mathematicians to the mathematical modeling of specific engineering problems, in most cases, do not drive to success, since successful solution of the applied problem requires a deep understanding of its essence.

3. Data, Analysis, and Results

Our analysis of performed work shows that when it comes to material dispersion as the increment of new surfaces, various researchers agree only in that particle dispersion is dependent on such factors as non-homogeneity and anisotropy of media (Sumelka, Zaera & Fernández-Sáez, 2016; Ouelaa et al., 2017; Gordienko, Mustyatsa & Kovaleva, 2016). The remaining issues are highly debatable; various hypotheses and scattered empirical facts are in contradiction.

Despite a large number of research papers, they are focused mainly on studying and improving energy-consuming and costly ways to produce powders and fibers, such as reducing metal oxides or metal salts to metal, electrolytic deposition, plasma spraying and electrospark dispersion (Kalpakjian & Schmid, 2014; Şahin & Yalcinkaya, 2016; Hayes, 2014). There are

attempts to study and improve mechanical methods of dispersion (Hamran & Rashid, 2017; Webster & Eren, 2014; Parveen, Rana & Fangueiro, 2013). Their results are provided mainly to increase the process productivity while maintaining the physicochemical properties of materials. As a result, used methods lag behind, and the equipment is morally obsolete.

Therefore, research on material fracture mechanics, associated with the process of developing the fundamentals of chip geometry control and its surface uniformity control while forming the rotating multiple-cutting-edge tools through forcibly changing the amplitude-phase-frequency characteristics of their transverse oscillations (Lakirev et al., 2003; Sergeev et al., 2009), will become a scientific basis for the improvement of modern vibration technologies, used in the course of solid dispersion in condensed media.

Since (Kumabe, 1979; Poduraev, 1985), cutting kinematics determines the shape and size of chips, then it is expedient to control the chip formation according to the method (Sergeev et al., 2009) – by changing the kinematic movements of the rotating multiple-cutting-edge tool through the forced controlled radial vibration. This approach is fundamentally new. According to this granulation method (Sergeev et al., 2009), movement patterns of the milling cutter teeth 1 (cutter diameter is D) are formed by combining three trajectories (Figure 1): cutting speed as a uniform rotation around the axis $O0$ with a frequency ωvr; uniform feed motion S; oscillatory feed motion forced in the radial direction with a frequency ωk and amplitude A ($A = 2\rho$) as a rotational movement of the eccentric 2 relative to Oe. As a rule, tool oscillations can be any, for example, if one uses (Sergeev et al., 2014), he/she has to consider the major property of treated material while making a mathematical model – namely, the shape stability typical for solids. In other words, the main qualitative difference between a solid, a liquid and gaseous media is that the solid media "remembers" all past impacts. Besides, the path of a penetrating element depends not only on its current location, but also on a number of its previous positions.

Figure 1
Scheme of chip formation with a vibrating cutting tool
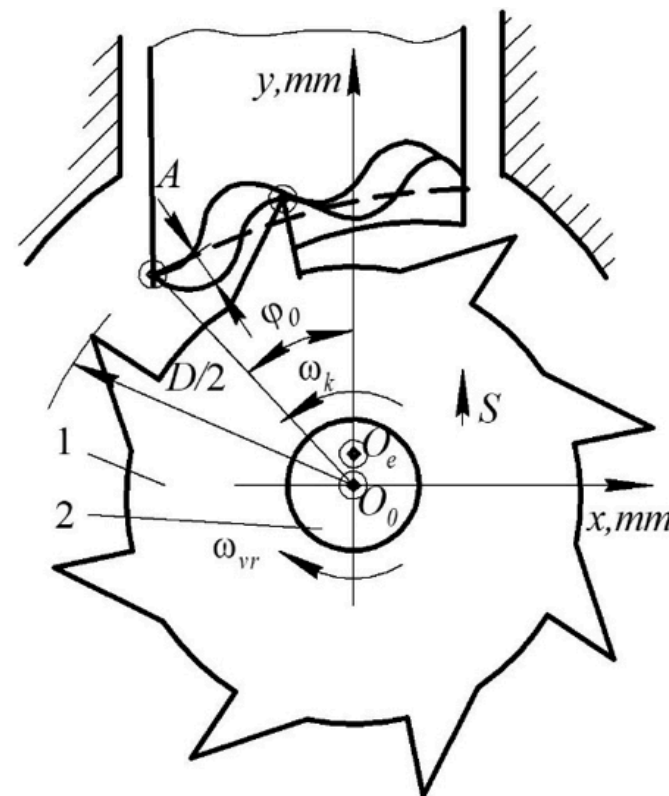
For example, if oscillations are harmonic and we assume that the cutter's tooth apex movements are discrete while penetrating into the treated material, we will represent these movements as a sequence of previous m and subsequent n sinusoidal curves with zero lines as circles arranged in 2 S/ω_{vr} with a phase shift on each turn $2\pi i$. In this case, we well take $\omega_k/\omega_{vr}=c+i$, where c is an integer and i is a non-integral. Thus, we will get the system of equations
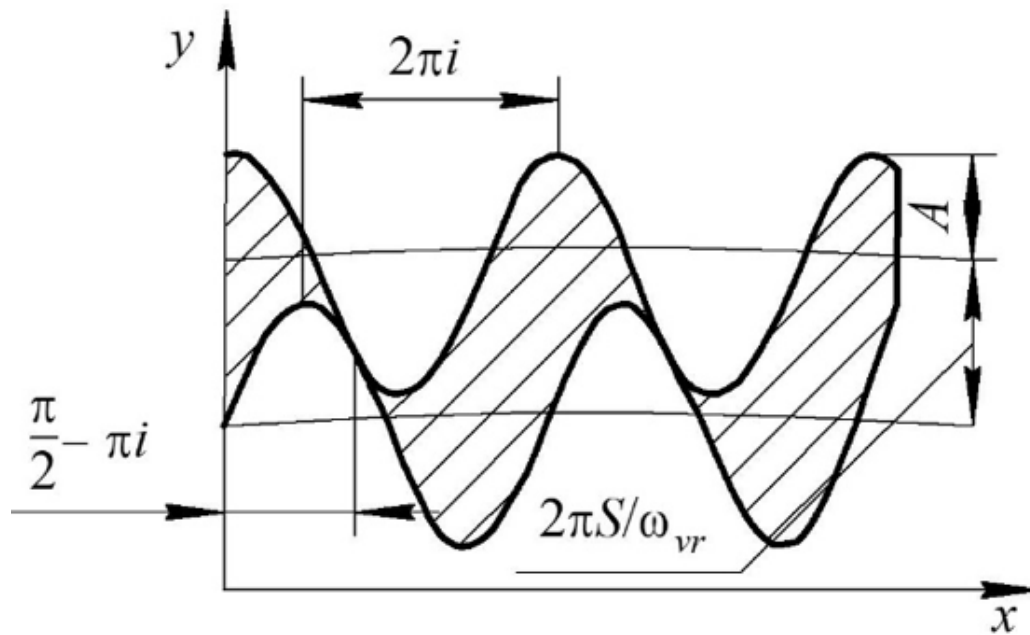
$$
\begin{cases}
x_0 = D/2\sin(\omega_{vr}t+\varphi_0)+A\sin(\omega_k t); \\
x_1 = D/2\sin(\omega_{vr}t+\varphi_0)+A\sin(\omega_k t+2\pi i); \\
\qquad\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots ; \\
x_m = D/2\sin(\omega_{vr}t+\varphi_0)+A\cdot\sin(\omega_k t+2\pi i m), \\[4pt]
y_0 = St + D/2\cos(\omega_{vr}t+\varphi_0)+A\cos(\omega_k t); \\
y_1 = St + \dfrac{2\pi S}{\omega_{vr}}+D/2\cos(\omega_{vr}t+\varphi_0)+A\cos(\omega_k t+2\pi i); \\
\qquad\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots ; \\
y_m = St + \dfrac{2\pi S}{\omega_{vr}}m+D/2\cos(\omega_{vr}t+\varphi_0)+A\cos(\omega_k t+2\pi i m),
\end{cases}
$$

Where: φ_0 – starting angle, rad; t – current time, s.

As a result, we will have the interrupted cutting condition guaranteeing the separation of dispersed chips (Figure 2):

Figure 2– Scheme of chip formation

It is presented as an amplitude illustrating the touch of the previous and subsequent trajectories of the tooth apex

$$A \geq \frac{\pi S}{Z\omega_{vr}\left|\sin\left(\pi\omega_k/\omega_{vr}\right)\right|},$$

Where: Z – number of teeth.

Such a condition ensures the separation of chips with the required dimensions. At the ratio ω_k/ω_{vr} equal to an integer, previous and subsequent trajectories of the tooth movement do not intersect while its apex penetrates into the treated material no matter how large are the amplitudes of oscillations. The cut-off chip formation model can be represented as the current value of its cut-off layer thickness a_i (along the y axis) determined by the m and m-n curves, as the corresponding y_m and y_{m-n} coordinates are different:

$$a_t = y_m - y_{m-n} = \frac{2\pi S}{\omega_{vr}}n + \left[A\cos\left(\omega_k t + 2\pi i m\right) - \cos\left(\omega_k t + 2\pi i (m-n)\right)\right] \quad (1)$$

Where n – number of trajectories forming the cut-off element

There has been written a computer program to calculate the geometric dimensions and profile shape of the cut-off chip separated in the feed direction of the cutter (Sergeev et al., 2011). This makes it possible to determine the points common to trajectories forming the element and, accordingly, the shape of disperse elements.

In the course of computer-based experiments, we have found sections of measured trajectory, in which the direction of the total cutting motion is opposite to the main motion. This will be possible if the rotation motion of the eccentric and the milling cutter are opposite. Vector analysis of the cutting edge speed (Figure 3) has showed their positions relative to the main surface P_v and the cutting surface P_n, where $P_{vf}^{min}, P_{vf}^{max} P_{nf}^{min}, P_{nf}^{max}$ are positions of the main and cutting surfaces penetrated by the oscillatory tool tooth. At the same time, cutting edge speed vector is equal to the vector of total rotational speeds of a milling cutter V_{cir}, transmission V_{sa} and the vibrating motion V_{ba}.

Figure 3 – Scheme of the changing positions of a cutting plane under radial feed and oscillations
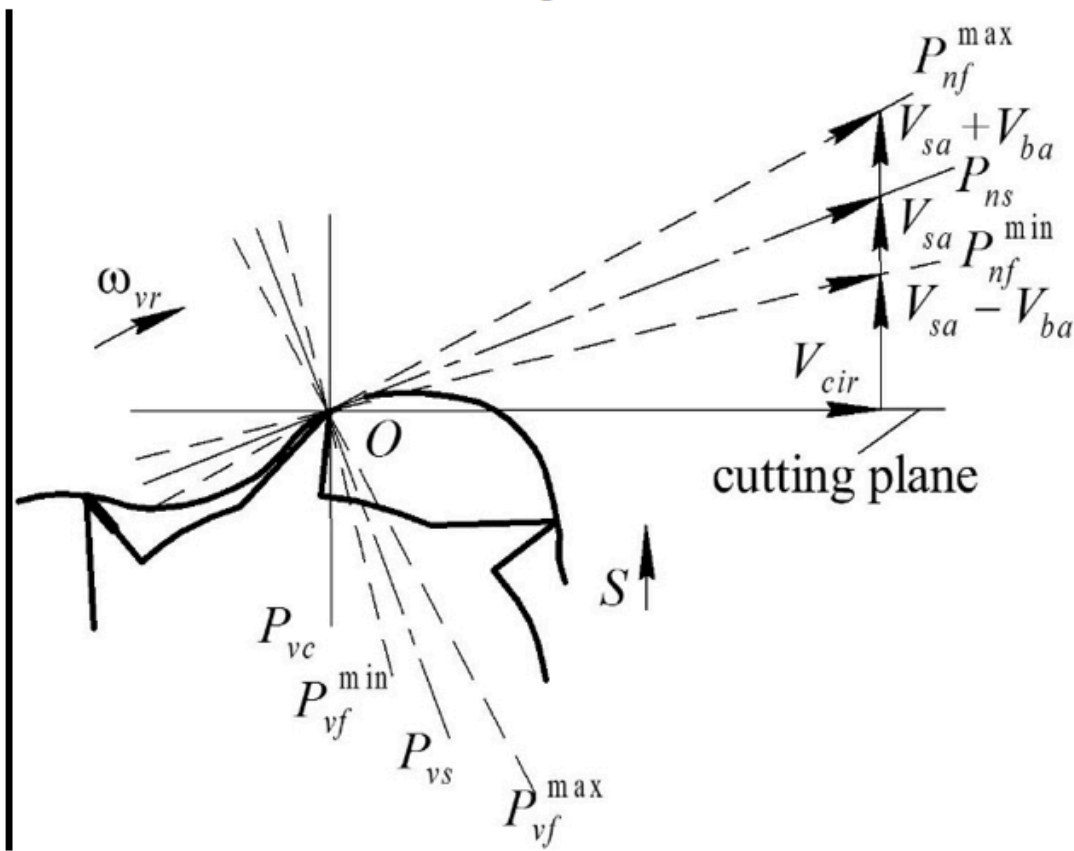
This means that the cutting plane is deflected due to the feed motion with the V_{sa} speed and the vibration displacement with the V_{ba} speed. This, in turn, leads to a decrease in the kinematic back angle down to zero. Therefore, direction of the resulting cutting motion will be opposite to ω_{vr}. In other words, if

$$A = \frac{1}{2\omega_k}\left(D\omega_{vr}\,\mathrm{tg}\alpha - 2S\right), (mm),$$

Where: α – back angle. At such an amplitude, finely dispersed (less than 0.2 mm) chips will separate randomly (Sergeev & Gordeev, 2010).

We have shown that the process of cutting with vibration allows obtaining stable chip dimensions while grinding viscous plastic materials. Let us measure the size of specified chip segments. We will show how the transverse oscillations of the cutting blades, installed on the drum type rotor (, affect the dispersed particle size by comparing the granulating processes without oscillations (Figure 4) and with oscillations (Figure 5).

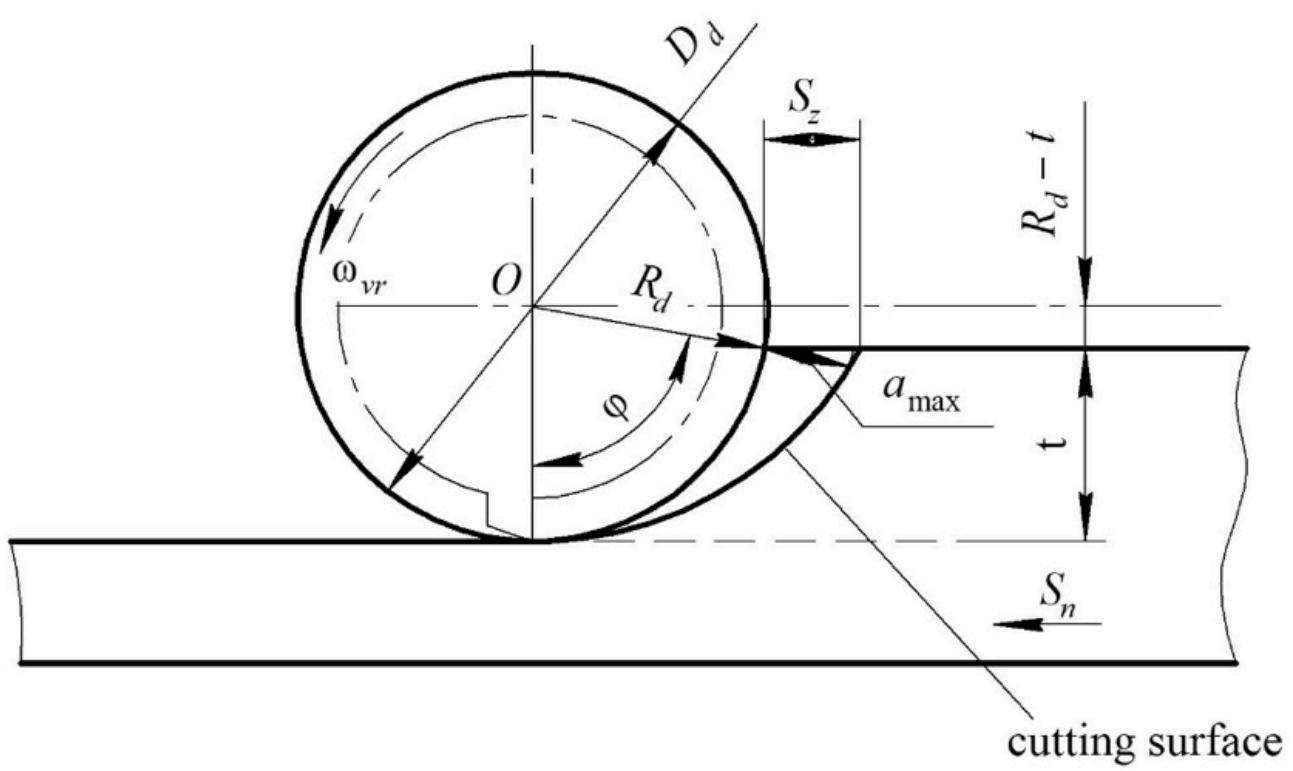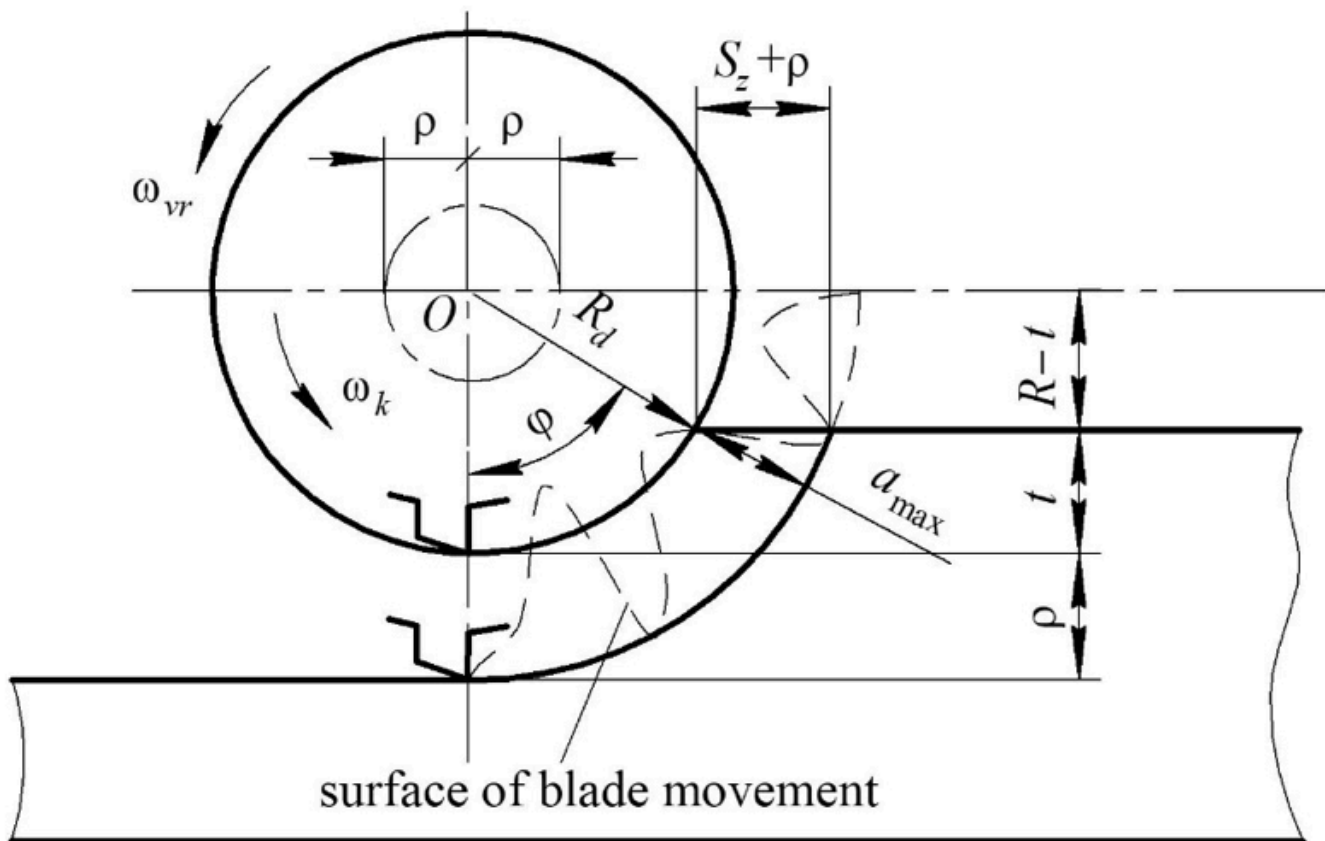**Figure 4** – Kinematics of grinding without radial oscillations

Figure 5 – Kinematics of grinding with radial oscillations

surface of blade movement

If there is no vibration, grinding process on the drum type grinding mill will correspond to the chip removal process when milling with a cylindrical mill (Svinin & Samorodov, 2016) with straight teeth.

If there are no oscillations, cut thickness will be measured along the normal to the cycloid of the cutting surface. This cycloid can be considered as a circle due to non-stable characteristics describing the properties of a treated material and a cutting alloy. The cut thickness is measured along the radius vector R_d. The cut-off particle thickness is variable. The greatest thickness will correspond to the engagement angle ϕ (Figure 4).

Approximately, the greatest thickness is measured as

$$a_{max} = S_z \sin \varphi, \qquad (2)$$

Where: S_z – knife feed

$$S_z = S_n /Z; \qquad (3)$$

S_n – feed per revolution, mm/r.;

Z – number of drum knives;

φ – angle of drum's engagement with the workpiece.

Based on Figure 4, we have found

$$\cos\varphi = \frac{R_d - t}{R_d} = 1 - \frac{t}{R_d}, \qquad (4)$$

Where R_d – radius of the drum in its cross-section;

t – grinding depth.

Since

$$R_d = D_d /2, \qquad (5)$$

Where D_d – diameter of the drum in its cross-section,

we plug (5) in (4) to get

$$\cos\varphi = 1 - \frac{2t}{D_d}, \qquad (6)$$

If we expand $\cos\phi$ into a Fourier series and restrict ourselves to the first two terms, we will get

$$\cos\varphi = 1 - \frac{\varphi^2}{2} = 1 - \frac{2t}{D_d},$$

It follows that

$$\varphi = 2\sqrt{\frac{t}{D_d}}. \quad (7)$$

The obtained expression will allow determining how many knives work simultaneously at grinding.
If we start measuring sinφ, we will find the maximum thickness of the cut

$$a_{max} = S_z \sin\varphi = S_z\sqrt{1-\cos^2\varphi} = S_z\sqrt{1-\left(1-\frac{2t}{D_d}\right)^2} = 2S_z\sqrt{\frac{t}{D_d}-\left(\frac{t}{D_d}\right)^2}. \quad (8)$$

Based on (3)

$$a_{max} = \frac{2S_n}{Z}\sqrt{\frac{t}{D_d}-\left(\frac{t}{D_d}\right)^2}. \quad (9)$$

At $t/D_d \leq 1/20$

$$a_{max} = \frac{2S_n}{Z}\sqrt{\frac{t}{D_d}}. \quad (10)$$

Particle thickness for the mean engagement angle is

$$a_m = \frac{S_n}{Z}\sin\frac{\varphi}{2} = \frac{S_n}{Z}\sqrt{\frac{1-\cos\varphi}{2}} = \frac{S_n}{Z}\sqrt{\frac{t}{D_d}}, \quad (11)$$

Namely, it is equal to the half of a_{max}.

If there are transverse oscillations of the drum, knife blade will additionally cut into the material or leave it at the distance equal to the magnitude of the oscillation amplitude ρ relative to the feed motion (Figure 5) with the oscillation frequency ω_k. In this case, particle sizes will vary within various limits. Thus, the maximum thickness of the cut-off particles will correspond to the case when the value of the maximum knife engagement into the material, equal to the sum of feed S_z and the oscillation amplitude ρ, is equal to value of the engagement angle φ.
Approximately, the greatest thickness can be measured as

$$a_{max}^{\kappa} = (S_Z + \rho)\sin\varphi = S_z\sin\varphi + \rho\sin\varphi, \quad (12)$$

Where: ρ – oscillation amplitude of the knife blade in the cross-section of a drum.

Since (6)

$$\rho \sin \varphi = \rho \sqrt{1 - \cos^2 \varphi} = 2\rho \sqrt{\frac{t}{D_d} - \left(\frac{t}{D_d}\right)^2}, \quad (13)$$

then, according to (10)

$$a_{max}^{\kappa} = a_{max} + 2\rho \sqrt{\frac{t}{D_d} - \left(\frac{t}{D_d}\right)^2} \qquad (14)$$

or

$$a_{max}^{\kappa} = 2\left(\frac{S_n}{Z} + \rho\right)\sqrt{\frac{t}{D_d} - \left(\frac{t}{D_d}\right)^2}. \qquad (15)$$

At $t/D_d \le 1/20$

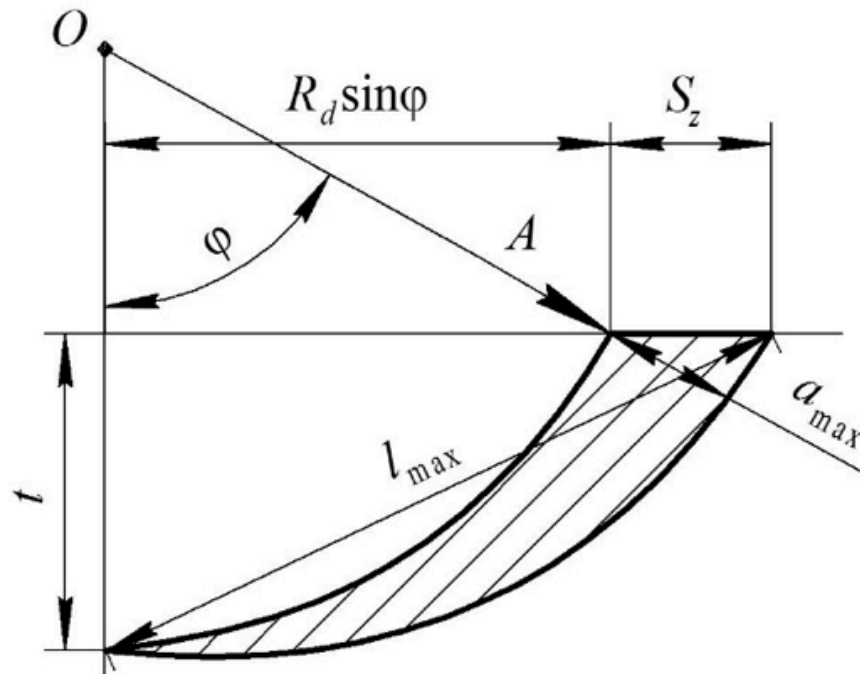$$a_{max}^{\kappa} = 2\left(\frac{S_n}{Z} + \rho\right)\sqrt{\frac{t}{D_d}}. \qquad (16)$$

Now, let's measure particle height. If there are no oscillations, we will get

$$l_{max} = \sqrt{t^2 + (R_d \sin \varphi + S_z)^2} = \sqrt{t^2 + \left(2R_d \sqrt{\frac{t}{D_d} - \left(\frac{t}{D_d}\right)^2} + S_z\right)^2}$$

in accordance with Figure 6, or

$$l_{max} = \sqrt{t^2 + \left(D_d \sqrt{\frac{t}{D_d}} + \left(\frac{S_n}{Z}\right)\right)^2}. \qquad (17)$$

**Figure 6** – Particle cross-section

If there are oscillations during the rotation with ω_{vr} frequency, the knife will perform oscillatory movements in radial directions (Figure 7) with frequency ω. In other words, particle will be cut off not only in the direction of rotation during the engagement with the workpiece, but also cut in radial directions.

In this case, the greatest particle length will be expressed by the relation

$$l^k_{max} = \frac{l_{max}}{k}, \quad (18)$$

Where: k – value characterizing how many times the knife will cut the material in the radial direction during the engagement.

Figure 7 – Facility diagram
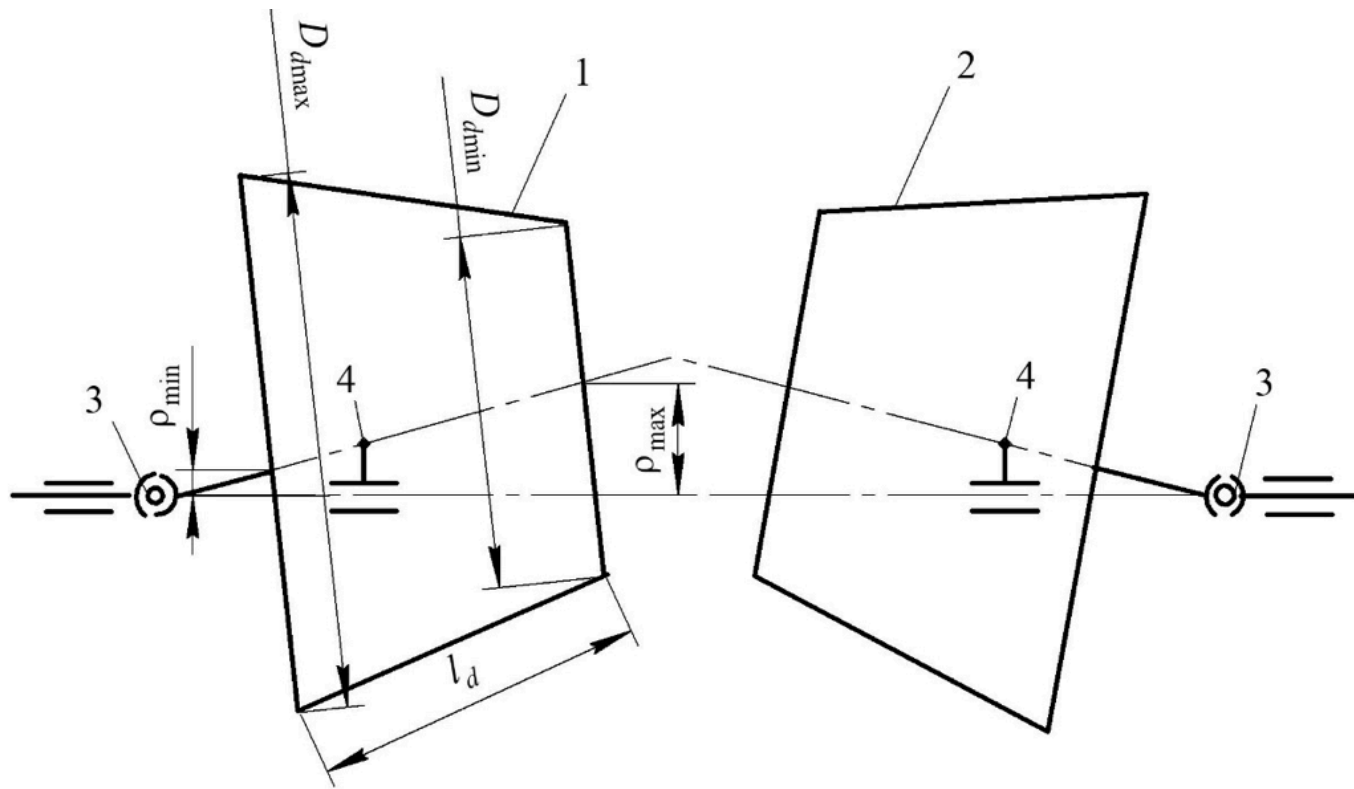
$$k = \frac{\omega_k}{\omega_{vr}} \frac{\varphi}{2\pi}, \quad (19)$$

or

$$k = \frac{\omega_k}{\omega_{vr}\pi} \sqrt{\frac{t}{D_d}}, \quad (20)$$

if we take into account (7).

In the second case, ω_{vr} – drum rotation frequency;
ω_k – drum oscillation frequency.

Particle length will be determined by the drum length l_b, namely – by the length of knife blades. For the record, drum can consist of disc milling cutters.

Since the 1st and the 2ed drums of the cutter are conical (Figure 7), they will have different diameters at different lengths. It will increase with distance from the support 3 connected to the cam 4. In this case, the amplitude of drum oscillations will decrease with distance from 3. According to (15), value of the greatest particle thickness will be equal to the value of the smallest knife blade diameter, namely – to the diameter of the smaller drum cone base.

4. Discussion

As the oscillation amplitude increases, the greatest value of the cut-off particle thickness increases. As the oscillation frequency decreases, the greatest value of the cut-off particle length increases.

Since mathematical models (1,15,17-20) allow us to measure the shape and size of dispersed particle hypersurface, we are able now to model and control the process of dispersion with a computer and modern software tools in real time (Sergeev et al., 2015).

The computer-based simulator of chip formation with specified shape and size through cutting is based on the mathematical logic apparatus, since our problem can be mathematically described as the process of finding constituents. Thus, problem to be solved involves the main fundamental factors affecting the cutting process. Secondly, we have had regard to the fact that shapes of particles cut off by the cutting edges (due to the influence of these factors) are complex related hypersurfaces and depend on whether there is (conjunction) a trace left by the previous cutting blade at the each moment of time or not (disjunction). In other words, mathematical model takes into account that each subsequent chip surface cut off by the i-th cutting blade has initial conditions, depending on the previous cut-off layers.

We have used (instead of conjunction and disjunction) the R-conjunction $u_{i-1} \wedge_{i-1} u_i$ in a mathematical model consisting of logical predicates for real chip surfaces separated from the workpiece by each cutting blade:

$$u(i_1, i_2, ..., i_z) = (...(u_1 \wedge_1 u_2) \wedge_2 ...) \wedge_{z-1} u_z \geq 0, \text{ (21)}$$

Where: z – number of cutting blades;

u_i – amount of chips cut off by the i-th cutting blade (target or objective functions in the algebra of logic)

$$u_i = f_i \times l_i \geq 0; \qquad \text{(22)}$$

$(u_{i-1} \geq 0) \wedge (u_i \geq 0)$ – conjunction (logical multiplication) of two boolean variables or a function

$$f(u_{i-1}, u_i) = u_{i-1} u_i = \min(u_{i-1}, u_i).$$

f_i – surfaces of layers cut off by the i-th cutting blade;

l_i – cutting blade's midpoint trajectory.

For example, mathematical model (21) at $z = 4$, based on (22), will be as follows

$$u(i_1, i_2, i_3, i_4) = ((f_1 \times l_1 \wedge_1 f_2 \times l_2) \wedge_2 f_3 \times l_3) \wedge_3 f_4 \times l_4 \geq 0.$$

If we consider a chip as an object bounded by half-planes, equation for the area of the cut-off layers with conjunction will be as follows

$$f_i = \sum_1 \wedge \sum_2 \wedge \sum_3 \wedge ... \wedge \sum_j, \quad \text{(23)}$$

Where: $\sum_j$ – boundaries of the half-planes.

This program is designed for high-precision simulation of the real-time dispersion by cutting. Layer formation by each of the mill teeth is modeled with regard to the synchronization of its rotation frequencies and transverse oscillations. This program allows measuring and adjusting the chip size and shape by redistributing the cut-off layers by means of the cutter teeth. In terms of dispersion visualization (Figures 8 and 9), simulator can serve as an application and complement different (VeriCut, Sprut, NCTuner, NX, etc) software packages, designed to test the control programs. It will be useful to disperser designers, powder and fiber producers, specialists engaged in treating solid waste into secondary raw material.

Figure 8 – Animated process of grinding a plate with a five-tooth mill
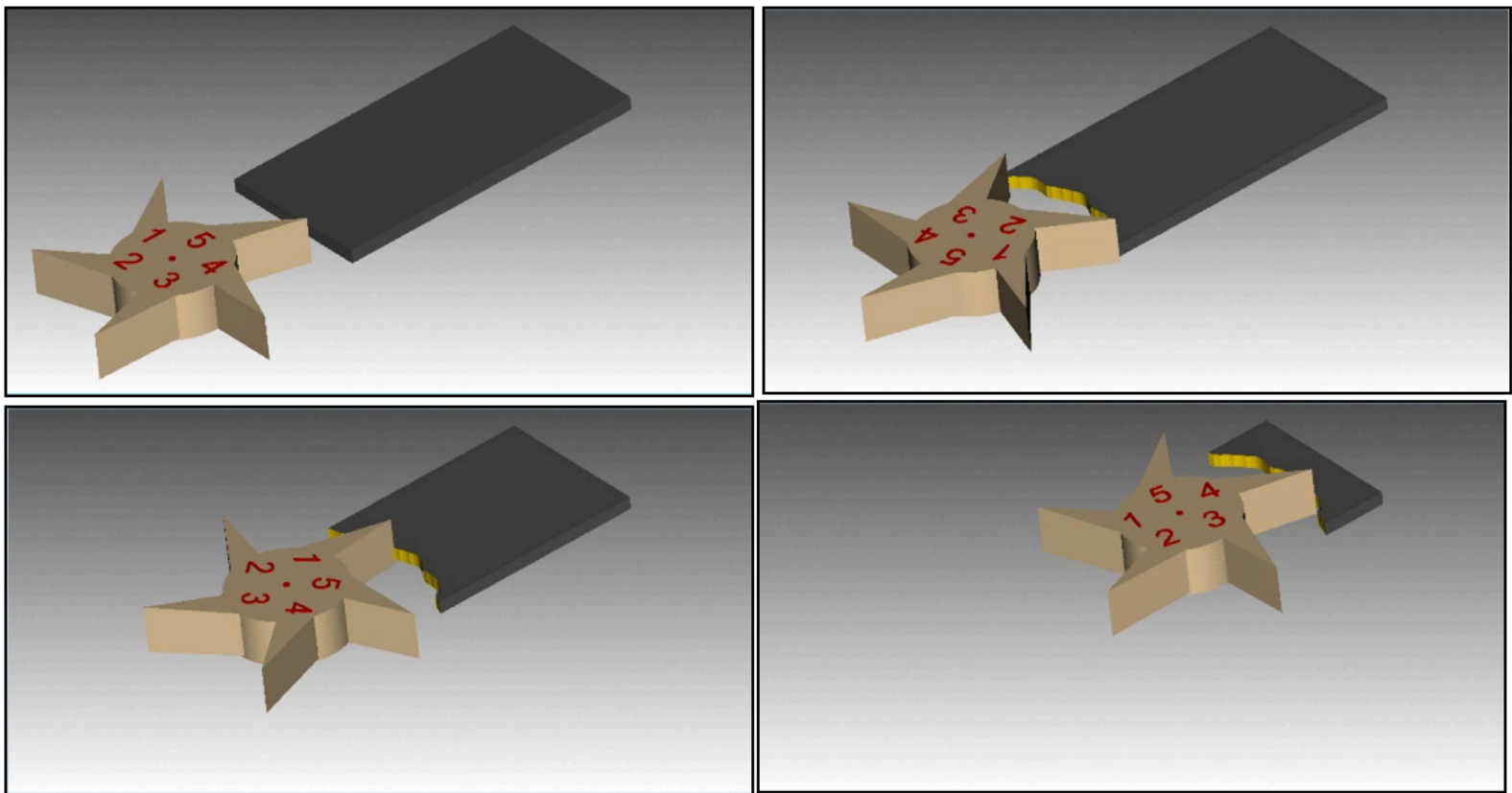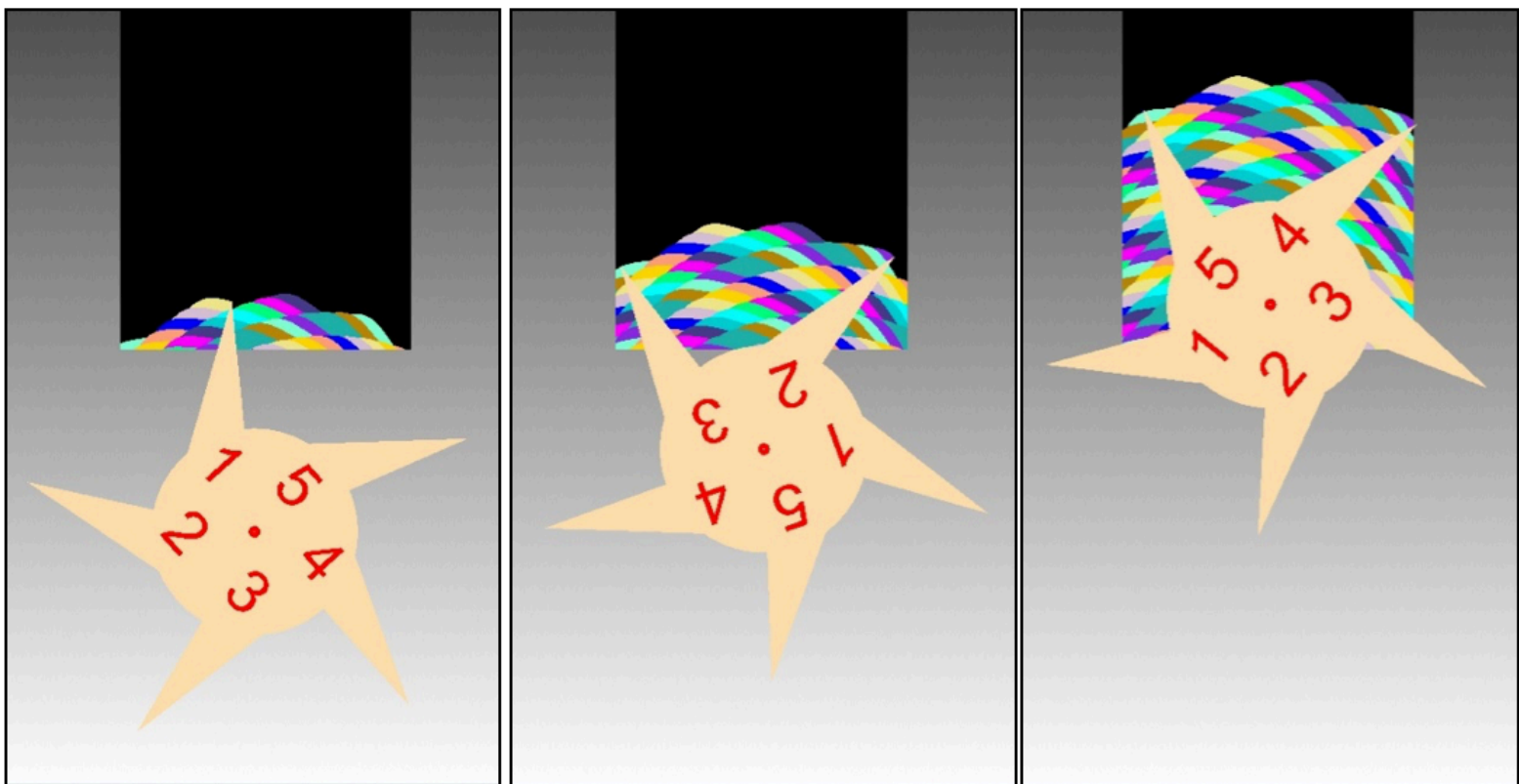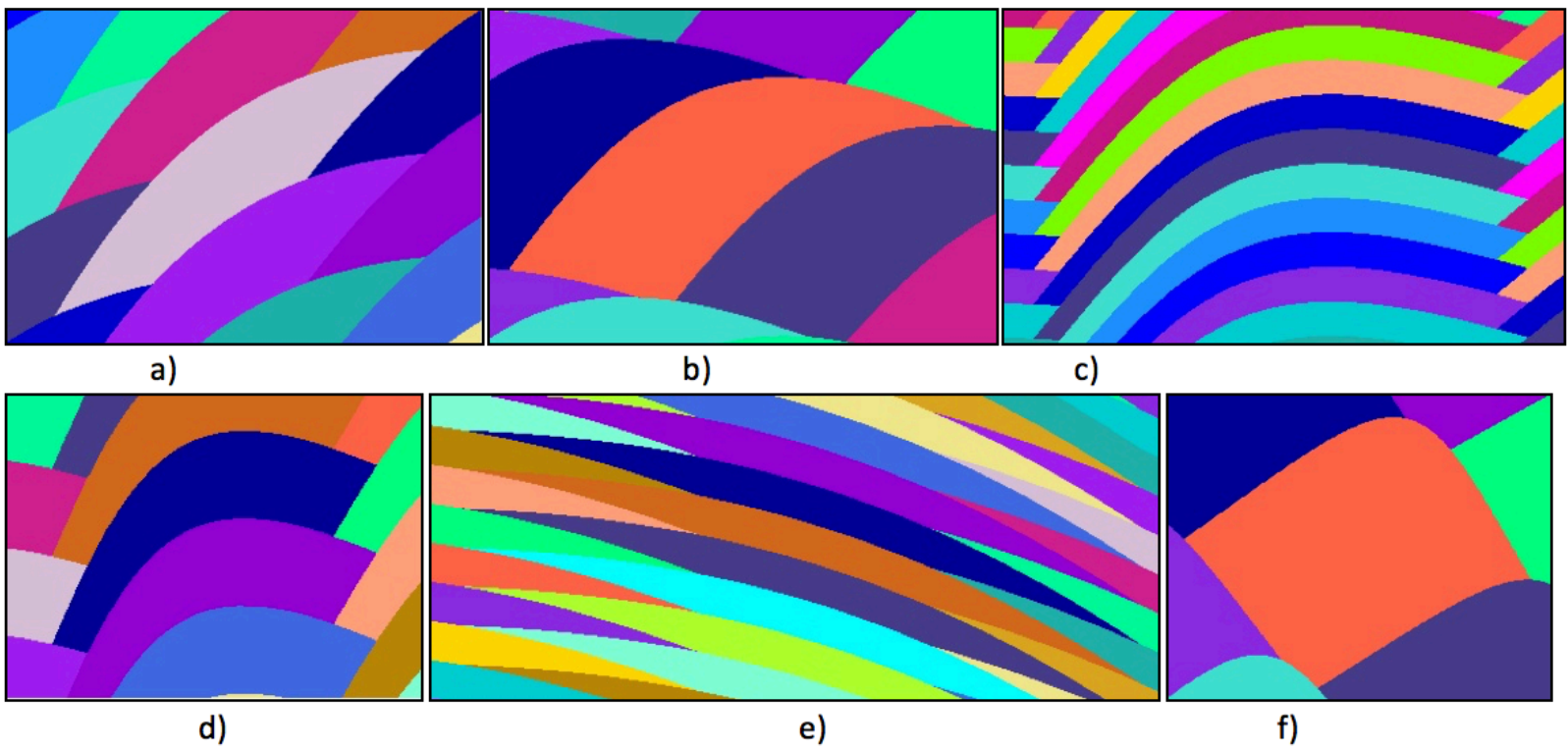

Figure 9 – Animated process of particle formation with specified shape by the oscillatory mill movements

In the course of computer-based dispersion modeling, this program allows controlling the shape and size of dispersed particles in a wide range (Figure 10)

Figure 10 – Examples of particle shape control by changing the oscillation parameters

a)

b)

c)

d)

e)

f)

a) $A = 2.5$ mm, $k/v_r = 6.5$; b) $A = 4.5$ mm, $k/v_r = 4.3$;

c) $A = 3.5$ mm, $k/v_r = 4.2$; d) $A = 5.5$ mm, $k/v_r = 4.2$;

e) $A = 0.5$ mm, $k/v_r = 6.5$; f) $A = 6.5$ mm, $k/v_r = 4.3$;

The control is carried out by changing the technological process parameters: forced oscillation amplitude of the mill and the ratio of rotation frequencies and its oscillations. The simulator allows not only measuring the sizes and volumes of dispersed particles, but also visualizing the entire cutting process (Figures 11 and 12).

Figure 11 – Granulation process report form. The first report sheet
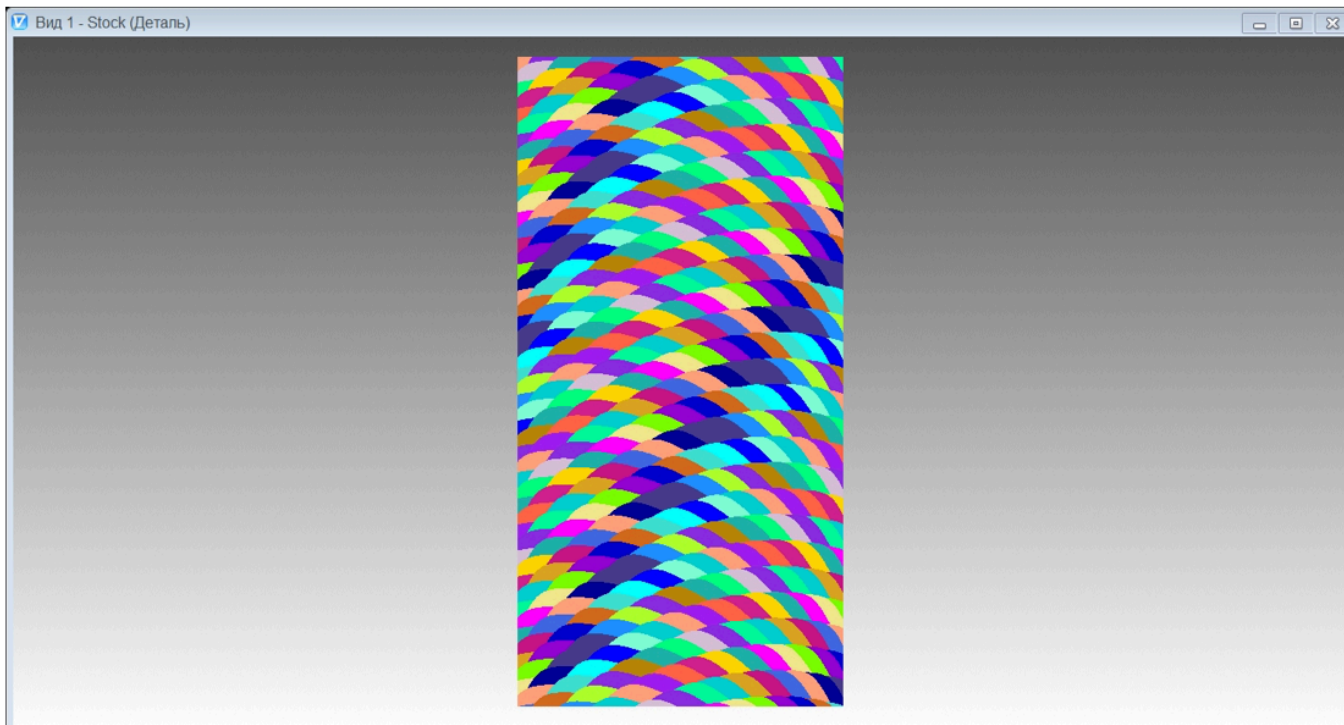(automatically generated when the simulation is complete)

Figure 12 – Granulation process report form. The second report sheet
(automatically generated when the simulation is complete)

Volume of formed particles (cubic millimeter)						
7.8059	55.1151	52.7499	52.0928	55.2392	55.7833	54.4369

19.9729	54.8043	90.9609	55.1215	52.7104	52.0783	55.2545
18.8837	61.8199	53.5314	54.8591	55.0076	55.1431	52.7144
51.4513	64.9913	55.3955	61.8097	53.5274	54.8259	90.9958
31.8045	54.6571	53.9282	64.9907	55.3941	61.8292	53.5234
22.0125	55.3084	55.6384	54.6676	53.9472	64.9753	55.3926
55.1633	52.5689	52.2133	55.2808	55.6253	54.6636	53.9231
54.7765	55.0591	55.1767	52.5858	52.1609	55.2682	55.6852
15.3481	53.4453	54.7079	55.0769	55.2047	52.588	52.1085
21.0451	55.2213	61.6898	53.4452	54.7271	55.0948	55.1454
54.4016	53.8848	65.1271	55.2226	61.6728	53.4454	54.7464
55.1889	55.9097	54.4022	53.8838	65.1295	55.2093	61.6704
52.7588	52.0916	55.2332	55.9237	54.4027	53.8681	65.1464
16.8998	55.0662	52.8584	52.0765	55.2187	55.8496	54.4179
53.5572	54.8215	55.1492	55.0658	52.8539	52.0468	55.2189
55.5224	61.7484	53.5789	54.8497	55.1158	55.08	52.8201
53.8446	65.0154	55.4767	61.7648	53.6261	54.8486	55.1234
48.8037	54.55	53.8603	64.9851	55.4748	61.8105	53.6587
52.016	55.2308	55.5056	54.5526	53.8468	64.984	55.4875
55.0748	52.5481	52.0355	55.2316	55.5701	54.5845	53.8772
54.6668	55.0336	55.0882	52.5496	52.0396	55.2468	55.5756
55.4256	53.4674	54.5945	55.0634	55.1016	52.5364	52.0454
52.9726	55.4663	62.1062	53.4215	54.6103	55.0934	55.115
54.5521	53.9503	65.0553	55.4478	62.0678	53.3755	54.6127
55.3739	55.875	54.5294	53.9356	65.0282	55.4584	62.0148

52.7209	52.1591	55.4436	55.8371	54.5214	53.9355	65.0321
55.1358	55.09	52.6962	52.1585	55.4401	55.8431	54.4987
53.3933	54.9263	55.0931	55.1043	52.6861	52.1575	55.3914
55.3088	61.6021	53.3666	54.8809	55.1376	55.0602	52.7051
53.8245	64.9514	55.3421	61.6351	53.3554	54.8943	55.1237
55.7623	54.3633	53.7799	64.9534	55.331	61.6239	53.4028
52.0634	55.2093	55.7876	54.3929	53.7938	64.9845	55.3783

5. Conclusion

Thus, obtained results have proved the principal possibility of forming cut-off layers of required size and shape by introducing forced oscillations of a rotating multiple-cutting-edge tool into the cutting area. In the future, this opportunity made it possible to implement a fundamentally new direction in processing metals and plastics – dimensional dispersion of materials, including waste.

The process of modeling dimensional dispersion by cutting allows controlling the size and shape of dispersed particles while their PSD stability increases, as well as determining its capabilities in regards to criteria.

The major conceptual basis is the practical implementation of the very process of dimensional dispersion, since the literary sources presented this concept only as a problem statement. Currently, dimensional mechanical dispersion is a fundamentally new direction, which is only being formed under the demand of powder and fiber producers, as well as under the demand of specialists engaged in industrial and household solid waste treatment. The existing dispersers work on the principle of "coffee grinder" and do not allow controlling the process. Therefore, it is important to conceptually change the attitude towards the dispersed particle formation. In other words, one has to treat it as the process of producing parts with metrological parameters: size and shape accuracy. Therefore, cutters and grinders have to be brought to the level of vibration disperser designs, which make it possible to meet these parameters. Their designs must also have the technological parameter tuning units. Obtained mathematical models make it possible to carry out the computer-based predictive modeling of dispersed particle formation. This opens the way to the creation of automatically-operated vibration dispersers for viscous media.

References

Balaykin, A. V., Smelov, V. G., Chempinskiy, L. A. (2012). Application of additive technologies for creating combustion chamber parts. Bulletin of Samara University. Aerospace technology, tech-nology and engineering. no. 3–2 (34), 47–52.

Chumanov, I. V., Chumanov, V. I., & Anikeev, A. N. (2015). Investigating the effect of carbide

disperse particles on hardness and wear resistance of experimental materials in cast and deformed conditions. Indian Journal of Science and Technology, 8(34).

Chumanov, I. V., Kareva, N. T., Chumanov, V. I., & Anikeev, A. N. (2012). Study and analysis of the structural constituents of billets hardened by fine-grained particles and formed by centrifugal casting. Russian Metallurgy (Metally), 2012(6), 539-541.

Chumanov, I., Anikeev, A., & Chumanov, V. (2017, February). Reinforcement of the bulk crowns excavator technology by dispersion hardening of titanium carbide to increase wear resistance. In IOP Conference Series: Materials Science and Engineering (Vol. 179, No. 1, p. 012031). IOP Publishing.

Chumanov, V. I., Chumanov, I. V., Anikeev, A. N., & Garifulin, R. R. (2010). Hardening of the surface layers of a hollow billet formed by centrifugal casting. Russian Metallurgy (Metally), 2010(12), 1125-1128.

Gordeev, E. N., Sergeev, S. V., & Chumanov, I. V. (2010). Improvement of the processing of the wastes of nonferrous metals into high-quality secondary raw materials. Russian Metallurgy (Metally), 2010(12), 1173-1174.

Gordienko, V. P., Mustyatsa, O. N., & Kovaleva, G. N. (2016). The effect of combined dispersion of polyethylene and carbides on the structure and physicomechanical properties of composite materials. International Polymer Science and Technology, 43(7), T15.

Hamran, N., & Rashid, A. A. (2017). Effect of combination ultrasonic and ball milling techniques of commercial fillers dispersion on mechanical properties of natural rubber (NR) latex films. In AIP Conference Proceedings (Vol. 1865, No. 1, p. 040011). AIP Publishing.

Hayes, E., Cnuts, D., Fullagar, R., Pardoe, C., Clarkson, C., & Stephenson, B. (2014). Experimental replication of Australian grinding stone implements.

Kalpakjian, S., & Schmid, S. R. (2014). Manufacturing engineering and technology (p. 913). Upper Saddle River, NJ, USA: Pearson.

Kumabe, J. (1979). Vibration cutting—basic principle and application. Japan: Jikkyo Shuppan Books.

Lakirev, S. G., Sergeev, S. V., Gordeev, E. N., Reshetnikov, B. A., Zakirov, R. G. (2003). Sposob i ustroystvo izmel'cheniya materialov. Method and device for grinding materials. Patent RF 2213618, no. 2002102797/03; decl. 31.01.2002. No. 28. 56.

Lakirev, S. G., Sergeev, S. V., Reshetnikov, B. A., Zakirov, R. G., Gordeev, E. N. (2003). Research and improvement of technology of manufacturing of products from a concrete mix. Bulletin of South Ural State University. Ser. «Construction and architecture». vol. 2, no.7 (23), 32–34.

Ouelaa, N., Younes, R., Hamzaoui, N., & Djebala, A. (2017). Experimental Study of Real Gear Transmission Defects Using Sound Perception. In Applied Mechanics, Behavior of Materials, and Engineering Systems (pp. 267-274). Springer International Publishing.

Parveen, S., Rana, S., & Fangueiro, R. (2013). A review on nanomaterial dispersion, microstructure, and mechanical properties of carbon nanotube and nanofiber reinforced cementitious composites. Journal of Nanomaterials, 2013, 80.

Poduraev, V. N. (1985). Tekhnologiia fiziko-khimicheskikh metodov obrabotki. Mashinostroenie.

Şahin, Y., & Yalcinkaya, S. (2016). Application of Taguchi Technique to Surface-Grinding of Mold Steel. Delta, 3(2.3051), 0-6546.

Salernitano, E., Migliaresi C. (2003). Composite materials for biomedical applications: a review Journal of applied biomaterials & biomechanics. JABB. Jan-Apr;1(1). 3-18.

Sandalov, V. M., & Sergeev, Y. S. (2012). Dynamic model of switched reluctance vibratory drive. Russian Electrical Engineering, 83(8), 432-435.

Sergeev S. V., Gordeev E. N. (2009). Recycling of composite materials based on metal. Safety

in Technosphere, 2009, no. 2, 38–40.

Sergeev, S. V., Gordeev, E. N. (2010). Improvement of the process of grinding of metal and plastic wastes during their processing. Chelyabinsk, South Ural St. Univ. Publ. 110.

Sergeev, S. V., Gordeev, E. N., Sergeev, Yu. S., Sahautdinov, I. R., Gogolev, V. P., Schepin, M. A. (2011). Program for calculating and modeling chip elements for size grinding on vibration milling machines. Certificate of state registration of a computer program 2011617667, no. 2011615885; decl. 03.08.2011.

Sergeev, S. V., Reshetnikov, B. A., Gordeev, E. N., Sergeev, Yu. S. (2009). Method for grinding viscous materials. Patent RF 2365469, no. 2007136686/02; decl. 04.10.2007. No. 24. 14.

Sergeev, S. V., Reshetnikov, B. A., Gordeev, E. N., Sergeev, Yu. S., Gogolev, V. P., Zakirov, R. G., Mikryukov, A. A., Irshin, A. V. (2014). Method of excitation of oscillations. Patent RF 2533743, no. 2013121307/28; decl. 07.05.2013. No 32. 12.

Sergeev, S. V., Sergeev, Yu. S., Shelegov, A. A., Karpov, G. E., Egorov, S. I. (2016). Simulator of the forming of chip elements of a given shape and size. Certificate of state registration of a computer program 2016616657, no. 2016613942; decl. 21.04.2015.

Sergeev, Yu. S. (2011). Drives of vibration machines based on switched reluctance drive. Abstract of cand. sci. diss. Chelyabinsk, 22.

Sergeev, Yu. S., Sergeev, S. V., Karpov, M. A. (2016). Results of search design of devices for extraction of metal-containing waste from metallurgical slags. Nauka YUUrGU. Materialy 68-y nauch-noy konferentsii. Science of SUSU. Materials of the 68th scientific conference. 1209–1213.

Sumelka, W., Zaera, R., & Fernández-Sáez, J. (2016). One-dimensional dispersion phenomena in terms of fractional media. The European Physical Journal Plus, 131(9), 320.

Svinin, V. M., Samorodov, P. A. (2016). Investigation of the dynamic stability of a heavy technological system in the face milling with the variable step of the tool torques. Mechanics of the XXI century. № 15. pp. 167-173.

Webster, J. G., & Eren, H. (Eds.). (2014). Measurement, instrumentation, and sensors handbook: spatial, mechanical, thermal, and radiation measurement (Vol. 1). CRC press.

1. South Ural State University, Ave. Lenin, 76, Chelyabinsk, 454080, Russia.
2. South Ural State University, Ave. Lenin, 76, Chelyabinsk, 454080, Russia.
3. South Ural State University, Ave. Lenin, 76, Chelyabinsk, 454080, Russia.

[Index]

[In case you find any errors on this site, please send e-mail to webmaster]