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AUTOMATED DEFINITION OF THE DISCRETE ELEMENTS INTERACTIONS IN WORKSPACE OF EQUIPMENT

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Abstract. *Automated monitoring of the presence of such particles present near the main operational means of production or medical equipment with the determination of their trajectories is necessary to improve the efficiency of this equipment and the quality of operations. When performing measurements of the parameters of abstract objects of different origin and properties, for example, at precise parts production, problems of contamination of the surface of the object with discrete particles of another origin are often encountered. It is now known that every abstract entity forms around the area of the presence of solid particles. These solid particles, under the action of interaction forces, have the property to be ordered in space and on the surface of the object.*
This paper is a result of research and modelling of the interaction of such particles during their shredding and their structural self-organization. Severally consideration is given to the formation of dust layers under the action of coupling forces is reviewed. Models of behaviour of these layers for some typical surface forms of control object are created.

Keywords: workspace of equipment, abstract entity, presence zone, space, interaction of elements

AUTOMATYCZNE OKREŚLANIE INTERAKCJI ELEMENTÓW DYSKRETNYCH W PRZESTRZENI PRACY URZĄDZEŃ

Streszczenie. *Zautomatyzowane monitorowanie obecności takich cząstek znajdujących się w pobliżu głównych środków operacyjnych produkcji lub sprzętu medycznego wraz z określaniem ich trajektorii jest niezbędne do poprawy wydajności tego sprzętu i jakości operacji. Podczas wykonywania pomiarów parametrów obiektów abstrakcyjnych o różnym pochodzeniu i właściwościach, na przykład przy wytwarzaniu precyzyjnych części, często napotykane są problemy z zanieczyszczeniem powierzchni obiektu dyskretnymi cząstkami obcego pochodzenia.*
Obecnie wiadomo, że każdy abstrakcyjny obiekt podmiotu tworzy strefę obecności stałych cząstek wokół siebie. Te stałe cząstki pod działaniem sił oddziaływania mają właściwość do uporządkowania w przestrzeni i na powierzchni obiektu. W artykule przedstawiono wyniki badań i symulacji interakcji takich cząstek podczas ich niszczenia i ich strukturalnej samoorganizacji. Osobno rozważa się tworzenie warstw pyłu pod działaniem sił sprzęgających. Modyfikuje się zachowanie tych warstw dla pewnych typowych powierzchniowych obiektów kontrolnych.

Słowa kluczowe: obszar roboczy sprzętu, abstrakcyjny obiekt, strefa obecności, przestrzeń, interakcja elementów

Introduction

The problem of determining the presence of particles of various origins in the space of working equipment is characteristic both for application in industrial production conditions and in the conditions of operation of medical equipment. Therefore, the automated monitoring of the presence of such particles present near the main operational means of production or medical equipment with the determination of their trajectories is necessary to improve the efficiency of this equipment and the quality of operations. At the same time, it is necessary to take into account the possibility of correcting particle trajectories to obtain a certain number of particles and their location coordinates in the working space of the equipment.

Since all research concerns objects of different origins and different applications, however, the problem is the same in view of the importance of determining the nature of the presence and interactions of particles in space, we will define the main object of research as an abstract entity (AE).

On the general background of the abstract entity properties, there are a number of physicochemical effects characteristic of the formation of a zone of presence of individual elements in the space around this entity. These effects form the criteria for determining the parameters of the interaction of elements. One such criterion of signs is the gradual decrease of any parameter of the presence zone of the individual elements and the object itself without determining the critical situation of the function, that is, its derivative does not change the sign within the scope of this law [17, 18].

So, for the time being, we have a series of laws that, in one case or another, gradually decline in their capacity without a hopping derivative. That is, it is a field structure of a steady decrease in power interaction [18]. As a result, we have a case where several independent forces act on the presence zone's discrete segment. For equilibrium and rest in space, the sum of all forces acting on the AE object must be zero. However, this is far from the case, since equilibrium exists only in an imaginary form.

In a real coordinate system, this is simply impossible, because we have the possibility of an imaginary stop for an imaginary coordinate system and we have no possibility of such a stop for the real one. Thus, the situation with regard to the presence zone's segment is illusory and does not correspond to reality. Consequently, as a result, we have drift in space and time as a result of the action of a number of deterministic spatial forces. At present, it has the form of the Brownian movement with a number of diverse varieties [3]. The following parameters are very important for this type of movement: form, speed, mass and size of the Pandan zone [16–18], and the resulting vector of external force.

Thus, in the purpose to research all these parameters, it is necessary to determine with those that have not been considered in one or another researches.

1. Model of the force's interactions in presence zone of abstract object

Thus, it is first necessary to consider the varieties of cases of placement of presence zone's particles in the near-surface layer of media and circle of the AE surface. Currently, such cases are shown in Fig. 1.

Thus, in the study of behaviour of the particles in presence zone of object, we must take into account the following variants of power interaction with environment. The simplest case and the most generalizing are discussed (Fig. 1a). In this variant, we have a generalized situation, which is partly in the near-surface layer of environment relative to the AE surface.

So, we have a classical three-element diagram.

The first component, this is the main force, which attracts the particles to the AE surface. The second component is counterproductive to the previous, that is, it is repulsive. The third component is a tangential force that moves a part along the AE surface.

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Consequently, the total vector amount of forces has the form

$$\mathbf{F}_{\Sigma} = \mathbf{F_O} + \mathbf{F_B} + \mathbf{F}_{\tau} \quad (1)$$

where $\mathbf{F_O}$ – component of the precipitate; $\mathbf{F_B}$ – repulsive component; $\mathbf{F}_{\tau}$ – tangential force.

Analyzing the forces that form the equation (1), we have the opportunity to assert the following.

The forces that create values $\mathbf{F_O}$, $\mathbf{F_B}$, $\mathbf{F}_{\tau}$, have the following components:

$\mathbf{F}_{\mathbf{grav.}}$ – gravitational force acting between any AE that has the final shape and mass,

$\mathbf{F_e}$ – electrostatic gravity between objects of AE;

$\mathbf{F_m}$ – component of the magnetic force of attraction in the presence of magnetic properties between objects,

$\mathbf{F_{ADF}}$ – aero and dynamic forces, which create not only active forces in the direction to the surface, but also different projections from planar parallel to near-surface action.

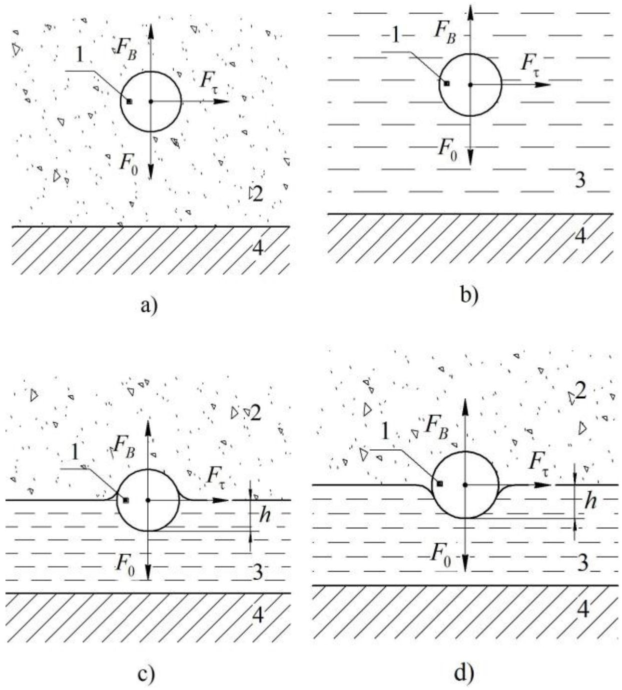

Fig. 1. Cases of location and interaction of presence zone particles on AE surface: a) a general diagram of the forces acting on the presence zone segment in the uncertain environment; b) a diagram of the forces acting on the presence zone portion in a liquid near the surface of the AE; c) a diagram of the forces acting on the presence zone lattice that is wetted when it is located on the surface of the liquid in near-surface layer of AE; d) a diagram of the forces acting on discrete particle that is not damped on the surface of near-surface layer of the liquid AE; 1 – discrete particle, 2 – environment, 3 – liquid, 4 – AE surface

The next component is repulsive $\mathbf{F_B}$, which has a number of components of the following type; $\mathbf{F_A}$ – archimedean force, which is essential in the case when the particle is in the surface environment; $\mathbf{F_e}$ – electrostatic force in the case where the charge particles and the AE surface are opposite; $\mathbf{F_{CF}}$ – centrifugal force, when the objects are in a state of rotation.

The next component is a tangential force $\mathbf{F}_{\tau}$, that is parallel to the surface and has a number of components of the following type: $\mathbf{F_{ST}}$ – force of the surface tension, which does not always have a constant value; $\mathbf{F_{ADF}}$ – aero and hydrodynamic force, which is a consequence of movement of the environment.

Consequently, if we considered to the classical cases of the location of a particle in the near-surface layer of the environment around the AE (Fig. 1a). At the same time, we obtain the situation with respect to the external environment, its density and motion, which causes the displacement of the particles in space. As a result, the spatial vector diagram has the following components.

Firstly, this is what causes the sediment processes in the stratum relative to the surface of the AE.

$$\mathbf{F_0} = \mathbf{F_{grav.}} + \mathbf{F_e} + \mathbf{F_m} + \mathbf{F_{ADF}} \quad (2)$$

Consequently, the force $\mathbf{F_O}$ leading to the precipitation is always directed towards the AE surface by normal and is main holding part [3].

The first force $(\mathbf{F_{grav.}})$, that leads to this movement is the gravitational, directed towards the straight line, carried through the centers of the weight of the object and the lobes. This force is unipolar, that is, in any case, it does not change its polarity

The second force $(\mathbf{F_e})$, that is part of the sediment force is electrostatic. The peculiarity of this force is that it may have different polarity. In this case, with multipolar charges of particles and surfaces, the gravitational force is much larger than gravitational and is higher.

The direction of action is similar to gravitational and is directed to normal to the surface.

The next force acting in the direction of the sediment is magnetic force $(\mathbf{F_м})$. The peculiarity of this force is that it operates in two cases. First, if the lattice and the AE have magnetic properties, they are attracted according to the laws of the magnetic field.

In the second case, if the lattice has electrostatic properties, and AE is magnetic.

In this case, in any third-party motion, the interaction between the particle and the field of the AE arises according to Maxwell's law [1].

The resulting motion is a combination, which gives the corresponding components force $\mathbf{F_O}$ and $\mathbf{F}_{\tau}$.

Another forces worth paying attention to is aero and hydrodynamic, which has the properties of both repulsion and attraction, depending on the direction of the environment flow.

The force that opposes the sediment is the force $\mathbf{F_B}$ of repulsion. This force has the following components. Firstly, it is the Archimedes force, since it acts on any environment density

$$\mathbf{F_B} = \mathbf{F_A} + \mathbf{F_e} + \mathbf{F_{CF}} + \mathbf{F_{ADF}} \quad (3)$$

This force acts in the direction of the minimum pressure of environment.

As already mentioned above, one of the components of the repulsion force can be electrostatic in the case, where the polarity of the particle and the AE is such, that they are repulsed from each other. Another one may be the centrifugal force that arises from the joint rotation of the particle and AE.

The last component of this force can be aero and hydrodynamic ($\mathbf{F_{ADF}}$), which occurs during the movement of the environment relative to the AE surface.

The third force acting on a particle is tangential $(\mathbf{F}_{\tau})$ force, which has an orientation vector, which is perpendicular to the two forces $\mathbf{F_O}$, $\mathbf{F_B}$. This force has the following components that act on the particle of presence zone. The first force is force $\mathbf{F_{ST}}$ of the surface tension

$$\mathbf{F}_{\tau} = \mathbf{F_{ST}} + \mathbf{F_{ADF}} \quad (4)$$

This force is formed on the interface between two media with different physical properties.

The second component is the aero and hydrodynamic forces, or rather its component, which directed along the surface of environments distribution.

By imaginary presence zone of solid elements modelling, we took a discrete element in the form of a sphere of the correct form with the required diameter for the solution of the problem [1, 11]. However, in the transition to a real situation, this is far from the case. There are currently several classifications. All of them have specific directions and components. According to the authors, the main classification should be considered natural because it does not have artificial signs.

The second artificial classification has a specific technical application that meets our technological requirements.

So, first let's look at the natural classification of discrete solid presence zone, since it is the oldest and most used.

It currently consists of the following groups:

- wreck breeds, which are fragments of different rocks and minerals;
- clay rocks, which are different types of fine dispersed fractions of amorphous nature;
- chemical rocks, which are residues, having fallen into the precipitate of chemical compounds (gypsum, limestone, etc.) [11, 12];
- organic breeds, which are residues that have fallen into the sediment of dead plants and animals (shellfish, coal, etc.);
- mixed breeds, which represent a mix of all previous components in different proportions.

All these breeds represent the Earth's presence zone [6, 10] and meet us in everyday life at every step. At present, we are interested in wreck breeds, as their destruction leads to the appearance of most others.

The natural classification of the debris of rocks is immediately divided into two main groups: loose (loose) and compact (compacted) [11–13]. Both of these and other groups in turn consist of two subgroups, namely corrugated and rolled. In addition, some of the rock sedimentary rocks refer to both, and to the second subgroup.

Since we are more interested in wrapped up as a product of natural "processing", then we will consider them more reliably. Coated sedimentary rocks are in the shape of the closest to the ball, because in this case the Pandan zone of the debris is exposed to intense pressure. Such a load leads to the destruction of acute protrusions [8]. The general diagram of the action of forces on the fragment leads to the fact that there is a resultant force that rotates a fracture when interacting with others. In the end it leads to a spherical shape.

So, according to this classification, for loose rocks we have the following:

- boulders – rolled up fragments larger than 100 mm;
- pebbles – rolled fragments with a diameter of 10 to 100 mm;
- gravel – rolled fragments with a diameter of 1 to 10 mm;
- sand – rolled and not rolled fragments in diameter from 0.1 to 1 mm;
- aleurite – rolled and not rolled fragments in diameter from 0.01 to 0.1 mm;
- dust – rolled and not rolled fragments with a diameter less than 0.01 mm.

The last three varieties refer to both rolled up and not rolled up. All these varieties, when deposited in a precipitate, form a cemented mass called conglomerate, gravelite, sandstone, and aleurolite. All these factions, consisting in different proportions form the surface accumulation of the globe, creating a number of mineral deposits that are used in the science and technology of industrial production [4]. For engineering, it is very important to mix solid particles and liquids called slurries. Suspensions are conventionally divided into the following kinds:

- coarse suspensions are liquid substances that contain suspended particles with a diameter greater than 100 μm;
- thin suspensions, these are liquid substances filled with particles of solid phase in the size from 0.5 μm to 100 μm. It is at this level of size that the beginning of the Brownian motion begins to occur;
- cloudy are suspensions, where the particle size from 0.5 μm to 0.1 μm has an intense Brownian motion when the particles do not fall precipitated;
- colloidal solutions with particles of a dispersed phase of 0.1 μm or loess to the size of molecules.

Consequently, dust particles are either on the surface of the AE or move in the near-surface area. In addition, the movement is of such a nature that particles of dust are trying to settle on the surface of the object. With all the chaos of this movement, he has some focus on the principle: the smaller object moves towards the greater. Usually this process takes place under the action of gravity, which is always present between bodies that have a finite mass [6]. The collision of particles and deterministic motion is very similar to Brownian motion.

At present, this kind of movement deals a molecular physics, so it is possible with certain restrictions to apply its theoretical foundations. In this case, we have the opportunity to consider the discrete presence zone up to the level of the molecule, because the molecule is also an element of this zone, under such a thesis the application of molecular-kinetic physics is quite justified. The best example here may be sublimation. Consequently, we need to investigate the speed of motion, the trajectory and the degree of its determinism [7, 14, 15].

Let's start with the elementary motion, which occurs in the solid state zone, namely, by the force of gravity. Clearly, the velocity obtained by the lobe during the fall t will be determined as

$$V = g \cdot t \tag{5}$$

where g is the acceleration of gravity.

This equation is valid for a vacuum, but in the presence of liquid or air in the surface space, it does not justify itself. Consequently, when the objects fall in small sizes, less than 1 mm, at a certain speed, they have such resistance to material, that begins to move at a constant rate. The velocity of such a uniform fall is called the rate of precipitation [9]. in the general case, this speed can be determined from the general law of motion resistance of the mass in the environment. The constant rate of precipitation will be reached when gravity becomes equal to strength of the material resistance of environment, which is determined by Newton's law, that is

$$F_0 = \eta \cdot S \cdot d_c \frac{V_0^2}{2g} \tag{6}$$

where η – coefficient of material resistance, S – projection of cross-section of Pandan zone particle, d_c – specific gravity of material.

If we accept the conditions of simulation, that is, the particle has the form of a sphere, then $S = \pi D^2/4$, and equation (6) takes the form

$$F_0 = \eta \frac{\pi D^2}{4} d_c \frac{V_0^2}{2g} \tag{7}$$

In this case, the weight of the spherical particles (except Archimedes forces) will be determined as

$$P = \frac{\pi D^3}{6}\left(d_0 - d_c\right) \tag{8}$$

where d_0 – specific gravity of the particle.

When a constant velocity is reached, that is, the velocity of precipitation, equality is performed

$$F_0 = P \tag{9}$$

and as a result after substitution

$$\eta \frac{\pi D^2}{4} \cdot d_c \frac{V_0^2}{2g} = \frac{\pi D^3}{6}\left(d_0 - d_c\right) \tag{10}$$

we obtain

$$V_0 = \sqrt{\frac{4gD\left(d_0 - d_c\right)}{3\eta d_c}} \tag{11}$$

The material resistance coefficient is a function of the Reynolds number and is determined experimentally, i.e. it depends on the velocity of movement of their size, density and viscosity of the material of object. That is, the coefficient of resistance has a nonlinear dependence on the Reynolds number. If necessary, this dependence can be divided into three relatively linear parts, especially if you take the form of a particle as a ball. For value of the Reynolds number we get

$$\eta = \frac{24}{R_e} \tag{12}$$

which is called the Stokes' law [3, 19].

When we measure the Reynolds number as $0.2 < R_e < 500$, we obtain an intermediate law in the form

$$\eta = \frac{18.5}{R_e^{0.6}} \tag{13}$$

For a numerical value within $500 < R_e < 150000$ the value of the coefficient there is a constant, that is $\eta = 0.44$, it is the law of Newton. Consequently, if we use these laws, we obtain from equation (11)

$$V_0 = \frac{D^2\left(d_0 - d_c\right)}{18\mu} \tag{14}$$

which a consequence of the Stokes' law is obtained.

If neglected by forces of inertia, orienting only on frictional forces, then the strength of the environment can be defined as

$$F_0 = 3\pi D\mu V_0 \tag{15}$$

Consequently, as can be seen from equation (15), the material resistance of the environment during the movement of small objects is proportional to the first degree of fall velocity.

The use of equation (15) applies only to the upper limit $R_e \le 0.2$. At the same time, the maximum particle size has a limitation. To do this, in equation (14), instead of speed V_0, the substitution of its value according to the Reynolds criterion is $V_0 = R_e\mu g / Dd_c$, i.e. at $R_e = 0.2$ we get it

$$D_{\max} = \sqrt[3]{\frac{3.6\mu^2 g}{d_c\left(d_0 - d_c\right)}} \approx 3.3\cdot\sqrt[3]{\frac{\mu^2}{d_c\left(d_0 - d_c\right)}} \tag{16}$$

For the lower limit of the application of the Stokes' law, the criterion is the deposition conditions, when the size of the particles reaches values equal to the free run of the molecules of the dispersion material.

As a result, the material resistance of the environment in this case will be determined as follows:

$$P_0 = \frac{3\pi D\mu V_0}{1 + A\frac{l_0}{D}} \tag{17}$$

where $l_0 = 10^{-7} m$ – the average mileage of the gas molecule under certain conditions; A is a constant.

Of course, the value is quite conventional and rather strongly dependent on the environment.

The rate of falling particles in the sediment for this case will be determined as

$$V_0 = \frac{D^2\left(d_0 - d_c\right)}{18\mu}\cdot\left(1 + A\cdot\frac{l_0}{D}\right) \tag{18}$$

Thus, for $R_e < 0.2$ the velocity of the particles of the discrete solid presence zone the spherical shape is proportional to the square of their diameter, the difference between the specific gravity of the particles and the environment, and inversely proportional to the viscosity of the environment.

For the values $500 < R_e < 150000$ of the Reynolds number the resistance of the environment is $\eta = 0.44$. If we substitute this value in equation (11), then we obtain the following dependence for the particle motion rate

$$V_0 = 5.48\sqrt{\frac{gD\left(d_0 - d_c\right)}{d_c}} \tag{19}$$

For an intermediate law $\mu = \frac{18.5}{R_e^{0.6}}$, the drop speed will be determined as

$$V_0 = 0.268\sqrt{\frac{gD\left(d_0 - d_c\right)}{d_c}} \tag{20}$$

Thus, having the speed of motion in different cases, we can consider the accumulation of discrete solid presence zone on the AE surface. The basis for solving the problem using equation

$$Q = S\cdot V, \tag{21}$$

where S is the cross-sectional area, V is the velocity of particles moving through this area.

Consequently, if we imagine that it stays at time t and distance, it should have velocity

$$V_\tau = \frac{a}{t} \tag{22}$$

On other, falling of the particles from height h above the AE surface with speed V_0 gives us the same time, that is

$$t = \frac{h}{V_0}. \tag{23}$$

Consequently, substituting (22) and (23) in equation (21), we obtain

$$Q = a\cdot b\cdot\frac{h}{t} = a\cdot b\cdot h\cdot\frac{V_0}{h} = a\cdot b\cdot V_0 \tag{24}$$

where b – length of the incident particles front.

Since the product $a\cdot b$ is area of the AE surface, it is obvious that the amount of deposited mass will be determined as

$$Q = \frac{S_{AC}}{d_ч}\cdot V_0\cdot t \tag{25}$$

That is, this slow-moving part of the discrete presence zone is directly dependent on speed and time. Since the velocity chart is chosen in the plane of vectors, we can assume that, according to the aforementioned principle, the entire front of the particles is in siege.

Thus, if our particle is in the environment whose density is different from zero, then the hydrostatic pressure acts on it. To solve problems related to the location of an object in an environment, use the basic equation of hydrostatics [14]. This equation relates the force acting within a unit volume of liquid or gas and measured pressure in a state of balance

$$F_{FA} = grad\,P. \tag{26}$$

For projections on the axis of Cartesian coordinates [10]

$$F_{FA}(x) = \partial P / \partial x,\ F_{FA}(y) = \partial P / \partial y,\ F_{FA}(z) = \partial P / \partial z$$

In this case, the gradient of the scalar P is determined by the Hamiltonian as a potential field.

In the particular case of gravity

$$F_{FA} = d_c g. \tag{27}$$

where d_c – density of the environment, g – acceleration of free fall.

In the general case, equation (26) is a partial case of the Euler equations, which gives a description of the motion of an ideal fluid (environment) in the static case [11], and as a consequence, the simplest law and elementary force that we have a description through of Archimedes law. In general, the law is written as

$$F_A = Q\cdot d_C\cdot g \tag{28}$$

where Q is the volume of the displaced environment.

For a spherical particle with a diameter D this force will be

$$F_0 = \frac{1}{3}\pi h\left(\frac{3}{2}D - h\right) \tag{29}$$

where h is the immersion depth (Fig. 1c).

The pushing force is always directed to the top and passes through the centre of object weight. In addition, there is still a buoyancy centre, as the centre of mass of displaced environment. As a result, we have two centres on which different forces operate. As a result, the stability of the balance of the mass of the AE depends from the distance between these centres. This situation creates the following three cases.

In the first case, the mass of the particle is at balance, if its weight is equal to weight of the environment pushed out by it, and both centres are on the same vertical.

In the second case, if the particle is completely immersed in the environment, then the balance will be, if the centre of mass is below the centre of buoyancy and does not become, if the opposite.

In the third case, for a partial immersion, then the balance will be, if the center of mass is below the metacentre and not constant in the opposite.

Another force that can be directed vertically is Magnus force [2, 8]. The essence of this effect lies in the fact that any object is located, which is in the directed flow of environment begins to rotate. The consequence of such a rotation is the emergence of a dynamic force perpendicular to the direction of motion of the environment. The basis of the effect is that the velocity of the environment on both sides of the ball is different. As a result, there is a dynamic force. Consequently, if our particle is in the incoming of environment's stream. So, in order to simulate the rotation of a particle, we introduce a circulation of velocity around it [1, 9]. Using Bernoulli's law, we can prove that the full force acting on a part in this case will be:

$$F_m = -d_C Circ. \times u \tag{30}$$

where *Circ.* – circulation of the velocity vector around particles, *u* – the flow velocity in infinity.

From (30) it is evident that the total force is perpendicular to the flow, and the direction, depending on the circulation and the flow velocity, has a lifting or lowering character.

At this time, it is possible to determine the magnitude of this force for a globular particle as:

$$F_M = \frac{1}{2} d_C V \cdot S_0 \cdot G \tag{31}$$

where V is the velocity of the particles relative to the environment; G is the coefficient of lift, which is determined experimentally by Reynolds number and the rotational factor, S_0 is the cross section of sphere.

Since the basis of our model is a sphere, we eventually get it

$$F_m = \frac{1}{8} d_c VDG \tag{32}$$

2. Modelling

At present, the forces discussed above relate to the behavior of the particle without taking into account the interaction with the surface layer of the liquid. However, the surface is not just a coordinates, it is a layer that has certain properties. By its compatibility, it is a layer of molecules combined by intermolecular forces on one side only because it is on the verge of two media. The frequency (sphere) that falls on such a surface behaves in two ways (Fig. 1b, c) since it becomes dependent on the power of intermolecular forces. In the first case, it adheres to the surface (wetting) in the second slip (no wetting). Consequently, the curvature of the surface occurs under the weight of the particles and as a result of additional pressure on the liquid. This additional pressure is dependent on the surface tension (β) and the curvature of the surface.

A superficial tension is called the work performed for isothermal formation of 1 m^2 surface at the boundary with another phase:

$$\sigma = \frac{A}{S}(\overline{E_S - E_V})\frac{N}{S} = (\overline{E_S - E_V})n_1 \tag{33}$$

where $n_1 = \frac{N}{S}$ – number of molecules is 10^{-4} m^2 of the surface layer, $\overline{E_S - E_V}$ is the mean free energy difference and the surface E_S and in the volume E_V, and N is number of molecules in the surface layer.

According to Laplace's law, the surface has the environment curvature

$$H = \frac{1}{2}\left(\frac{1}{R_1} + \frac{1}{R_2}\right) \tag{34}$$

are determined by the main radii of curvature R_1 and R_2.

As a result, the pressure under the broken surface

$$P_K = P_o + \sigma\left(\frac{1}{R_1} + \frac{1}{R_2}\right) \tag{35}$$

where P_o – pressure on the flat surface of the liquid.

At that

$$P_{RK} = \sigma\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = 2\sigma H \tag{36}$$

$P_{RK} > 0$, if the meniscus is convex, $P_{RK} < 0$, if the meniscus is concave.

For a spherical surface

$$P_{RK} = \frac{4\sigma}{D} \tag{37}$$

Thus, we considered a series of forces that are related to the mechanical properties of the environment, is, the viscosity, the Reynolds number, the surface tension, and so on. But in addition to mechanical properties, all physical objects have a number of electrical properties. At the moment, it is an electrostatic and magnetic field that causes a series of phenomena and processes that create active forces. Of course, in the first place is an electric field that is inherent in all AE without exception in one degree or another. In terms of electricity, there is a charge of an object, which for a discrete solid presence zone's segment as q_0 can be determined by the elementary charge of an electron which is defined as a measure of charge, that is,

$$q_0 = ne \tag{38}$$

where n – number of electrons, $e = 1.6021892 \times 10^{-19}$ C – charge of electron.

In relation to our situation we are interested in forces acting on the charge near a charged plane. Consequently, the field strength which creates the plane of AE in the surrounding space is defined as

$$E = \frac{1}{2\varepsilon_c \varepsilon_o}\sigma \tag{39}$$

where σ – surface charge density, ε_c – dielectric permeability of environment, ε_o – dielectric constant.

Since the force acting on the charge q_0 is defined as

$$F_0 = q_0 E \tag{40}$$

So, as a result we get

$$F_0 = \frac{q_0 \sigma}{2\varepsilon_c \varepsilon_o} \tag{41}$$

The force of interaction of two particles with a charge q_0 at a distance r is determined by the Coulomb's law [1] as

$$F = \frac{1}{4\pi\varepsilon_c \varepsilon_0}\frac{q_0^2}{r^2} \tag{42}$$

Under the action of these forces, a piece in space will move in dependence on the direction of the vectors of the velocity and intensity of electric field.

If we have a homogeneous electric field with parameters $E_x = E,\ E_y = E_z = 0,\ B = 0,\ \ V_x = V_0,\ V_y = V_z = 0$, then the equation of motion can be described as follows

$$m_0 \frac{d^2 x}{dt^2} = -q_0 E \tag{43}$$

Solving this equation we obtain a fluid coordinate

$$x(t) = V_0 t - \frac{q_0}{2m_0} Et\ ,\ \ y(t) = z(t) = 0 \tag{44}$$

at speed

$$V_x(t) = V_0 - \frac{q_0}{m_0} Et\ ,\ V_y(t) = V_z(t) = 0 \tag{45}$$

From equations (40), (41) we obtain the conclusion that the particle will move along the direction of the vector of electric field intensity. In addition, the movement will be either equally accelerated or deceleration, depending on how the vectors one-sidedly or towards one another are directed.

In the case, when the particle moves across the electric field (E_y), we obtain the following result for each coordinate

$$m_0 \frac{d^2 x}{dt^2} = 0\ ;\ m_0 \frac{d^2 y}{dt^2} = -q_0 E\ ;\ m_0 \frac{d^2 z}{dt^2} = 0 \tag{46}$$

Solving all equations (46) we obtain the following dependences for determining the fluctuation of the particle coordinate

$$x(t) = V_0 t; y(t) = -\frac{q_0}{2m_0} Et^2; z(t) = 0 \tag{47}$$

The velocity of motion along the coordinate axes will be

$$V_x(t) = V_0;\ V_y(t) = -\frac{q_0}{m_0} Et\ ;\ V_z(t) = 0 \tag{48}$$

In this case, the trajectory of a particle's motion has a parabolic character

$$y(t) = \frac{q_0}{2m_0} E \frac{x^2}{V_0^2} \tag{49}$$

Thus, the motion of a particle in a transverse electric field is similar to the motion of an object in the conservative field of gravity.

In contrast to the electric field and the generating electric charge, for example, in equation (34), the magnetic field does not have magnetic charges as such. Thus, the theory of magnetism, which is based on the notions of magnetic charges that uses purely external similarity of the interaction of magnets with the interaction of imaginary magnetic charges, is called the formal theory of magnetism.

At present, the formal theory of magnetism is seen in the case when we imagine a long, thin magnet on the extremities concentrated magnetic charges and we have the dependence of the operating force between two magnetic charges in the form of the Coulomb law

$$F = \frac{\mu\mu_0}{4\pi} \frac{q_{m1} q_{m2}}{r^3} r \tag{50}$$

where q_{m1}, q_{m2} – magnitude of charges or quantity of magnetism, $\mu_0 = 4\pi 10^{-7}$ H/m – magnetic force, μ – relative permeability of the environment.

That is, in the case if the discrete presence zone's partical has magnetic properties, then with some assumptions it is possible to use the equation (50). We will now consider how this is considered when using the formalized model. To consider, we take the thesis, that the inner structure of the sphere is the one that creates a homogeneous constant magnetization M_0, which is equal to M_0 in magnitude and directed along the axis Z (by the single vector $\mathbf{e}_3$). Externally, spheres from where at $r > a$ vector can be written, if we take with the negative sign the gradient of scalar magnetic potential satisfying the Laplace equation:

$$B_e = -qrad\Phi_m, \nabla^2\Phi_m = 0 \tag{51}$$

Solving these equations leads to the conclusion that

$$B_0 = B_c e_3\ ,\ H_0 = (B_c - 4\pi M_0) e_3 \tag{52}$$

Hence, as a result, we obtain the result that the field outside the sphere coincides with the field of the dipole and the dipole moment

$$T_0 = \frac{\pi}{6} D^3 M_0 \tag{53}$$

In this case, the internal fields receive the following dependencies

$$B_0 = \frac{8\pi}{3} M_0\ ,\ H_0 = -\frac{4\pi}{3} M_0 \tag{54}$$

In addition, it should be noted that the induction is parallel to the magnetization, while the field, albeit in parallel, but opposite, is directed.

If our particle falls into an external magnetic field, then, based on the linearity of the field equations, we can add external magnetic induction to equations (54). Consequently, as a consequence, the total magnetic induction in the middle of the sphere is defined as

$$B_0 = B_c + \frac{8\pi}{3} M_0\ ,\ H_0 = B_c - \frac{4\pi}{3} M_0 \tag{55}$$

If we imagine that our ball is not a permanent magnet and there is a magnetic or paramagnetic with magnetic permeability of μ, then the magnetization of M occurs in the sphere under the action of the external field, we find the value of M, given μ

$$B_0 = \mu_0 H_0$$

when

$$B_c + \frac{8\pi}{3} M_0 = \mu_0 (B_c - \frac{4\pi}{3} M_0) \tag{56}$$

And as a result we get

$$M_0 = \frac{3}{4\pi} \frac{\mu_0 - 1}{\mu_0 + 2} B_c \tag{57}$$

From equation (57) it can be seen that in the absence of an external field, the magnetization vector disappears. Therefore, this consideration is suitable only for macromolecules and paramagnets, and in any case for ferromagnets. The problem is that even in the absence of an external field, the magnetization of a ferromagnet does not disappear. Nevertheless, if we exclude M from equation (54), we get the relation between H and B

$$B_0 + 2H_0 = 3B_c \tag{58}$$

So, for any external field we have the opportunity to find the corresponding value of the internal field. From the consideration of magnetic properties it can be seen that these properties are either intrinsic to the particles or formed by the external field. In any case, we see that the particle reacts to an external magnetic field. As a result, when any lattice enters the magnetic field, the moment of forces depends on the angle (α) of the difference between the magnetization $\bar{M}_0$ and induction vectors $\bar{B}_c$. The magnitude of the moment is defined as

$$T_0 = \frac{1}{2} \frac{\pi\mu_0 D^3 M_0 B_c}{2\mu_c + \mu_0} \sin\alpha \tag{59}$$

Consequently, the particle gets to the magnetic field with a torque which forces it to rotate. As a consequence of such a rotation, the lens creates around itself the motion of the environment, which leads to the Magnus effect. Thus, if the particle does not even move before it begins to rotate around its magnetic axis, especially if the magnetic field changes its direction. In addition, the magnetized particle reacts with an external magnetic field, there are other cases of interaction. At present, a moving charge (particle) has the property to create around itself a magnetic field which is its presence zone. Thus, we have the case of the interaction of two presence zones as a consequence of motion, that is, it is one example of the power interaction of objects in the presence zone.

According to theoretical electrodynamics, in the general case, the particle with charge q_0, which moves at a velocity in a magnetic field with induction, acts on the force perpendicular to the vectors and is determined by

$$F_m = q_0(V \times B) \tag{60}$$

The module is defined as

$$F_m = q_0 VB \sin\alpha \tag{61}$$

As a consequence, the motion of a charged particle in a magnetic field can be written as an equation of kinetic motion as

$$m_0 \frac{dV}{dt} = q_0(V \times B) \tag{62}$$

So, if the induction *B* is independent of time i.e. $B = B(x, y, z)$, then

$$\frac{m_0 V_0^2}{2} = const \tag{63}$$

That is, the kinetic energy of a particle in a magnetic field does not change. Under this condition, the equation (58) splits into two equivalent ones

$$m_0 \frac{dV_\perp}{dt} = q_0(V_\perp \times B),\ m_0 \frac{dV_{II}}{dt} = q_0(V_{II} \times B) \tag{64}$$

where $V = V_{II} + V_\perp$, V_{II}, $V_\perp$ – components of velocity *V*, parallel and perpendicular to field *B*, $(V_{II} \times B) = 0$.

The acceleration of the particle in this case is steady and absolute in magnitude and is directed perpendicularly to the component of the velocity *V*. Therefore, the particle moves in a circle with velocity. Circle radius with this

$$R = \frac{m_0 V_\perp}{q_0 B} \tag{65}$$

R value is Larmor's radius. The angular frequency ω of rotation is defined as

$$\omega = \frac{2\pi}{T} = \frac{V_\perp}{R} = \frac{q_0 B}{m_0} \tag{66}$$

Consequently, a particle, which enters the magnetic field's moves behind a screw-trajectory with a step $V_{II}T$ radius *R* with a constant angular velocity ώ and a velocity *V*. As a consequence of *V II B*, this particle $V_{II} = V$ moves along the field.

If that $V \perp B$ and $V_\perp = V$, $V_{II} = 0$ the particle moves perpendicular to the field, rotating around the power line at a velocity $V_\perp$ in the circle of radius *R*.

Thus, the magnetic field, along with other external forces, affects the movement of the particles. At present, there are three types of such movement: motion under the influence of extraneous force, movement in an electric field, motion under the action of gravitational field. Consequently, the general equation of motion of a segment in an electromagnetic field can be described in accordance with the second Newton's law by equation

$$P = \frac{d}{dt}(m_0 V) = -q_0 E \ \ -q_0(V \times B) \tag{67}$$

where *P* is a pulse of a charge with q_0.

That is, we have the motion of a q_0 charge in electromagnetic fields. In classical physics, such a movement is called drift with an appropriate magnitude which is defined as

$$V_D = \frac{1}{q_0} \frac{F \times B}{B^2} \tag{68}$$

where *F* is outside force perpendicular to field *B* behind *Z* axis.

If a particle moves under the action of force not perpendicular to the magnetic field, then it performs a complex motion which can be decomposed into three constituents. The first component is the equally accelerated motion along the magnetic force lines under the action of the F_{II} component. The second component is the uniform movement of the larval circle under the action of force

$$F = q_0(V_0 \times B) \tag{69}$$

where $V_0 = V + V_D$ is the velocity of a particle in a coordinate system, which moves with the drift speed

$$V_D = \frac{1}{q_0} \frac{(F_\perp \times B)}{B^2} \tag{70}$$

The third component is the speed of V_D. Electric drift occurs when the external force of excitation is the strength of electric field (40).

In this case, the particle will rotate around the direction of the magnetic field *B* at a rate

$$V_D = \frac{1}{B^2}(E \times B) \tag{71}$$

The velocity V_D is independent of the sign, charge q_0 and of the particle mass. As a result, layers with different charges and masses can't be present in the presence zone

$$V_D = \frac{m_0}{q_0} \frac{(g \times B)}{B^2} \tag{72}$$

If $B \perp g$, that is a scalar

$$V_D = \frac{g m_0}{q_0 B} = \frac{g}{\omega} \tag{73}$$

where ω is the cyclotron frequency. For example, for a proton in the magnetic Earth's field (B = 7.96 · 10^{-4} *T*)

$$V_D \approx 0.98 \cdot 10^{-2} \text{ m/s}$$

In conclusion, considering the secondary presence zone, it is necessary to consider the interaction of particles between themselves. Consequently, a charged electric energy in the course of its motion reacts not only with the electric and magnetic fields, which form the field's presence zone of AE, and between themselves.

The principles of this interaction consist in the fact, that any electric charge during its motion creates around itself in accordance with Maxwell's magnetic field. Consequently, if a charge with q_0 moves uniformly in a space with velocity V_0, then in any part of the space of charges in vector r forms a magnetic field with induction

$$B = \frac{\mu_0 q_0}{r^3}(V_0 \times r)$$

So, if we have two particles with charges q_{01} and q_{02}, which move with speeds V_1 and V_2, then they will interact with each other with forces

$$F_{12} = \frac{\mu_0 q_{01} q_{02}}{r_{12}^3}(V_2 \times (V_1 \times r_{12}))$$

$$F_{21} = \frac{\mu_0 q_{01} q_{02}}{r_{21}^3}(V_1 \times (V_2 \times r_{21}))$$

F_{12} is the force acting on the charge q_{02} from the side of the field B_{01} generated by the charge q_{01} at the point of charge q_{02}; r_{12} is the radius from the charge q_{01} to the charge q_{02}; F_{21} is the force acting on the charge q_{01} from the field B_{02} generated by the charge q_{02}.

In the particular case, if the vectors V_1 and V_2 are parallel with each other and are equally directed, but perpendicular to the vector r_{12}, then

$$F_{12} = F_{21} = \frac{\mu_0 q_{01} q_{02}}{r_{12}^2} V_1 V_2 \tag{74}$$

In this case, the direction of force is dependent on the signs of charges q_{01} and q_{02} , that is, the attraction for the same charge charges of particles and repulsion for the same name.

Consequently, we considered a whole range of forces of different physical origin, which are constituents of the basic equations (5), (6), (7), (8). These forces are the basis of the spatial motion of the particle and are the basis for determining its trajectory.

3. Automated measurement of the features of interaction of particles in the working space of equipment

Measurements are carried out by a measuring integrated sensor of a continuous structure, containing an integrated electromagnetic sensor and an optical sensor for determining the movement of particles. Adjusting the position of the contact on the axis between the flanges of upper and lower parts provides a gap, the change of which allows you to change the position of measuring sensor relative to the axis.

The equipment for determining the interactions of particles provides an opportunity on the basis of digital control to carry out input and functional control of processes in the studied environment with help of measuring tools in a system with common functional characteristics (Fig. 2).

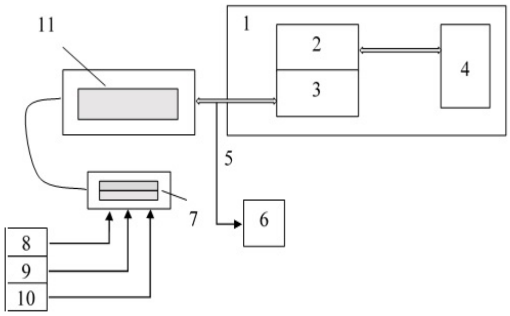

Fig. 2. Functional scheme of the system of correction of the probing trajectory: 1 – digital control unit; 2 – digital control drive; 3 – automatic machine; 4 – block of processing and intermittent sounding; 5 – communication system; 6 – storage of output data; 7 – control panel; 8 – processing and probing programming unit; 9 – block of statistical quality research; 10 – trajectory correction programming module, 11 – visualization unit

The automation system of intermittent sounding is used to control complex trajectories of particle movement at 3D coordinates, it is equipped with software for the formation of trajectory corrections. In addition, the system is designed to measure the dimensions and force interactions of particles in space.

The system allows you to predict tolerance deviations, to investigate the statistical quality of monitoring the presence of environmental pollution [4, 5]. Similar studies provide opportunities to determine the nature of particle interactions, the trajectory of their movement in the working space of the equipment.

4. Conclusions

The article defines the need to solve the problem of determining the presence of particles of various origins in the space of working equipment. The model for determining the presence of such particles and their location coordinates in the working space of the equipment by an automated system that has the ability to correct particle trajectories to obtain a specified number of particles near the main working executive means is shown.

By their natural essence, discrete elements that are located within the space of the presence of an abstract object, always interact with each other.

The basis of these interactions is the forces that create potential forces, inherent in both the AE and each of its individual particles.

Depending on the properties of the substance, of which a discrete particle is formed, there are corresponding force fields that surround each of the particles. The character of these fields is not necessarily the same. The proposed analytical models of the interaction of power fields prove that the particles within the space of the presence zone of the abstract object can't be in a state of rest. As a result of this interaction, the particles try to take such a position, when the allotment of all these field structures at the center of its mass will approach zero. Therefore, for example, the particles that are located on the surface of the AE, try to create a layer of even energy load.

Further directions of scientific research are the creation of analytical models of the grinding process of discrete elements of a solid state zone during power interaction.

Such automated diagnostic equipment for monitoring the state of production or medical equipment is intended to improve the quality of technological operational actions in the conditions of equipment operation.

References

[1] Beer F. P. et al.: Mechanics of Materials. McGraw-Hill Education Private Limited, New Delhi 2017.

[2] Carroll J. S.: Effect of Seam-Height on Curveballs. Senior Theses. 14, 2015 [https://digitalcommons.linfield.edu/physstud_theses/14].

[3] Feynman R.: The character of physical law. A series of lectures recorded by the BBC at Cornell University USA, Cox and Wyman LTD, London 1965.

[4] Globa L. et al.: Approach to building uniform information platform for the national automated ecological information and analytical system. CEUR Workshop Proceedings 3021, 2021, 53–65.

[5] Globa L. et al.: Uniform Platform Development for the Ecology Digital Environment of Ukraine. Progress in Advanced Information and Communication Technology and Systems, 2022, 83–100 [http://doi.org/10.1007/978-3-031-16368-5].

[6] Kittel C.: Introduction to Solid State Physics. Wiley 2004.

[7] Klotchko T. R.: Formalized model of the zone presence of structures of the biological objects. 21st International Crimean Conference "Microwave & Telecommunication Technology", 2011, 1036–1037.

[8] Korn G. A. et al.: Mathematical Handbook for Scientists and Engineers: Definitions, Theorems, and Formulas for Reference and Review (Dover Civil and Mechanical Engineering). Dover Publications, 2000.

[9] Kukharchuk V. et al.: Features of the angular speed dynamic measurements with the use of an encoder. Informatyka, Automatyka, Pomiary w Gospodarce i Ochronie Środowiska 12(3), 2022, 20–26.

[10] Lezhniuk P. et al.: The Sensitivity of the Model of the Process Making the Optimal Decision for Electric Power Systems in Relative Units. IEEE KhPI Week on Advanced Technology, 2020, 247–252.

[11] Lutgens F. K. et al.: Essentials of Geology, 13th Edition. Pearson, 2017.

[12] McPhee J.: Annals of the Former World. Farrar, Straus and Giroux, 1999.

[13] Polishchuk L. et al.: Mechatronic Systems II. Applications in Material Handling Processes and Robotics. Taylor & Francis Group, CRC Press, Balkema book, Boca Raton, London, New York, Leiden 2021.

[14] Semat H., Katz R.: Physics, Chapter 8: Hydrostatics (Fluids at Rest). Rinehart & Company, Inc., New York 1958.

[15] Skytsiouk V. I., Klotchko T. R.: Determination of the coordinates of the pathological zones in the mass of the biological object. 23rd International Crimean Conference "Microwave & Telecommunication Technology", 2013, 1083–1084.

[16] Tymchik G. et al.: Modeling of The Phantom Geometry of Biotechnical Object's Pathological Zone. 41st International Conference on Electronics and Nanotechnology – ELNANO 2022, 363–368.

[17] Tymchyk G. et al.: Forces balance in the coordinate system of object's existence 3D space. Proceedings of SPIE 12476, 2022, 124760U. [http://doi.org/10.1117/12.2659188].

[18] Tymchyk G. et al.: Distortion of Phantom Object's Realizations in Biological Presence Zone. 40th International Conference on Electronics and Nanotechnology – ELNANO 2020, 464–468 [http://doi.org/10.1109/ELNANO50318. 2020.9088896].

[19] Wójcik W. et al.: Mechatronic Systems I. Applications in Transport, Logistics, Diagnostics and Control. Taylor & Francis Group, CRC Press, Balkema book, London, New York 2021.

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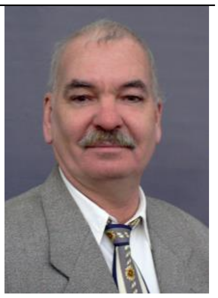

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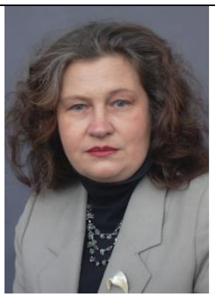

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