# CONSTRUCTION OF CENTRIFUGAL WORKING DEVICE FOR MINERAL FERTILIZERS SPREADING
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# *КОНСТРУКЦІЯ ВІДЦЕНТРОВОГО РОБОЧОГО ОРГАНУ ДЛЯ РОЗКИДАННЯ МІНЕРАЛЬНИХ ДОБРИВ*

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## ABSTRACT
*The original methods for determining the critical velocity impact on a metal surface, taking into account the moisture content of the granules and the influence of the wind on the final distribution have been developed. The research technique of influence on the airflow make possible to determine the effect of speed, both in laminar and turbulent modes.*

*The proposed rotary working body designs, structural features of which enable to improve the dispersion evenness of mineral fertilizer, are presented.*

## РЕЗЮМЕ
*Розроблені оригінальні методики визначення критичної швидкості удару об металеву поверхню з урахуванням вологості гранул і впливу дії повітря на кінцевий розподіл. Методика досліджень швидкості повітряного потоку дозволяє визначити вплив скорости, як у ламінарному, так і в турбулентному режимах.*

*Запропонований роторний робочий орган, конструкційні особливості якого дозволяють покращити рівномірність розкидування мінеральних добрив.*

## INTRODUCTION
It is known that, in Europe, over 90% of the granular fertilizers are distributed using spinning disc spreaders. Fertilizer efficiency largely depends on proper method, combinations of their dressing into soil *(Ning et al, 2015)*. Depending on the terms and standards, there are main pre-sowing fertilizing and top-dressing.

There are two ways to use granular fertilizers: solid surface spreading and subsoil fertilization (*Antille et al., 2013; Fertilizer Manual, 1998)*. The granular fertilizers must be especially properly handled and distributed (*Hofstee., 1992)*.

The most common granular fertilizer application device is the centrifugal disk spreader *(Petcu et al.*, *2014; Tijskens et al.*, *2008)*. The main advantages of this spreader are the large spread width, the simple construction and the low cost (*Petcu et al., 2015*). Meantime the distribution pattern of fertilizer is affected by many variables. It depends on machinery model, working conditions and physical characteristics of fertilizer (*Allaire and Parent, 2004; Macmillan, 2007; Šima T. et al., 2013*). In this case disks with the possibility of working with mixture application on the soil surface at an angle to the horizon are used.

First of all, it is explained by the versatility of aggregate. By disc reorienting, we can get high quality fertilizing and achieve high performance by coverage.

However, lack of a clear interpretation of numerous design features of the working body and the car, in general, creates problems for the implementation of agro-technical requirements and increases the burden on the environment (*Biocca et al., 2015*). It is known that the optimal dose of fertilizing for each crop is recommended for specific soil and climatic conditions *(Fertilizer Manual, 1998*).

Methods and terms of fertilizing depend on biological and varietal characteristics of culture, predecessors, soil conditions, specific farm possibilities. Usually local and dispersing methods are used. Dispersed and local fertilizing can be main, pre-sowing or top-dressing.

Fertilizing is one of the indicators of agronomic requirements for such operations like irregularity in the distribution by coverage - 25%, while aggregate moving - 10%.

Unfortunately, national machines for mineral fertilizing provide application evenness near 50-60%, leading to deterioration of the quality and quantity of crops (*Kravchuk et al., 2004; Vasylieva N., 2016; Velychko O., 2015*). It was established that the uneven application of mineral, organic fertlizers and lime leads to significant yield losses and deterioration of its quality. Another negative consequence is environmental pollution.

The main disadvantages of centrifugal machines for mineral fertilizing are:

- high distribution unevenness by coverage;
- fractions redistribution by coverage;
- coverage instability.

It is clear that the quality of national spreading machines should be raised, but it requires significant expenditures in Ukraine. That is why improvement of the technical level of machines should be focused on economically reasonable limits. All these indicate the need for further research regarding the fertilizing process.

During the analytical research we have created mathematical model of the granular fertilizer which uses a centrifugal disk. The construction diagram of our own design spreader has been suggested.

The objective of experimental research is to determine the effect of wind direction on uniformity of fertilizing by the fertilize spreader working body.

According to the goals we identified the following tasks such as:

- to develop a methodology for determining:
  - parameters of granules distribution by the soil surface in laboratory conditions;
  - wind impact on the parameters of the distribution of the granules by the soil surface.
- to develop constructive scheme of experimental installation and produce experimental stand;
- to produce disk model with the main design parameters;
- to perform laboratory experiments according to the research program;
- to perform mathematical analysis of the results.

## MATERIAL AND METHODS

Achievements of the laboratory research were:

- determination of basic mechanical and technological properties of the fertilizers used in experiments;

- establishing granules distribution by kinematic and geometrical parameters: rate of disk rotation $n$, rad/s; angles $\gamma_1$, $\gamma_2$, $\gamma_3$ of flow setting, deg; angles $\alpha_1$, $\alpha_2$, $\alpha_3$, – tilting angles of blades to disk rotation area, deg;

- calculation of distribution parameters by the surface of each stream separately and simultaneously from all streams for different fractional composition of fertilizers;

- determination of the design parameters of the disk in which distribution is closest to even;

- research of the impact of different wind speed and direction on the final distribution of fertilizers;

- establishing the impact on fertilizers final distribution by axial vibrations of the disk and tilting angle relative to surface of soil.

Several field testing trials were included into the program, namely:

- making prototype of the disk with structural and kinematic characteristics, which was determined by results of laboratory and field research;

- determining the quality of surface fertilization under different applying rules;

- comparative analysis of fertilizing quality by serial and developed centrifugal working body.

Major mechanical and technological properties of fertilizers that have been used for the research, were determined during the experiment.

Standard methods were used to determine moisture, specific gravity, coefficient of internal and external friction, metal restitution ratio on hit. Methods of acceptable impact velocity of granules by the metal surface and determining of their aerodynamic properties can be considered as original.

Acceptable impact velocity can be determined by the scheme (fig. 1).

Laboratory installation consists of a blade disc *1* with a vertical rotation axis, bin *2*, driving gear *3* with installed r.p.m. meter, percentage feeder *4*, light-absorbing screen *5*, collector of waste material – bag *6* and bin *7*.

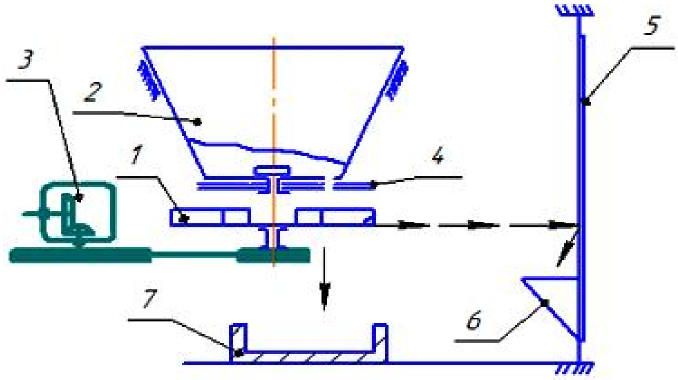


**Fig.1** - **The scheme for determining acceptable impact velocity of fertilizer granules by metal surface**
*1 – blade disc; 2 – tanker; 3 – driving gear; 4 – percentage feeder; 5 – light-absorbing screen; 6 – bag; 7 – bin*

Critical velocity was determined on sailing classifier with somewhat modified design (fig. 2), where the flow rate is measured directly by anemometer *3*. In this device airflow is formed by fan *5*, which is powered by transformer *7*. The flow rate is regulated by excluder *6*. Using of the anemometer *3* instead of the Pitot tube makes possible to measure velocity directly without performing assistive calculations.

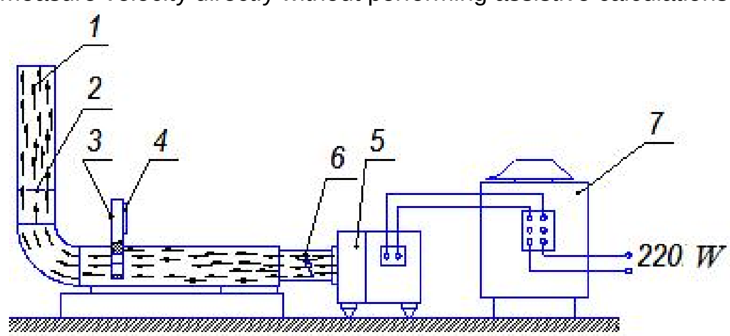


**Fig.2 - Scheme of modified sailing classifier**:
*1 – tube; 2 – net; 3 – anemometer; 4 – anemometer screen; 5 – throttle; 6 – fan; 7 – transformer*

The laboratory installation was constructed to perform the research program (fig. 3).

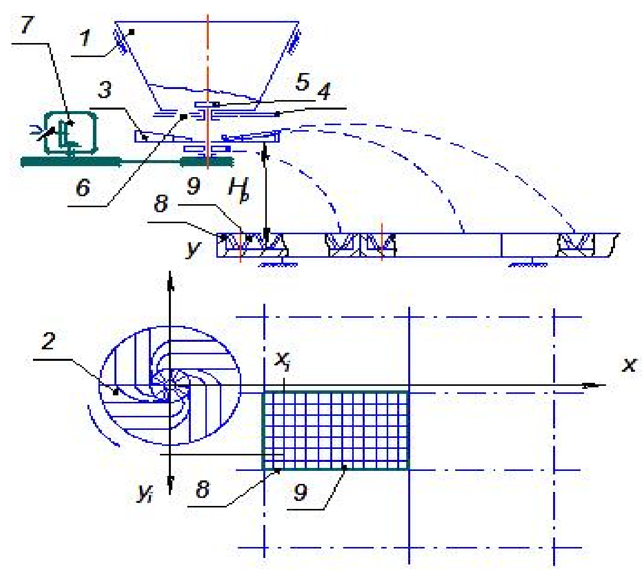


**Fig.3 - Scheme of laboratory installation**
*1 – tanker; 2 – disk; 3 – blade; 4 – percentage feeder; 5 – activator; 6 – activator's window;*
*7 – reducer; 8 – bin; 9 – samplers*

Bins with installed samplers, which take falling granules, are used to determine the distribution parameters. It provides opportunities to determine the distribution of the granules coordinate-wisely ($X_I$, $Y_I$). Only one bin was used because of distribution parameters which have been pre-installed coordinate-wisely.

Wind flow was created by the bladed fan. Speed and direction of air flow were regulated by changing the position of the fan *3* relatively to bin *2*. The flow rate was measured by anemometer *4* (fig. 4).

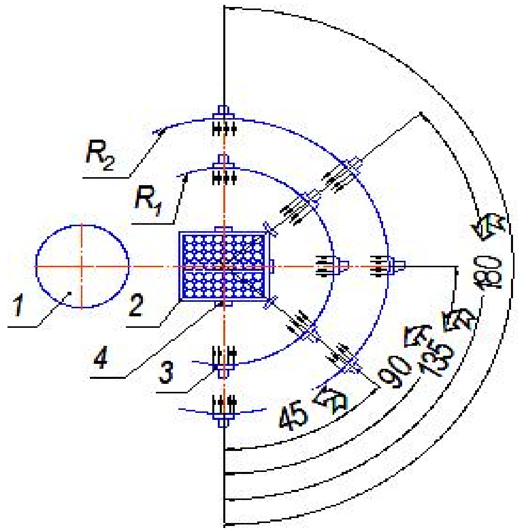


**Fig.4 - Research scheme of airflow action**

*1 – disk spreader; 2 – bin with samplers; 3 – fan; 4 – anemometer*

At higher speeds unevenness dramatically increases and exceeds the allowable agrotechnical limits. The obtained data testify that the airflow negatively affects the evenness. The direction of the flow is also an important factor that determines evenness.

The lowest effect is observed when the wind direction is perpendicular to aggregate motion. This can be explained by receiving the smallest dose by outermost bins.

The biggest impact was at the action of two angles: 45° and 135°. It was revealed that the influence of the wind is selective, that air flow which is directed at an angle from 45° to 135° has the greatest impact on evenness distribution of fertilizer by the surface. If the wind speed is greater than 2.0 m/s than the fertilizing quality indicators deteriorate dramatically.

However, the value of unevenness in the presence of airflow in general, was within agrotechnical requirements.

Field tests were performed using two serial machines, equipped with disks of our own design. Sizes of the disk, its fastening elements and driving gear fully correspond to the serial disk sample. The only difference was establishment of a special adapter on the shaft. It gives the possibility to change the height position of the disk above soil.

Provision of butting overlap has been provided using GPS navigator.

The tightly placed bins were placed (one to each other) to evaluate the evenness of the surface distribution of granules. They were identical to those ones, used in the laboratory experiments.

## RESULTS

Despite the fundamental researches in theory of granules interaction with disk and numerous improvements of working body construction, the question of uneven distribution of fertilizers which is provided by existing spreaders, is still not resolved fully, because the aim of analytical researches was to create a design disk, which is able to provide technologically sufficient evenness while fertilizers spreading.

One of the significant reasons of uneven distribution explained by scheme – Fig.5.

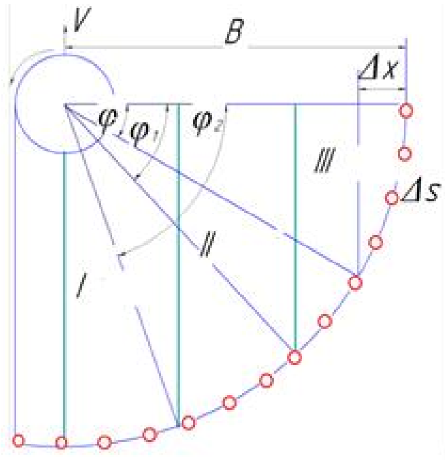


**Fig. 5 - Scheme for analysis of uneven sowing of fertilizer by capture width according to even rotation of centrifugal working body**

Assuming that all the granules during disc discharge are thrown at the same distance B toward the center, on the condition the aggregate does not move, then, if the granules are evenly distributed over a radius of circle B while the aggregate moves, it becomes obvious a dense distribution at the edge of the distribution strip.

Based on accepted assumption it can be argued that the number of granules, which falls on the strip Δ*x* by capture width is proportional to length of corresponding arc Δ*s* (Fig.5). This allows to characterize intensity of the area sowing which is processed, by formula $\Delta s/\Delta x = \psi$. The most intense sown area, the width of which is determined by one third of half of width and corresponds to the angle $\varphi_2 \approx 0{,}841$ rad (48,19°) – Fig.6.

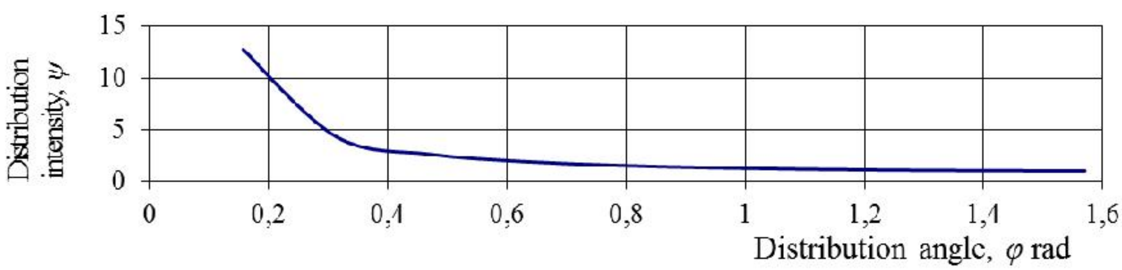


**Fig. 6 - Dynamics of uneven distribution of fertilizers by the area which is processed**

If half of operating width split into three equal areas (Fig. 5), then the third area will account 53.54% of the fertilizer, the second, determined angles $\varphi_1$ and $\varphi_2$ ($\varphi_1$ = 70.53°) – 24.83 % from total amount of fertilizers, and on the first - 21.63% of amount that accounts for half of operating width.

It is evident that actual distribution scheme will be different from the considered idealized version, but the overall picture of densified sowing operation width on stripes edges is observed in real conditions.

As seen from the above considerations, it is necessary to provide escaping of multiple streams of granules from disk with different initial velocities, while avoiding flows cross during flight.

The design of centrifugal working body, which is proposed for problem solving, provides opportunity of additional simultaneous distribution zones I and II to achieve an average density that is realized in zone III (Fig.5). The constructive scheme of a fertilizer spreader is shown in Fig. 7.

Disk 1 is equipped with four blades (sectors) *2*, inclined to the horizontal disk surface at an angle *α.* On working surface of each blade three vertical directing ribs *3* are mounted, longitudinal axis of which is perpendicular to the radial crossing line of blade and disk plane. Fertilizers are served to the center of disk and by centrifugal forces entering onto blades. Each blade fertilizer stream is divided into three independent streams that will have different velocities while escaping from surface, and besides on the longest edge granules are provided with the largest relative, and hence, the largest absolute escaping velocity; the lowest velocity will be developed on the short edge.

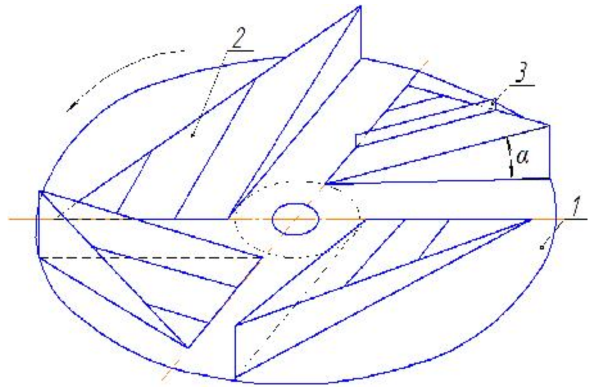


**Fig. 7 - Constructive scheme of a fertilizer spreader**
*1 – disc; 2 – blades (sectors); 3 – one of the guide ribs*

Considering that angles of escaping from each edge will be different, we can say that separate streams of fertilizer will be spaced and trajectories crossing will not happen. The inclination angle of each blade $\alpha$ is selected according to the ability to deliver material on strip which is specified for this.

When designing the centrifugal working body it is necessary to provide the following material delivery: on long edge 0,62$V$; on average–0,26$V$; on short–0,11$V$. To determine escaping velocity of granules from edge, which starts at an arbitrary distance $a$ from disk center ($a = 00_1$), theorem of velocity addition is used.

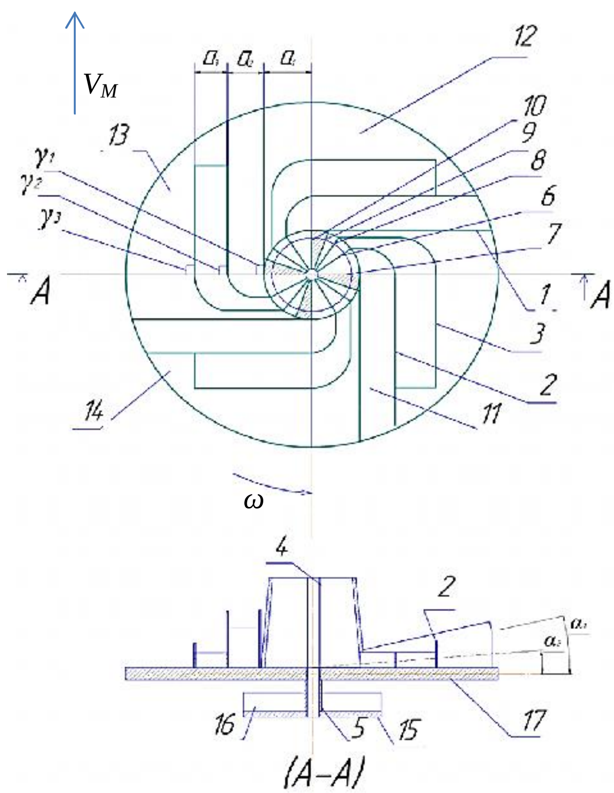


**Fig. 8 - Constructional and technological scheme of centrifugal working body for fertilization**

Analysis of possible options of centrifugal working body designs for fertilizing allowed to accept scheme, construction of which involves forming allocation of granules flows while loading (fig.8). Spreader consists of disk *17*, four blades (sectors 11-14) each of which is formed by two vanes side walls which are formed by vertical edges and bottoms are inclined at angles $\alpha_1$ and $\alpha_2$ to the disk horizontal surface. Each edge (1-3) is perpendicular to the joint crossing line of blades bottoms and disk plane (on Fig.4 direction of each edge is marked with angles $\gamma_1$, $\gamma_2$, $\gamma_3$ severally). In the center of disk there is a conical feeder *4*, interior space of which is divided into separate sectors with radial vertical plates (6–10). Each plate at it bottom part go beyond feeder on edge height and with bottom edge accedes to horizontal center disk part. The lateral edge of protruding from feeder (conical) part is connected to the curved section of edge *2*, which is placed on the horizontal plane of the disk.

In the same way edge *3* is connected with protruding side part of the plate *8*, and edge 1 – with 9. In each quarter of the centrifugal working body where the working blade is, feeder is divided into four sectors by plates. Three of them workable, through two blades fertilizer fall on upper disk, and on the second sector accounts 53.6 % amount of fertilizer from first, and onto the last – third – the least 11.24 % of the same amount. From this sector fertilizer falls onto disk *15*, which is situated lower on 60 mm from the upper which is provided by cup *5*, on which are placed perpendicular one to each other guiding edges *16*. One of feeder sectors closed from above (fig.1, shaded). Sectors areas are assigned proportional to the expenditure of material which falls on each edge. The material getting into the sectors falls on the horizontal surface of the disc from which, moves between the curved portions of edges gets to the inclined blades.

Mathematical model for investigation of granules flight suggests that environmental resistance is proportional to velocity (fig.9). We consider general case of a particle motion as a material point in air after escaping from the working body if wind presents:

- gravity $m\vec{g}$, where $g$ = 9.81 m/s$^2$ – acceleration of gravity;
- total resistance force (pressure) of environment:

$$\bar{R} = k \cdot m \cdot g \left(\bar{V} - \bar{V}_B\right) \tag{1}$$

where $k$ – resistance coefficient;

$\bar{V}$ – particle velocity at an arbitrary time $t$ (forms an angle α with horizon), m/s;

$\bar{V}_B$ – wind velocity which is directed at angle $\beta$ relative to particle, m/s;

$\bar{V}_0$ – initial velocity of material particle $M$ (forms an angle $\alpha_0$ with horizon), m/s.

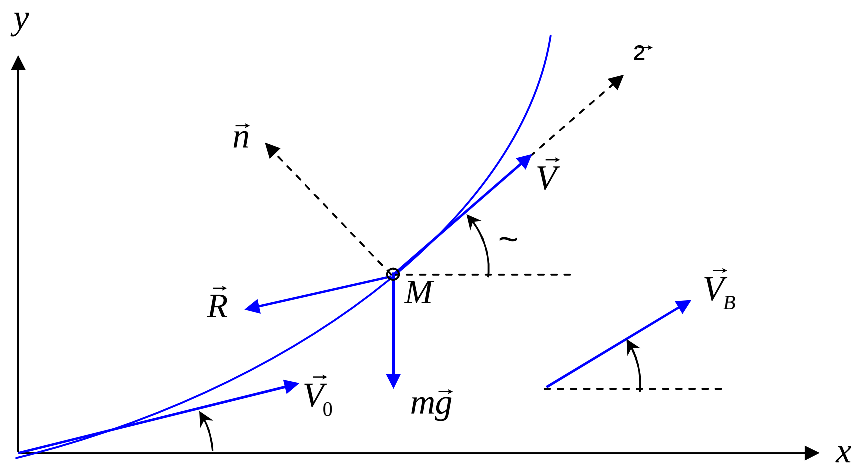


**Fig. 9 - Scheme to the mathematical model of granules movement in the air**

In true coordinate system *(τ,n)* system of differential equations of particle motion looks like:

$$m\frac{dV}{dt} = F_\tau, \qquad m\frac{V^2}{\rho} = F_n,$$

$$\begin{cases} m\dfrac{dV}{dt} = -m \cdot g \cdot \sin\alpha - k \cdot m \cdot g \cdot [V - V_B \cdot \cos(\beta - \alpha)]; \\ m\dfrac{V^2}{\rho} = -m \cdot g \cdot \cos\alpha + k \cdot m \cdot g \cdot V \cdot \sin(\beta - \alpha), \end{cases} \tag{11}$$

where

$\dfrac{1}{\rho} = \dfrac{d\alpha}{ds}$ – trajectory curvature;

$s$ – arc trajectory coordinate.

After the conversion and integration mathematical dependences we have:

$$x(\alpha) = \frac{1}{k \cdot g} \cdot \frac{A}{k}\left[\cos\beta \cdot \ln\frac{\sin(\alpha + \beta + \Omega)}{\sin(\alpha + \beta)} - \sin\Omega \cdot \cos(\beta + \Omega) \cdot ctg(\alpha + \beta + \Omega)\right] + C_1, \tag{12}$$

$$y(\alpha) = \frac{1}{k \cdot g} \cdot \frac{A}{k}\left[-\sin\beta \cdot \ln\frac{\sin(\alpha + \beta + \Omega)}{\sin(\alpha + \beta)} + \sin\Omega \cdot \sin(\beta + \Omega) \cdot ctg(\alpha + \beta + \Omega)\right] + C_2,$$

where $C_1$ and $C_2$ are obtained from the initial conditions: $x(\alpha_0) = 0 \;\; y(\alpha_0) = 0$

The range of granules flight, which escapes from scapula was calculated with the following initial data: wind velocity ($V_B$) – 3 m/s, fertilizers density *(p)*–1000 *kg*/m$^3$, granule diameter *(R)* – 0.001-0.005 m, blade inclination angle to disk rotation plane ($\alpha_1$) – 13°, environment viscosity *(η)* for air – 0.000018 kg /(m s). For initial velocity $V_0$, and escaping angle $\alpha_0$ from formulas (9) and (10) we obtained the values $V_0$ = 18.19 m/s, $\alpha_0$ = 8°.

The result of mathematiccal model graph solution is drawn and represented in Fig.10.

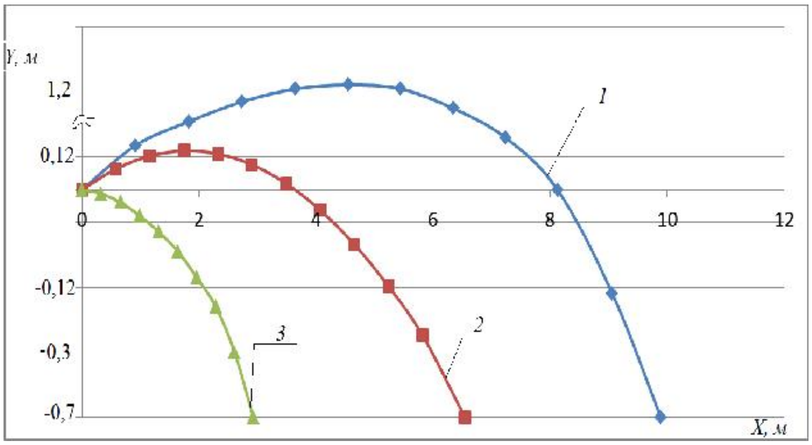


**Fig. 10 - The trajectory of particles which escaped from designed working body**

*1 – trajectory of fertilizer particles which were launched from the blade, which is installed at angle 13°, 2 – at angle 8°,3 – at angle 0°*

For flight range of granules which was determined by formulas (12), the obtained value is 9.94 m and the maximum height is 1.2 m. While analyzing granule's motion which is speeded up by second scapula that has a length of 0.25 m, the inclination angle is $\alpha_2$ – 8°, were obtained the granule escaping velocity $V_0$ – 11.75 m/s, launch angle – 7.5°. Under such conditions the flight distance was 6.35 m from the disk axis.

Trajectory of particle motion does not intersect with moving trajectory which is determined from the first scapula because of take-off height above disk, which in this case is 0.12 m.

Laboratory and field researches were performed using the most common granular fertilizers. They are: ammonia nitrate, superphosphate, mixtures *NPK* (complex fertilizers). Before work starting, their basic properties were determined in accordance with the methods, which count the great influence of mechanical and technological properties of the materials that were involved in the experiment for the final distribution by soil surface.

Figure 11 shows the effect of granules moisture on the maximum impact velocity by metal surface.

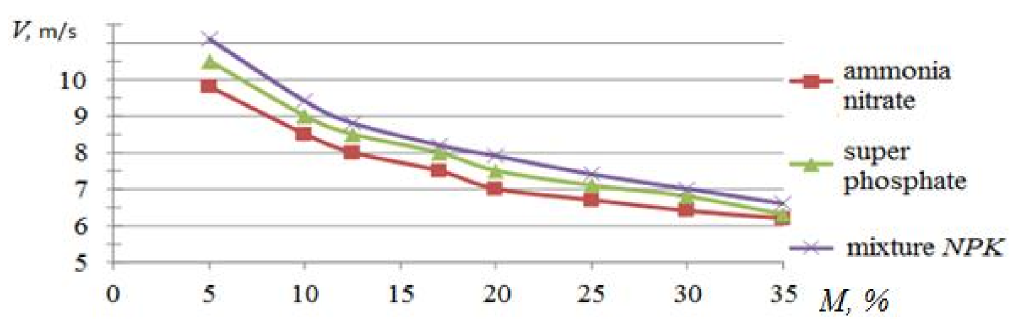


**Fig. 11 - Influence of granules moisture on maximum velocity stroke to metal surface**

The maximum permissible impact velocity by a metal surface with superphosphate – 11.3 m/s. If moisture of granules is from 5 to 12% then the speed reaches its maximum values in all researchable fertilizers (8-12 m/s). When the moisture rises from 12 to 35% an intense reduction of impact velocity by metal surface to 6.8 m/s was recorded. This is due to the destruction of the granules that hit and destruct. So this is the reason of acceptable impact velocity reduction.

Measured data of maximum impact velocity of fertilizers by metal are shown in Table 1.

**Table 1**

**Physical and mechanical properties of the fertilizers used in the experiment**

| Type of fertilizer | Moisture | Bulk density | Angle of friction | Angle of internal friction | Impact velocity |
|---|---|---|---|---|---|
| | [%] | [t/m$^3$] | [degree] | [degree] | [m/s] |
| Ammonia nitrate | 1.5 – 2.1 | 0.79 – 0.83 | 31 - 35 | 39 – 43 | 10.2 |
| Superphosphate | 4.4 – 4.9 | 1.13 – 1.19 | 26 - 34 | 31 – 35 | 12.3 |
| Mixture NPK | 5.8 – 6.7 | 1.03 – 1.12 | 30 - 35 | 40 - 44 | 9.7 |

Mechanical and technological properties of fertilizers, which affect the distribution process, were mainly determined experimentally. It has been established that the allowable impact velocity by metal surface is: superphosphate 12.3 m/s, ammonium nitrate - 10.2 m/s and a mixture NPK – 9.7 m/s, the optimal moisture is 12%.

The original methodology for determining critical impact velocity by metal surface with regard to granules moisture and wind influence on the final distribution has been developed. Methodology airflow influence research makes possible to determine the speed influence in laminar and turbulent modes.

Comparative laboratory tests proved that the proposed construction of a centrifugal spreader provides agro technical performance requirements for evenness of dispersion.

## CONCLUSIONS

The developed methods of determining:

- parameters of granules distribution by the soil surface in laboratory condition;
- wind influence on the parameters of the granules distribution by the surface.

Methods of critical impact velocity by metal surface regarding moisture of granules and wind influence on the final distribution have been developed. The research methodology of air flow influence makes possible to determine the influence of the speed in laminar and turbulent modes.

Air flow that is directed at an angle from 45 to 135 degrees has the most negative impact on the fertilizer evenness distribution by the surface. Deviation in the wind direction should not exceed 45° from the movement direction of aggregate. Wind speed that exceeds 3 m/s is not desirable.

Constructive scheme of experimental installation have been developed and implemented in manufacture. The design of the centrifugal fertilizer spreader ensures the formation of multiple streams of fertilizers. It also leaves the disk at different speeds and different angles of flight.

It has been proved that the permissible impact velocity is from 8 to 12 m/s, depending on moisture.

Maximum resistance of granules to impact has been observed at their moisture of 9-12%.

## ACKNOWLEDGEMENT

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