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DETECTION OF A HIDDEN REGULARITY BETWEEN VIBRATION NOISE AND THE DISTRIBUTION OF GRANULE MASSES BY DIAMETER IN AT FERTILIZER GRANULATION PLANT

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Abstract**—***Theoretical and experimental studies of the granulation process of mineral fertilizers were considered in order to identify a mathematical model of the relationship between the vibration noise spectrum of the installation and the fluidized bed distribution of granule mass by diameter, as the main indicator of the quality of the granulation product. A method of current (inertial-free) control of granule mass distribution by diameter in optimal time has been developed. The current control of the distribution based on the analysis of the noise of the installation allows you to optimize this process in terms of the quality of the output product and minimize the cycle time of its production.*

Index Terms—Granulation quality; pseudo-reinforced layer; vibration spectrum; distribution of granule mass; identification; optimization.

I. INTRODUCTION

Fertilizer production is always an actual task of the national economy. A dehydration devices with fluidized layer are the most effective [1]. The disadvantage of the granulation process (creation of granules of a given size from liquid and small fraction – centers of growth of the diameter of the granules) is a significant delay in determining the main indicator of product quality - distribution of masses of granules by diameters. The narrower this distribution (dispersion) relative to the desired diameter, the better the product.

The existing approach consists in periodic partial discharge of the manufactured product and construction of histograms of distribution of masses m of granules by diameter D using a grid system. This leads to a significant delay in the evaluation $m(D)$ and, as a result, in slowing down the process.

Therefore, the task of developing a method of current (inertial-free) distribution control $m(D)$ for the optimal time T is actual: for small T the distribution $m(D)$ is not optimal $D < D_{\text{opt}}$, for much – too, due to the destruction of large-diameter granules [1].

II. STATEMENT OF PROBLEM AND ALGORITHM OF THEIR SOLUTION

In order to attainment of the delivered goal, it is necessary to conduct an active experiment on the experimental installation, which on a large scale reflects the processes in industrial installations, with the aim of identifying correlations between the known (as a result of the active experiment) histogram distribution $m(D)$ and the vibration spectrum of the installation, which arise as a result of the impact of the formed granules on the walls or a special screen of the chamber with a fluidized layer.

The experiment was carried out for three correspondingly selected compositions of granules (small, medium and large fractions) in a mode close to the working one (by temperature, humidity, pressure drop above and below the fluidized layer). The natural noise background was recorded for the loaded unit. Experiments were repeated several times in order to evaluate the reproducibility of noise spectra for four cases: empty unit, nominally loaded with small, medium and large granules.

During the experiment, using the visual observation of the amplitude spectrum of the noise was determined:

- the noise of the empty installation is in the (0–300) Hz with peaks near 25 Hz and 50 Hz;
- noises of 8 kHz and more are not reproduced and are almost independent from particle size noises
- in the range (1–7) kHz have a clearly defined peak A_m, which the frequency f_m depends on the equivalent diameter D_e of the loaded mixture of

granules, and its sharpness depends from the satter of the diameters of this mixture.

As an example, Fig. 1 shows a histogram and distribution $m(D)$ and the corresponding spectrum of vibrations (Fig. 2).

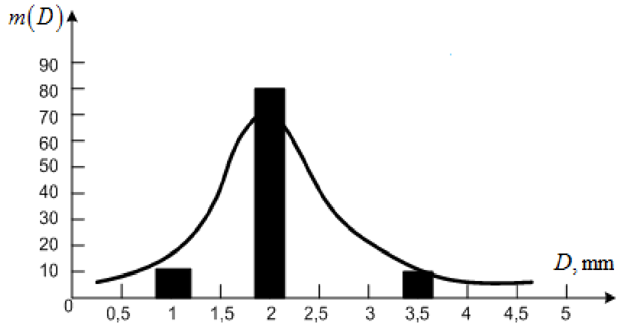

Fig. 1. Histogram and distribution of mass of granules by diameter

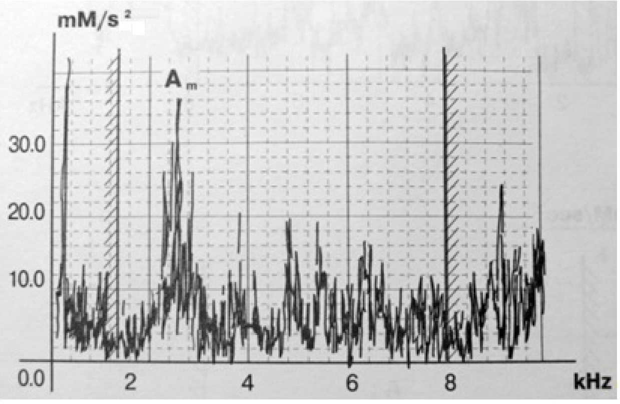

Fig. 2. Granules vibrations spectrum

Indirect indicators – the period T^* of the peak A_m of the spectrum $T^* \cdot 10^4 = 4.09$ c, spread $\sigma_{T^*} \cdot 10^4 = 0.338$ c, the ratio ζ of the amplitudes A_k of all kth harmonics in the (2–4) kHz band except A_m to A_m obtained from six experiments for a mixture with an equivalent diameter $D_e = 2.52$ mm, a spread of diameters $\sigma_D = 0.29$ D_e $\sigma_{De} = 0.05$ mm, a spread of D_e $\sigma_{De} = 0.05$ mm and relationship $\sigma_D / D_e = 0.115$

$$\zeta = \sum A_k / A_m = 4.6.$$

Similar results were obtained for the other two mixtures. Graphical dependences $T^* \pm \sigma_{T^*}$ on $D_e \pm \sigma_{D_e}$ and $\zeta \pm \sigma_\zeta$ on $D_e \pm \sigma_{D_e}$ are presented in Figs 3 and 4 respectively.

As you can see, even within the range of arguments and functions, it is possible guaranteed to assert about the existence of a linear relationship between direct and indirect indicators of the quality of the granulation product. In order to further specify this dependence, we will use the methods of confluent analysis [2].

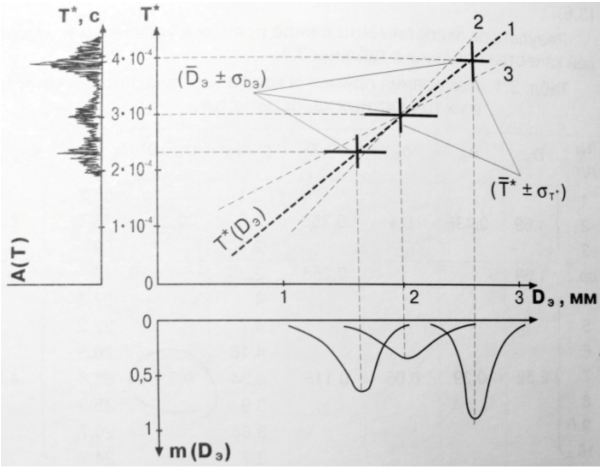

Fig. 3. Dependence of the periods of the spectral component of the maximum amplitude T^* on the diameter D_e

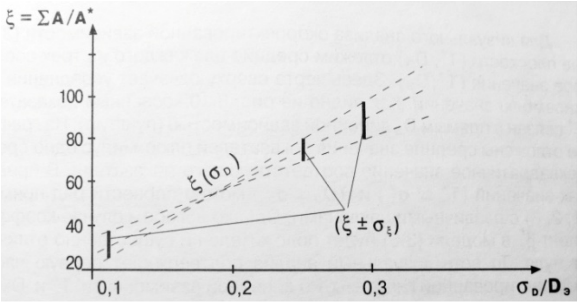

Fig. 4. Linear regression between scatters in the spectrum ζ and σ_D in particle diameters

Based on the physics of the process, before specifying the structure of the regression dependence $T^*(D_e)$ (Fig. 3), it should be taken into account that this dependence must pass through the origin of the coordinates $T^*(D_e)$. Indeed, if $D_e =$ goes to zero, then the frequency f_m of vibration noise goes to infinity, and T^*, like f_m^{-1}, will also go to zero. Therefore, we will approximate $T^*(D_e)$ by one-parameter model

$$T^*(k) = \beta_1 D_e(k) + \varepsilon_1(k). \qquad (1)$$

Similarly and $\zeta(\sigma_D / D_e)$, because if $\sigma_D = 0$, then and $\zeta = 0$

$$\zeta(k) = \beta_2(\sigma_D / D_e) + \varepsilon_2(k)\zeta. \qquad (2)$$

LSM-estimates $\hat{\beta}_1, \hat{\beta}_2$ of parameters β_1, β_2:

$$\hat{\beta}_1 = \frac{\sum_{k=1}^{13} T^*(k) D_e(k)}{\sum_{k=1}^{13} D_e^2(k)}, \qquad (3)$$

$$\hat{\beta}_2 = \frac{\sum_{k=1}^{13} \zeta(k) \frac{\sigma_{D(k)}}{D_e(k)}}{\sum_{k=1}^{13} \left(\frac{\sigma_{D(k)}}{D_e(k)} \right)^2}, \qquad (4)$$

Estimates (3), (4) were obtained based on the experimental data, which are shown in Table I.

Numerical values: $\hat{\beta}_1 = 1.54 \cdot 10^{-4}$, $\hat{\beta}_2 = 340$, $\sigma_{\hat{\beta}_1} = 0.28 \cdot 10^{-4}$, $\sigma_{\hat{\beta}_2} = 20.5$.

So, $\hat{T}^* = 1.54 \cdot 10^{-4} \cdot D_e$, $\hat{\zeta} = 340 \cdot \frac{\sigma_D}{D_e}$.

But denominators, as sums of squares of relatively exact values, will be overestimated by values $13\sigma^2_{De}$ and, accordingly, $13\sigma^2_{\frac{\sigma_D}{D_e}}$. If the denominators in expressions (3), (4) were exact, and the errors in the multipliers were mutually uncorrelated Gaussian noises, then the estimates $\hat{\beta}_1, \hat{\beta}_2$ would be unbiased and effective. The latter can be allowed. Therefore, LSM-estimates $\hat{\beta}_1, \hat{\beta}_2$ will be understated [3].

The uncertainty of these values does not make it possible to estimate the deviation of the estimates $\hat{\beta}_1, \hat{\beta}_2$. However, taking into account the one-parameter of the MNC-estimation problem, to determine the areas of their possible displacement, we will repeat the LSM-estimates for inverse models

$$D_e(k) = \beta_1^{-1} T^*(k) + \varepsilon_3(k), \qquad (5)$$

$$\frac{\sigma_D}{D_e}(k) = \beta_2^{-1} \zeta(k) + \varepsilon_4(k). \qquad (6)$$

LSM-estimates $\hat{\beta}_1^{-1}, \hat{\beta}_2^{-1}$:

$$\hat{\beta}_1^{-1} = \frac{\sum_{k=1}^{13} T^*(k) D_e(k)}{\sum_{k=1}^{13} \left(T^*(k)\right)^2}, \qquad (7)$$

$$\hat{\beta}_2^{-1} = \frac{\sum_{k=1}^{13} \zeta(k) \frac{\sigma_D}{D_e}(k)}{\sum_{k=1}^{13} \left(\zeta(k)\right)^2}, \qquad (8)$$

Numerical values: $\left(\hat{\beta}_1^{-1}\right)^{-1} = \hat{\beta}_1 = 1.55 \cdot 10^{-4}$, $\left(\hat{\beta}_2^{-1}\right)^{-1} = \hat{\beta}_2 = 350$.

Therefore, the exact value of the coefficients β_1 and β_2 the relationship of direct and indirect indicators will be $\beta_1 \in [1.54...1.55] \cdot 10^{-4}$, $\beta_2 \in [340...350]$. As a working option, we will take the average values β_1 and β_2, according to the measured parameters of the vibration spectrum of the installation, we will monitor the quality of the produced mixture of granules in the fluidized layer installation online:

$$\hat{D}_e(t) = \frac{10^4}{1.545} f_m^{-1}(t), \qquad (9)$$

$$\frac{\sigma_D}{D_e}(t) = \frac{1}{345} \cdot \frac{\sum A_k}{A_m}(t). \qquad (10)$$

TABLE I. EXPERIMENTAL DATA

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
T^*	2.1	2.5	2.1	4	4.7	4.16	4.34	3.9	3.86	3.7	3	2.6	3.4
D_e	1.69			2.52							2.05		
ζ	86.2	75.7	69	27.3	32.2	26.5	35.8	35.3	26.7	24.7	90	98	82
$\frac{\sigma_{D(k)}}{D_e(k)}$	0.258			0.115							0.29		

When $\hat{D}_e(t)$ and its distribution approaches to desired one, the finished product with a quasi-optimal distribution $m(D)$ is unloaded in the minimum time. If the time is extended, the large granules are destroyed, that is, an undesirable process occurs from the point of view of product quality, time and energy consumption.

It should be noted that the vibro-acoustic process of pellets hitting on surface with a vibro-sensor has a "tidal" character and the most accurate values of the spectrum are reached at the peak of the wave. It is not difficult to take this into account when implementing the proposed method.

III. CONCLUSION

To implement the proposed method, it is necessary to conduct a similar experiment for each industrial installation and, having obtained the necessary dependencies (9), (10), optimize the process.

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А. М. Сільвестров, М. Я. Островерхов, Л. Ю. Спінул. Виявлення прихованої закономірності між віброшумами і розподілом мас гранул за діаметром в установці гранулювання міндобрив

Розглянуто теоретико-експериментальні дослідження процесу гранулювання мінеральних добрив з метою виявлення математичної моделі взаємозв’язку спектру віброшумів установки з псевдозрідженим шаром і розподілу мас гранул за діаметром, як головним показником якості продукту гранулювання. Розроблено метод поточного (без інерційного) контролю розподілу мас гранул за діаметром за оптимальний час. Поточний контроль розподілу на основі аналізу шумів установки дозволяє оптимізувати цей процес за якістю вихідного продукту і мінімізувати час циклу його вироблення.

Ключові слова: якість гранулювання; псевдозріджений шар; спектр вібрацій; розподіл мас гранул; ідентифікація; оптимізація.

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