Scientific Journal of Silesian University of Technology. Series Transport
Zeszyty Naukowe Politechniki Śląskiej. Seria Transport

Volume 91 **2016**

p-ISSN: 0209-3324

e-ISSN: 2450-1549

DOI: 10.20858/sjsutst.2016.91.14

Journal homepage: http://sjsutst.polsl.pl

Article citation information:
Vinogradov B., Ostashko I. Substantiation of key parameters of a centrifugal mill intended for grinding solid residue from the pyrolysis of used automobile tyres. *Scientific Journal of Silesian University of Technology. Series Transport*. 2016, **91**, 133-141. ISSN: 0209-3324. DOI: 10.20858/sjsutst.2016.91.14.

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SUBSTANTIATION OF KEY PARAMETERS OF A CENTRIFUGAL MILL INTENDED FOR GRINDING SOLID RESIDUE FROM THE PYROLYSIS OF USED AUTOMOBILE TYRES

Summary. The study presents the results of an investigation into centrifugal mills with an energy-saving working body. Rational geometric parameters of the working body of the centrifugal mill, which grinds the solid residue from the pyrolysis of used tyres, have been justified on the criterion of the lowest specific energy consumption during the grinding process. A method to determine the dependence of the in-grinding power consumption on the basic parameters of the working body has been developed, while an analytical expression to determine the power consumption for grinding the solid residue from the pyrolysis of used tyres has been obtained. It has been found that the power consumption in the grinding process linearly depends on the rotational speed of the working body, which is to the 0.3 power on the average size of solid particles.

Keywords: centrifugal mill, working body, power consumption, solid residue from pyrolysis.

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1. INTRODUCTION

Centrifugal mills have been widely used in many industries for grinding various abrasives [1]. The main structural element in most centrifugal mills is a working body containing beater elements in the form of blades and baffles. The grinding process in these mills is performed through a high speed transferred to the material, which results in significant power consumption.

The aim of the article is to study the main parameters of a centrifugal mill for fine grinding of the solid residue from the pyrolysis of waste tyres with the lowest specific power consumption.

2. PRESENTING MAIN MATERIAL

After a careful study of various designs of centrifugal mills and preliminary laboratory tests, a new design of the centrifugal mill has been developed and presented (Fig. 1 [2]), which allows for grinding granular materials, such as the solid residue from used tyre pyrolysis, with the lowest specific power consumption.

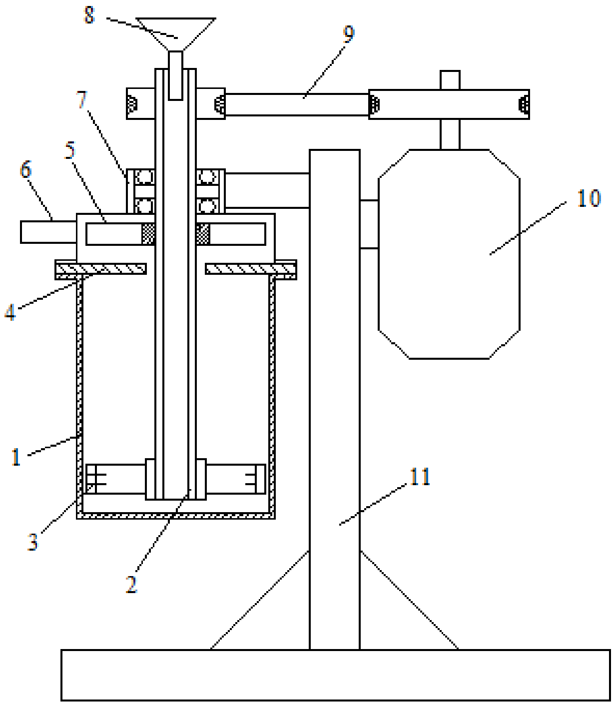

Fig. 1. Centrifugal mill: 1 - grinding chamber; 2 - hollow shaft; 3 - working body; 4 – ring for classification; 5 - impeller; 6 - outlet; 7 - bearing assembly; 8 - hopper; 9 - belt drive; 10 - motor; 11 - support column.

The design feature of the proposed mill is the shape of the working body and the method of discharging the finished grade, which can significantly reduce the specific energy consumption during the grinding process, thereby facilitating the classification of the ground material directly in the mill.

Preliminary studies were carried out on the mill, in which the grinding chamber was shaped as a regular cylinder with a diameter of 0.3 m. In the course of the studies, the rational design and technological parameters of the mill were determined in terms of minimum specific energy consumption during the grinding process [3]. It has been found that: a grinding chamber's effective filling level is 25-30% of its volume; an active length of the working body is shifted to its periphery by as much as 15-25% of its volume, depending on the rotational speed; the gap between the beaters is between 3 and 5 mm; and the specific energy consumption for grinding the class of less than 43 μ with a two-beater working body is 57 kWh / t, while it is 21 kWh / t for a four-beater working body.

The study of the granulometric composition of the ground material (Fig. 2) shows that an increase in the number of beaters from two to four results in increased efficiency, while specific energy consumption is decreased by 180% at the same time. However, a further increase in the number of beaters increases the specific energy consumption with no change in output. This can be explained by the fact that the two-beater working body does not cover the entire area of intense grinding, while the increased number of beaters reaches beyond this area.

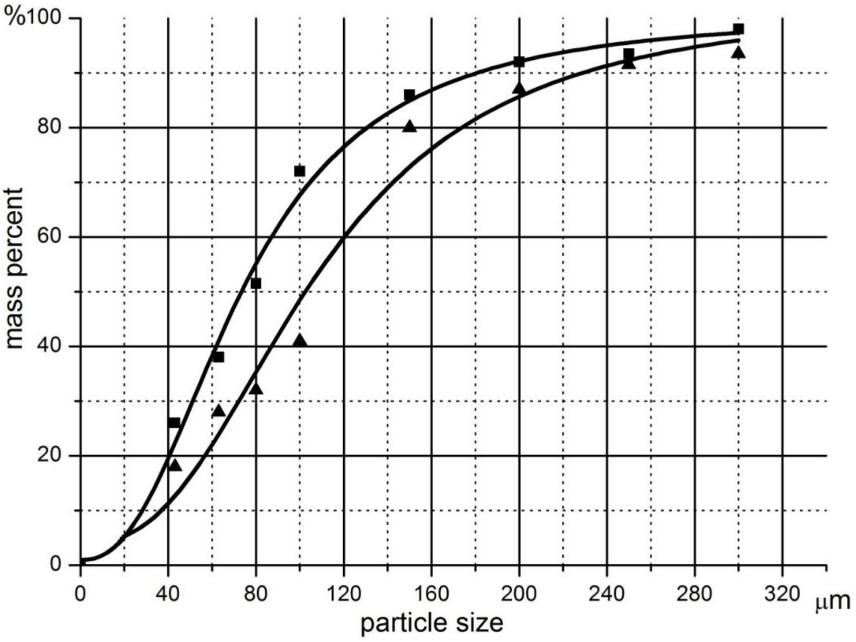

Fig. 2. Granulometric composition of solid pyrolysis residue milled for 1 min by working bodies with different numbers of beaters: 1 - four beaters; 2 - two beaters.

Strength calculations have confirmed the advisability of the closed-type working body design (Fig. 3). This type of working body design allows for grinding due to impact and friction. In this case, larger particles, whose size > 100 μ, are mostly destructed by their impact interaction with the working body in the peripheral area, while particles, whose size < 100 μ, are mainly destructed due to friction forces, which arise from the material interaction with the grinding chamber walls and the working body.

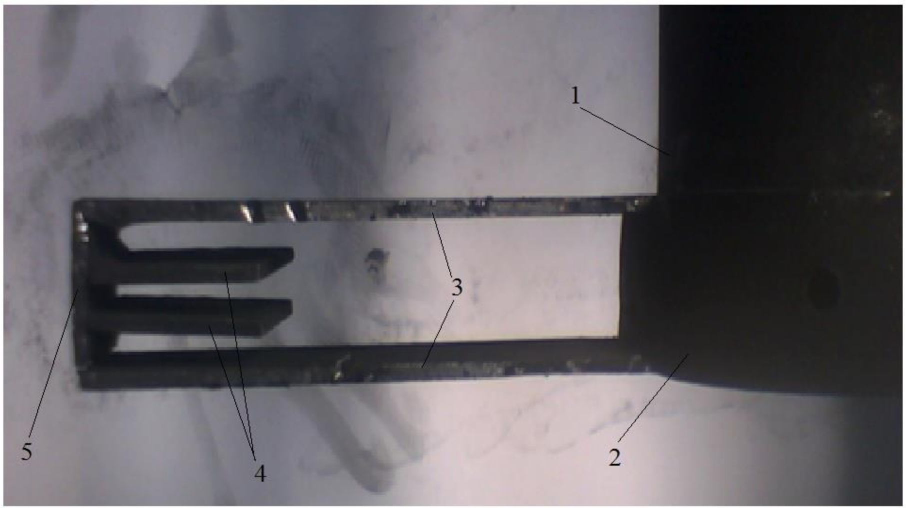

Fig. 3. Working body of the new design: 1 - hollow shaft; 2 - working body mount; 3 - beaters; 4 – beater in the area of intensive milling; 5 - end beater.

In an idling mode, i.e., in the absence of material feed, the working body of this design consumes the power determined by formula in [3]:

$$N = \xi \cdot \rho_m \cdot A_0 \cdot (k \cdot \omega_w)^3 , \qquad (1)$$

where $\boldsymbol{\rho_m}$ is the density of the medium that interacts with the working body (kg / m^3), ξ is the drag coefficient, A_0 is a parameter that takes into account the geometry of the working body, ($\boldsymbol{k\ \omega_w}$) is the relative angular velocity of the working body, $\boldsymbol{\omega_w}$ is the angular velocity of the working body, and k is the slip coefficient, which characterizes the speed of the working body's interaction with the medium. In turn,

$$k = 1 - \frac{\omega_{air}}{\omega_w} ,$$

where $\boldsymbol{\omega_{air}}$ is the angular velocity of the air.

The unknown terms in Equation (1) are ξ, k. To determine the terms, two separate cases were considered: when the mill was operated with either the grinding chamber removed or the grinding chamber mounted, no material charged. The power consumptions $N1$ and $N2$ can, respectively, be determined based on the following equations:

$$N_1 = \xi \cdot \rho_m \cdot A_0 \cdot (k_1 \cdot \omega_w)^3, \qquad (2)$$

$$N_2 = \xi \cdot \rho_m \cdot A_0 \cdot (k_2 \cdot \omega_w)^3, \qquad (3)$$

where $N1$, $N2$, $k1$, $k2$ are the power consumptions and coefficients of slipping with the removed and mounted grinding chamber, respectively.

The working body power consumption $N1$, N, at different rotational speeds, and the air angular velocity ω_{air} were experimentally determined with the grinding chamber removed with the use of a cup anemometer.

To determine the $N1$, $N2$ power consumptions of the working body, the total power consumption was first measured using the following formula: $N_{\Sigma m} = N_{lost} + N_i$, where N_{lost} is the power lost in the mill's electromechanical transmission with the working body removed, and i is the experiment number 1 or 2. Then, the power consumed by the working body was be determined by the formula: $N_i = N_{\Sigma m} - N_{lost}$.

Fig. 4 and Fig. 5 show the dependence of the angular velocity of the air and working body power consumption on the rotational speed. Fig. 6 shows the experimental dependence of the working body power consumption on the rotational speed when the grinding chamber is loaded with solid residue of tyre pyrolysis with average particle size $d_{av} = 43$ μ.

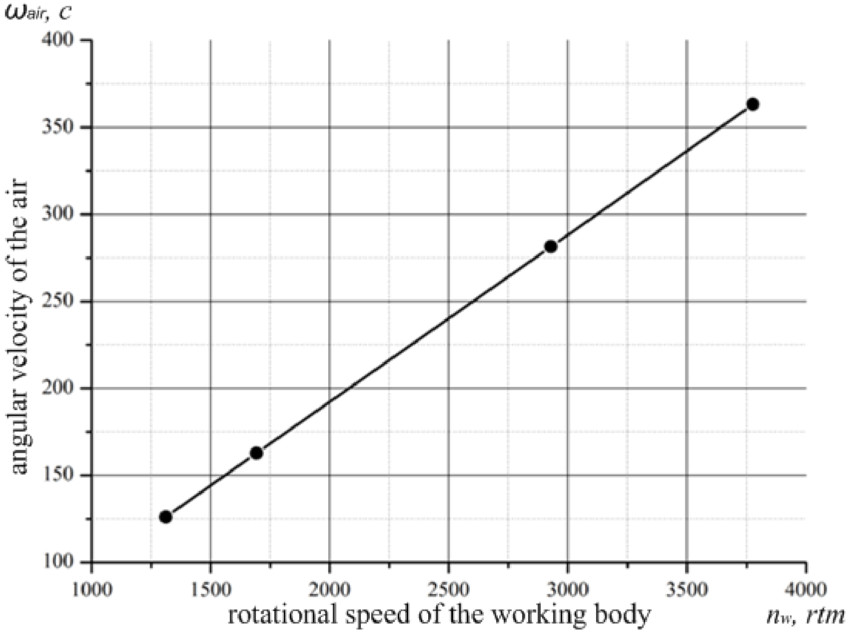

Fig. 4. Angular velocity of the air flow: ω_{air} – angular velocity of the air; n_w – rotational speed of the working body.

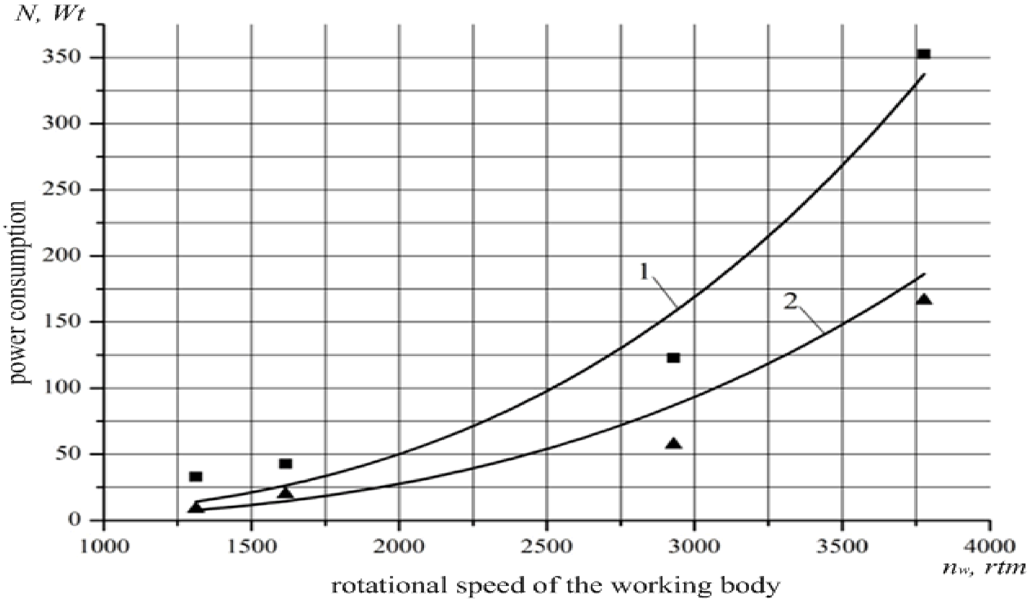

Fig. 5. Curves of power consumed by the working body: 1 - with the grinding chamber removed; 2- with the grinding chamber mounted.

By knowing the angular velocity ω_{air}^0 of the air during the rotation of the working body with the grinding camera removed, along with the power consumption, we can determine the relative angular velocity $k1 \cdot \omega_w = \omega_w - \omega_{air}^0$ and drag coefficient ξ. Assuming that the drag coefficient is the same whether the camera is removed or mounted, we calculate the relative angular velocity of the rotor with the chamber mounted as follows: $k2 \cdot \omega_r = \omega_r - \omega_{ac}$ (ω_{ac} is the angular velocity of the air during the working body rotation in the grinding chamber).

The experimental data show that the air velocity is directly proportional to the working body rotational speed (Fig. 4), while the slip coefficients are $k_1 = 0.92$, $k_2 = 0.83$, and the drag coefficient is $\xi = 12.6$. The experimental results also confirm the adequacy of Equation (1), namely, that the power consumed by the test working body, which operates in an empty chamber, depends on the rotational speed taken to the third power (Fig. 5).

Fig. 6 shows an experimental dependence of wattage consumed by the working body, which operates with the grinding chamber loaded. The material taken was the solid residue from the pyrolysis of used tyres, with an average particle diameter of $d_{av} = 43\mu m$. Meanwhile, the degree of filling in the grinding camera was $V_m / V_c = 0.27$ (V_m, V_c represent the volumes of the material and the chamber, respectively) and the material bulk density was 445 kg / m^3.

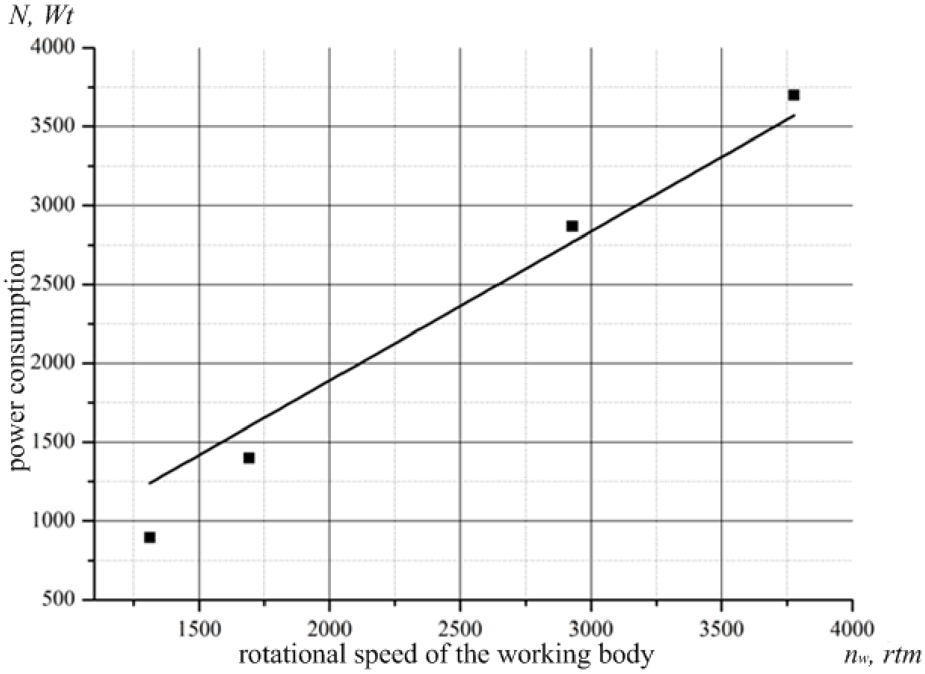

Fig. 6. Dependence of power consumption on the rotational speed of the working body during the grinding process.

In contrast to an empty chamber, where air is the medium, the power consumption in the loaded grinding chamber is linearly dependent on the rotational speed of the working body. This can be explained by the fact that, during the grinding process, the material influenced by centrifugal forces is unevenly distributed throughout the inside of the grinding chamber and concentrated along its walls. This reduces an active area of the working body, which results in further changes in the distribution of the forces of resistance. Based on the analysis of Equation (1) and the experimental data (Fig. 6), a conclusion can be made that the dependence of A_0 (the parameter characterizing the size of an active part of the working body) on the rotational speed takes the following form:

$$A(\omega) = A_0 \cdot \nu \cdot \omega_w^{-2}, \tag{4}$$

where $\nu = 1.72$ is the coefficient, which takes into account the decrease in an active part of the working body.

To determine the power consumption, we substitute the values of ν and assume that coefficients ξ are equal for either an empty or a loaded grinding chamber, while an average diameter of solid particles $d_{av} = 43$ μm. In turn, Expression (1) takes the following form:

$$N = \xi \cdot \rho_m \cdot A_0 \cdot \nu \cdot (k_2 \cdot \omega_w). \tag{5}$$

Fig. 7 shows the experimental dependence of the power consumption on the average material particle diameter at an angular velocity of 389 s^{-1}. Increased power consumption in relation to the increase in the average particle diameter may be explained by an increase in the relative angular velocity of the interaction between the working body and the medium.

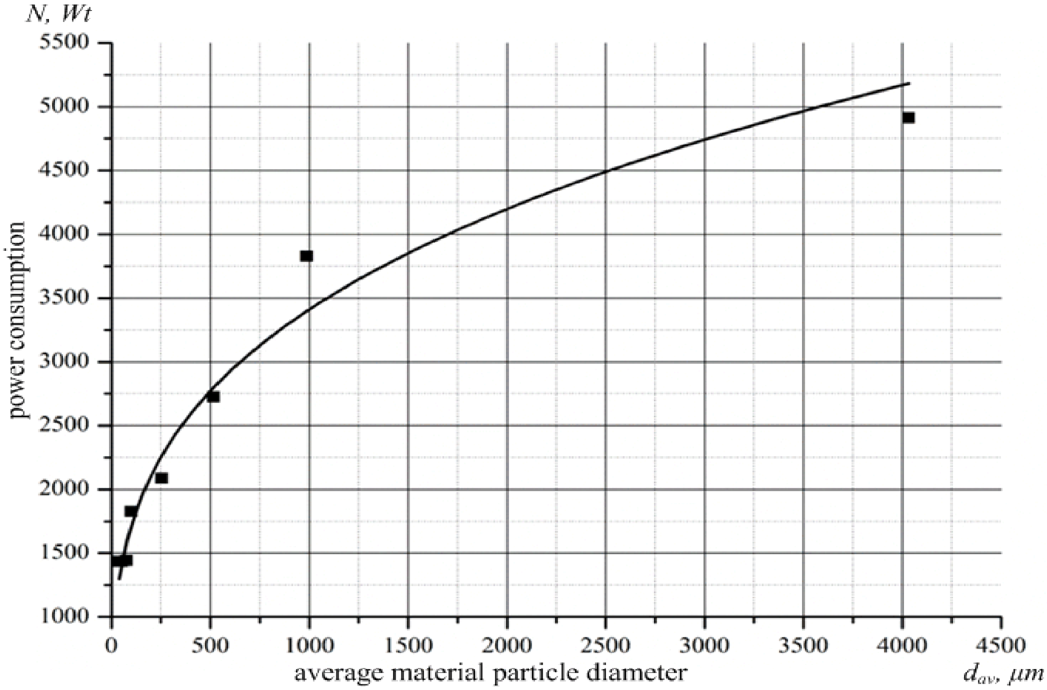

Fig. 7. Power consumption change with average particle diameters at an angular velocity of 389 s^{-1}.

When working with the material feed, slip coefficient k_2 undergoes changes due to the reduction in the rotational speed of the medium; the drag coefficient ξ is also subject to a change, since the parameters of the medium have changed. It is therefore necessary to consider the product of the two coefficients as a function of the average material particle diameter d_{av}.

$$\xi \cdot k_2 = f(d_{av})$$

Experimental dependence of power consumption on the average diameter of particles in the grinding chamber (Fig. 7) can be approximated with a dispersion of $R = 0.97$, according to the following function:

$$N(d_{av}) = 429.3 \cdot d_{av}^{0.3}. \tag{7}$$

By equating the power consumptions defined by Formulas (5) and (7), we obtain:

$$\xi \cdot k_2(d_{av}) = 21.21 \cdot d_{av}^{0.3} . \quad (8)$$

Thus, the general formula, which will determine the wattage consumption for grinding the solid residue from the pyrolysis in the centrifugal mill, takes the following form:

$$N = 36.48 \cdot \rho_m \cdot d_{av}^{0.3} \cdot A_0 \cdot \omega_w . \quad (9)$$

3. CONCLUSIONS

1. The proposed design parameters of the working body and the mill as a whole will provide the minimum specific power consumption during the material grinding.
2. The formula obtained by the authors can be used to determine the power consumed by the centrifugal mill’s working body for grinding the solid residue from the pyrolysis of used tyres.
3. It has been found that, during the grinding process, the power consumption linearly depends on the rotational speed of the working body and is proportional to an average size of solid particles, which are taken to the 0.3 power.
4. The method developed by the authors allows for obtaining a dependence of power consumption by the centrifugal mill’s working body on its basic parameters, as well as the parameters of the material to be ground.

References

1. Бардовский А. Д., Л. А. Летин, Н. М. Кряжев, И. И. Дерба, Е. В. Пухучкин. 2002. Определение параметров центробежной мельницы роторно-струйного измельчения при помоле отходов карбонатного сырья. *Горный информационно-аналитический бюллетень* 1: 204-206. Moscow: МГГУ. [In Russia: Bardovskiy A. D., L. A. Letin, N. M. Kryazhev, I. I. Derba, E.V. Pukhuchkin. 2002. „Defining the parameters of a centrifugal rotor-jet mill when milling waste carbonate raw materials”. *Mining Informational and Analytical Bulletin* 1: 204-206. Moscow: Moscow State Humanities University.]
2. Виноградов Б. В., И. О. Осташко. 2009. Об энергетических характеристиках центробежных мельниц с S-образным рабочим органом. *Вісник НТУ „ХПІ”* 25: 164-169. [In Ukraine: Vinogradov B. V., I. O. Ostashko. 2009. „On the energy performance of centrifugal mills with an S-shaped working body”. *Bulletin of the Kharkiv Polytechnic University* 25: 164-169. Kharkiv: Kharkiv Polytechnic University].
3. Виноградов Б. В., И. А. Осташко, В. И. Емельяненко. 2009. „Измельчение твердых остатков процесса пролиза изношенных автомобильных шин в центробежной мельнице”. *Вопросы химии и химической технологии* 2: 159-161. [In Ukraine: Vinogradov B. V., I. O. Ostashko, V. I. Emel'yanenko. „Shredding of solid residue pyrolysis of used tyres in a centrifugal mill”. *Issues of Chemistry and Chemical Technology* 2: 159-161. Dnepropetrovsk: Ukrainian State University of Chemical Technology].

4. PL 216901 B1. *Układ mechaniczny strojony w sposób płynny*. [In Polish: *Smoothly tuned mechanical system*.]. Homišin Jaroslav. 2014. Warsaw: Polish Patent Office.
5. Grega Robert, Jozef Krajňák. 2012. „The pneumatic dual-mass flywheel”. *Scientific Journal of Silesian University of Technology. Series Transport* 76: 19-24. ISSN: 0209-3324.
6. Homišin J., P. Kaššay, M. Urbanský. 2011. „High-flexibility characteristics of pneumatic flexible shaft couplings”. *Pneumatyka* 79(2): 26-29. ISSN 1426-6644.
7. Mantič M., J. Kuľka, J. Krajňák, M. Kopas, M. Schneider. 2015. „Influence of selected digitization methods on final accuracy of a 3D model”. *Production Management and Engineering Sciences*: 475-480. Proceedings of the International Conference on Engineering Science and Production Management (ESPM 2015). Tatranská Štrba, High Tatras Mountains, Slovakia, 16th-17th April 2015. Edited by Majerník M., D. Naqib, B. Martin. Boca Raton, FL: CRC Press, Taylor & Francis Group. ISBN: 978-1-138-02856-2.

Received 11.12.2015; accepted in revised form 02.05.2016