Determination of rational process variables for multi-step centrifugal mills

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Abstract. This paper presents the results of experimental studies into milling under multiple impacts in multi-step centrifugal mill designed at the Cherksky Institute of Mining. In order to enhance milling capacity, it is proposed to add breakers of the mill with more breaking elements. However, addition of breaking elements sometimes fails to intensify milling and can adversely affect on the milling efficiency to to higher velocity air flows generated in the working space between the top and bottom breakers. The tests have determined the rational number of additional breaking elements, conditioned by the critical air flow velocity of 10 m/s in the breaker chamber of the lab-scale multi-step centrifugal mill. Given these conditions are fulfilled, the fineness number of the multi-step centrifugal mill with additional breaking elements grows considerable as against the base case of the mill without additional elements.

1. Introduction
Improvement of milling machines was and remains a challenging problem calling for new approaches and solutions [1, 2]. Currently, many R&D projects are aimed at design of small-size and high-performance disintegrators, including commonly employed centrifugal impact mills. This is connected with less energy consumed by these machines, their simple design and small dimensions at relatively high capacity.

Designs of most impact mills neglect the variety of physical and mechanical properties of treated materials, and implement one- or-two-contact mechanical attacks insufficient for efficient disintegration. Enhancement of milling efficiency is impossible without new engineering solutions in centrifugal disintegrators, in particular, without design improvement of crushing elements and rational working conditions of milling machines.

Alongside with the physical and mechanical properties of treated materials, efficiency of milling machines is influenced by their process variables such geometry, design, rotational speed of crushing elements, and air flow velocity in the beater chamber, dependent on operation conditions of centrifugal mills [5, 6].

This paper describes the experimental research findings on the effect exerted by additional breaking elements and air flow velocity on crushing efficiency in a multi-step centrifugal mill. The multi-step centrifugal mill is designed at the Mineral Concentration Laboratory at the Institute of Mining of the North [7–9] based on multiple impacts on treated materials [10]. The aim of the study was to define rational design and process variables of multi-step centrifugal mills toward the enhanced milling efficiency.
2. Experimental results
The lab-scale testing of a lab-scale multi-step mill with a bottom breaker diameter of 180 mm and a top breaker diameter of 200 mm were carried out on black shale ore samples 150 g in weight and -3+2.5 mm in size. The mill allowed setting of various number detachable breaking elements at each step of the bottom breaker. The rotation speeds of the working elements of the mill were adjusted using lab-scale autotransformers and measured by tachometer ADS-lab. The air flow velocities at various rotation speeds of the working elements were measured at the outlets of the mill using air flow meter ATT-1004. The milled samples were forward to a screen analyzer for standard size composition determination.

The experimental results on the influence of the air flow velocity on the milling efficiency of a base-case multi-step centrifugal mill, without additional breaking elements are reported below. Table 1 shows that air flow velocities increases with the increasing rotational speed of the bottom breaker of the multi-step mill with the immobile top breaker.

| Rotational speed, rpm | Air flow velocity, m/s |
|-----------------------|------------------------|
| 1000                  | 2.78                   |
| 2000                  | 4.56                   |
| 3000                  | 5.75                   |
| 4000                  | 6.98                   |
| 5000                  | 8.19                   |
| 6000                  | 11.26                  |
| 7000                  | 14.21                  |

Table 2 compiles the values of the air flow velocities at different rotational speeds of the top breaker in the multi-step mill with the bottom breaker rotating at the most ration speed of 5000 rpm.

| Rotational speed, rpm | Air flow velocity, m/s |
|-----------------------|------------------------|
| 500                   | 8.22                   |
| 1000                  | 8.89                   |
| 1500                  | 9.14                   |
| 2000                  | 9.49                   |
| 2500                  | 10.11                  |
| 3000                  | 11.42                  |

The yield of the check size of -0.071 mm at the bottom breaker speed of 5000 rpm and the top breaker speed varied from 500 to 3000 rpm is depicted in Figure 1.

It follows from Figure 1 that as the speed is increased starting from 1500 rpm, the milling efficiency raises, while no such effect is observed at the rotational speed higher than 2000 rpm. Such a border in the milling efficiency occurs as the higher air flow rate in the breaker chamber drives unbroken particles off the breaking zone.

In this experimental manner, the rational rotational speeds of the working elements of the multi-step mill and the limiting air velocity in the breaker chamber to 10 m/s are determined. The excess over these values results in violation of circulation conditions of treated particles and the milling efficiency drops as a consequence.

Then, the influence of additional breaking elements on the efficiency of the lab-scale multi-step centrifugal milling was investigated. The tests with and without addition of breaking elements were
carried in few variants, with 4 to 10 breaking elements at each step of the bottom breaker, and at the most rational speeds of 2000 rpm and 5000 rpm of the top and bottom breakers, respectively.

Figure 1. Yield of check size -0.071 mm at different top breaker speeds.

Figure 2 show the breakers free from additional elements and with eight breaking elements at each step.

Figure 2. Breakers of multi-step mill: (a) without additional breaking elements; (b) with 8 breaking elements.

Figure 3. Lab-scale multi-step milling results.
The milling results obtained in the lab-scale multi-step centrifugal mill with different variants of breaking elements are compared in Figure 3. It is seen that in milling with 8 additional breaking elements as against the other variants, the milled product contains almost no size +0.315 mm, which is ground to finer sizes, and the fineness number of milling grows as a result.

Table 3 gives the obtained values of the air flow velocities in the breaker chamber of the multi-step mill with and without additional elements.

| Number of breaking elements | Air flow velocity, m/s |
|-----------------------------|-----------------------|
| —                           | 9.4                   |
| 4                           | 9.7                   |
| 8                           | 10.2                  |
| 10                          | 11.9                  |

Table 4 compares the fineness numbers and check size yield of mill products.

| Breakers                                | Fineness number (i = d\(n/d\(k\)) | Yield of check size of 0.071 mm, % |
|-----------------------------------------|-------------------------------------|-----------------------------------|
| Without additional elements             | 2                                   | 37.6                              |
| Added 4 breaking elements                | 4.2                                 | 52.27                             |
| Added 8 breaking elements                | 9.5                                 | 57.31                             |
| Added 10 breaking elements               | 3.7                                 | 50.2                              |

It is seen from Tables 3 and 4 that installation of additional elements and the increase in their number changes aerodynamics of the multi-step mill breakers at the same most rational speeds of the top and bottom breakers of 2000 and 5000 rpm, respectively. As a consequence, the air flow velocity gradually grows in the breaker chamber, the fineness number raises and the yield of the check size of -0.071 mm increases. Addition of breaking elements eliminates unbroken particles and creates the required conditions for particle circulation at each step in the mode of self-milling and dynamic loading. However, when more than 8 breaking elements are added, they contribute to air flow velocity, and the resultant air flow velocity of 10 m/s deteriorates the milling efficiency.

In this manner, the implemented experiments determined the rational number of breaking elements, governed by the critical air flow velocity of 10 m/s in the breaker chamber of the lab-scale multi-step centrifugal mill.

3. Conclusions
On the whole, from the described research data, it can be inferred that the fineness number of the lab-scale multi-step centrifugal mill grows considerably owing to addition of optimized number of breaking elements to stimulate the dynamic contacts between particles and the breakers. The experimentally found dependence of the lab-scale multi-step centrifugal milling efficiency on the air flow velocity in the breaker chamber of the mill at different rotational speeds of breakers makes it possible to determine the most rational working conditions of the multi-step centrifugal mill and to enhance its efficiency.

References
[1] Kafarov VV, Dorokhov IN and Arutyunov SYu 1988 Current conditions and prospects of intergated system resreach into milling of granular materials Zhurnal VKhO im. DI
Mendeleeva Vol XXXIII No 4
[2] Smirnov NM Improvement of flow charts and equipment for impact milling of various abrasiveness materials Doctor of Engineering Sciences Dissertation Ivanovo (in Russian)
[3] Baron LI and Konyashin YuG 1986 Scientific Grounds for Rational Rock Breaking Modes under Dynamic Loading Moscow: Inst. Gorn. Dela Skochinskogo (in Russian)
[4] Vlasov OE and Smirnov SA Comparison of performance data of various disintegrators Teor. Osnovy Khim. Tekhnol. Vol 2 No 4 pp 831–837
[5] Oliveira JFG, Silvab RJ, Duoc C and Hashimoto F 2009 Manufacturing technology Industrial Challenges in Grinding Vol 58 Issue 2 pp 663–680
[6] Potapov VYa and Lyaptsev SA 2012 Mathematica description of the behavior of ore articles in air flow spearators Sovr. Probl. Nauki Obraz. No 1 pp 7–10 Available at: www.Scienceducation.ru/101-5493
[7] Matveev AI, Grigoriev AN and Filippov VE 2000 RD Patent N 2150323 7 B 02 C 13/20 Countertow centrifugal grinder Izobret. Polezn. Modeli No 16
[8] Matveev AI, Lvov E. and Vinokurov VR 2016 New in ore preparation - multiple impact crusher and grinding machines Mining Informational and Analytical Bulletin Special Issue 21 pp 242–252
[9] Matveev AI, Grigoriev AN and Vinokurov VR 2003 RF Patent N 2198028, 7 B 02 C 13/20. Centrifugal grinder Izobret. Polezn. Modeli No 4
[10] Revnivtsev VI, Gaponov VG and Zagoratsky LP 1988 Selective Destruction of Minerals Moscow: Nedra (in Russian)