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# STUDY OF MODES AND PARAMETERS OF MINERAL RAW MATERIAL GRINDING PROCESS IN BALL DRUM MILLS

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**Abstract.** The paper presents the results of research on the vibration-acceleration signal of the ball mill drum bearing support depending on its load when grinding mineral raw materials. Investigations of vibration sensor readings, installed on the bearing support of the mill drum, and amplitudes of the vibration-acceleration signal from the volumetric filling of the installation drum have been carried out. The dependences of vibro-acceleration signal amplitudes on the frequency spectrum of Fourier series at different volumetric filling of the mill drum in the interval of loads from 0 t/h to 18 t/h are investigated. In research on the interrelation of a signal of vibro-acceleration and consumed power of an electric drive of a drum depending on the degree of its volume filling, their averaged values are established. According to the values of averaged numerical values of amplitudes of vibro-acceleration signal amplitudes, the graphs of their dependence on the frequency spectrum of Fourier series in the range from 0 to 30000 Hz are obtained, the dependences of the consumed power of the ball mill and the amplitude of the vibro-acceleration signal on the volumetric filling of the drum are established, the algorithm of determining the level of filling of the mill drum is developed, the dependences of the vibro-acceleration signal and consumed power on the level of filling of the ball mill in volumetric units are established. It is established that the filling of the mill drum by the consumed power of the electric drive can be controlled up to 0.7 of the volumetric filling of the mill drum. At the same time, the value of volumetric filling of the mill drum, expressed through the signal of vibration velocity of the bearing support, smoothly grows in the whole range of drum filling from 0.0 to 1.0. In this case the reliability of the received information on vibration acceleration of the mill drum support with deviation from the approximating curve, not exceeding 5–6%. Tracking of the level of filling of the mill drum is provided by the signal of the vibration sensor, which allows to maintain of optimal performance, grinding quality, and power consumption. The obtained results give grounds to use the vibration acceleration signal in the system of automatic control of the coal grinding process as a criterion for evaluating the degree of filling of the mill drum during its operation.

**Keywords:** ball drum mill, grinding, vibration acceleration signal amplitudes, coal.

## 1. Introduction

Disintegration of mineral raw materials in the world annually consumes at least 5% of all produced energy. At the same time, the efficiency of crushing and grinding equipment does not exceed 2%, and disintegration processes are characterized by high energy losses and low efficiency. The absence of control systems for raw material grinding leads to its overgrinding, loss of a significant part of surface energy and reduction of efficiency of the process of subsequent enrichment. The technical and economic performance of ball drum mills (BDM) requires improvement, especially at the grinding stage [1]. Therefore, improving the preparation of mineral raw materials of the required grinding quality, reducing energy consumption and increasing efficiency to maximize the performance of ball mills is an urgent scientific and technical problem [2].

Ball mills are widely used in many branches of industry. They are of special importance for thermal power plants (TPP) operating on hard coal [3]. As a rule, the methods of controlling the process of ore grinding in BDM are insufficiently effective due to the lack of methods for measuring the main parameters of the grinding process. For example, the amount of loaded coal, productivity, and determination of the pre-accident condition of the apparatus, when it is overloaded with the crushed material.

This leads to a sharp decrease in the productivity of the units and the need for manual regulation of the grinding process by reducing the coal supply. As a result, the inefficiency of the technological cycle of grinding leads to an increase in the energy intensity of the process as a whole [4]. The solution to many design problems, energy consumption problems, analysis of vibration data and mill dynamics using acoustic beamforming and numerical modeling, and operating conditions of the BDM is considered in [5–10].

The existing control systems [11–14] do not provide reliable prevention of possible overfilling of the mill with raw materials. The instability of this process does not allow to provide a constant particle size distribution of coal and completeness of filling the drum of the ball mill.

The search for a technical solution to this problem led to the conclusion that its solution is possible by controlling the load of the ball mill by the signal of the vibration sensor installed on the bearing support of the mill drum, and the power consumption of the electric drive of the drum from its volumetric filling with coal.

The solution to this problem will significantly improve the technical and economic performance of the mill and the TPP as a whole, as well as the working conditions of the operating personnel.

Proceeding from the accepted technical solution the purpose was set - to investigate the vibration acceleration signal of the mill drum bearing support and the power consumed by the electric drive of the drum in the process of its filling with coal.

In the process of research the following tasks were solved:

1. study of the scheme of installation of measuring devices on the technological line of preparation of pulverized coal mixture to supply steam boilers of TPP LLC "Kramatorskteploenergo";

2. Development of the structural scheme for data acquisition and processing from the vibration sensor installed on the bearing support of the mill drum 2;

3. Research of parameters and criterion for estimation of the degree of filling of the mill drum in the process of its operation at coal grinding;

4. Development of an algorithm for determining the level of filling of the mill drum and the system of automatic control of feeding the grinding raw material into the mill drum.

## 2. Methods

The results obtained in this work were achieved using:

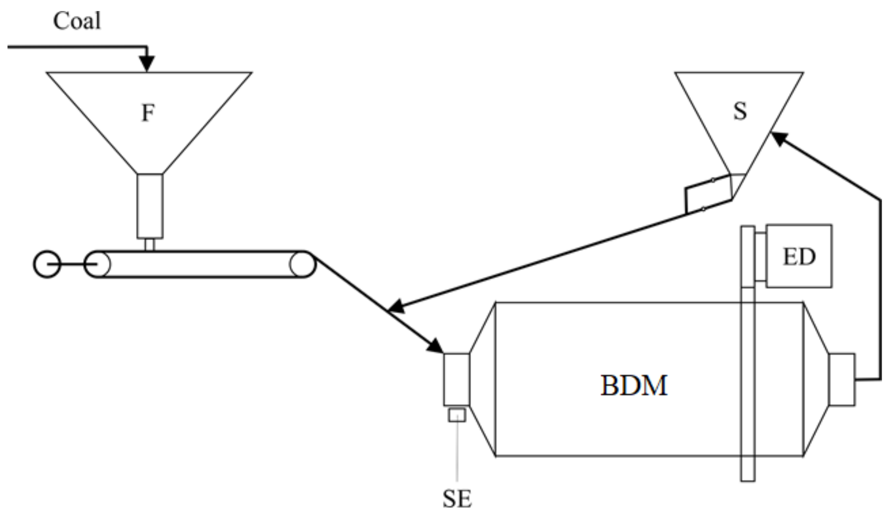
- experimental study of ball drum mills operation parameters at different volumes of their loading;

- fast Fourier series transformation of vibration signals of bearing support vibration acceleration and power consumption of the electric drive of the mill drum from its volumetric filling with coal;

- method of heuristic search of regularity between the level of coal loading of the drum, vibration signals of the bearing support and power consumption of the electric drive of the mill drum.

## 3. Theoretical and/or experimental parts

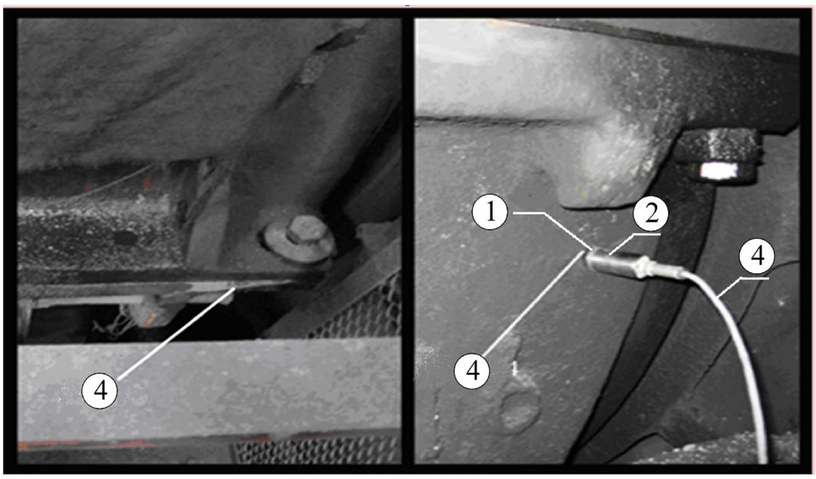
To study the operation parameters of ball drum mills at different volumes of their coal loading, the analysis of the vibration-friction signal of the mill drum bearing support was used. Experimental-industrial researches were carried out on the technological line of preparation of pulverized coal mixture for the supply of steam boilers of TPP "Kramatorskteploenergo". The principal scheme of the pulverized coal mixture mill is shown in Figure 1.




F– feeder; S–separator; BDM– ball drum mills; ED– electric drive

Figure 1 – Dependence of the vibration acceleration signal amplitudes and power consumption on the filling level of BDM in volumetric units

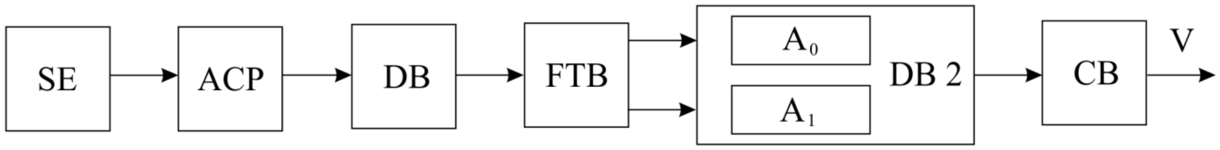
The vibration sensor (accelerometer AP-100-VM) is installed on the bearing support of the BDM and connected to the archiving unit. A general view of the sensor installation location is shown in Figure 2.




1 – permanent magnet; 2 – accelerometer AP-100-VM; 3 – connecting cable; 4 – ball drum bearing support

Figure 2 – Location of accelerometer mounting

The structural diagram of blocks for calculating the filling level of the mill drum depending on the vibration acceleration of the bearing support of BDM is shown in Figure 3.




SE – accelerometer; ACP – analog-to-digital converter; DB – database of numerical data; FTB – fast Fourier transform block; DB 2 – database of numerical data 2; CB – calculation block A0 – is the amplitude of the vibration acceleration signal of the empty BDM; $A_1$ – amplitude of vibration acceleration signal at loaded drum, dB;

Figure 3 – Structural diagram for vibration acceleration data acquisition and processing

To determine the dependence of the amplitude of the vibration acceleration signal of the ball bearing support on the volume filling of the drum, the signal of the empty mill drum is chosen as the zero reference point.

The amplitude of the vibration acceleration signal $\Delta A_n$ is defined as the difference of numerical values obtained by fast Fourier series expansion for the empty and filled ball mill drum. The calculation of $\Delta A_n$ was performed using the following equation:

$$\Delta A_n = A_0 - A_n = f(G_n), \tag{1}$$

where $A_0$ – is the amplitude of the vibration acceleration signal of the empty BDM, dB; $A_n$ – amplitude of vibration acceleration signal at loaded drum, dB; $G_n$– drum filling volume, t/h.

The data obtained are summarized in Table 1.

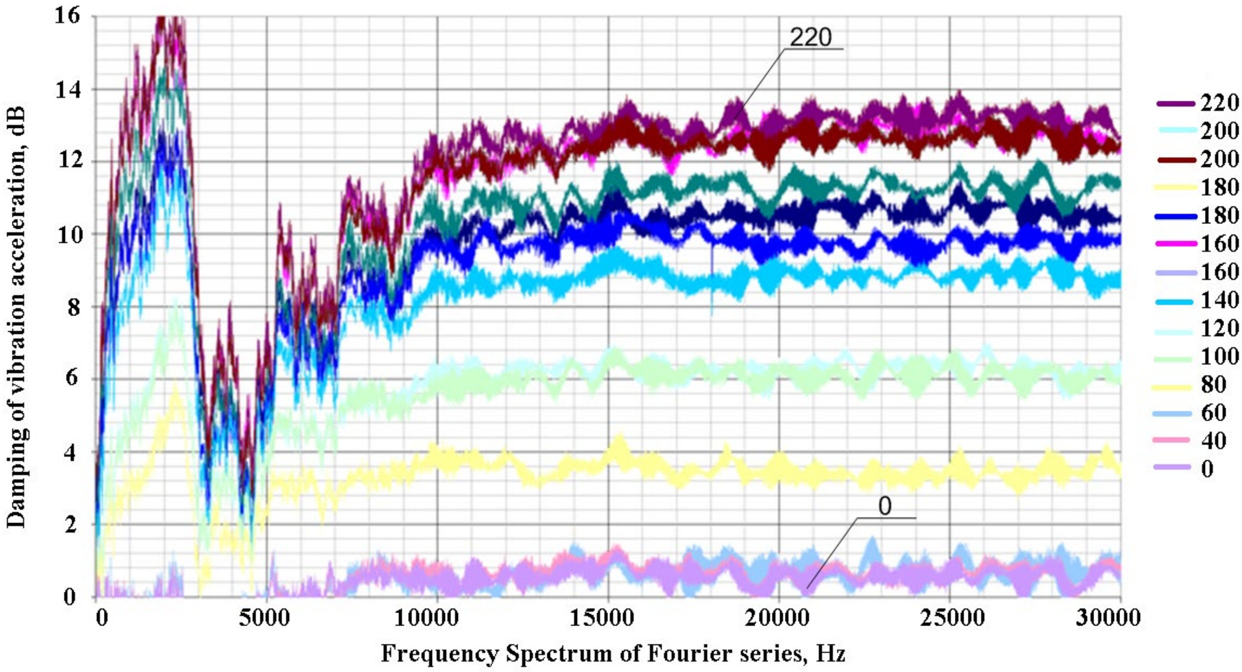
The dependence of the vibration acceleration signal amplitude of the BDM bearing support on the Fourier series frequency spectrum in the load-interval from 0 t/h to 18 t/h is shown in Figure 4.

Figure 4 shows that the magnitude of the vibration acceleration signal amplitude measured by the accelerometer in the range from 0 to 10000 Hz is unstable, and in the range from 10000 Hz to 30000 Hz is more uniform.

The amplitude of vibration acceleration at given loads was calculated by the frequency spectrum of the Fourier series and the magnitude of the signal amplitude (see Table 1) according to equation (2):

$$A_c = \frac{1}{n} \cdot \sum_{i=0}^{n-1} A_{ti}, \tag{2}$$

where $A_c$ – average value of vibration acceleration amplitude, dB; $n$ – smoothing interval; $A_{ti}$ – is the value of the random variable at the moment $t_i$, dB.




0 – spectrum at empty drum; 220 – spectrum at full drum loading

Figure 4 – Dependences of vibration acceleration signal amplitudes on the frequency spectrum of Fourier series at different volume filling of the mill drum

Graphs of vibration acceleration amplitude by the values of the averaged numerical values obtained with the help of equation (2) are presented in Figure 5.

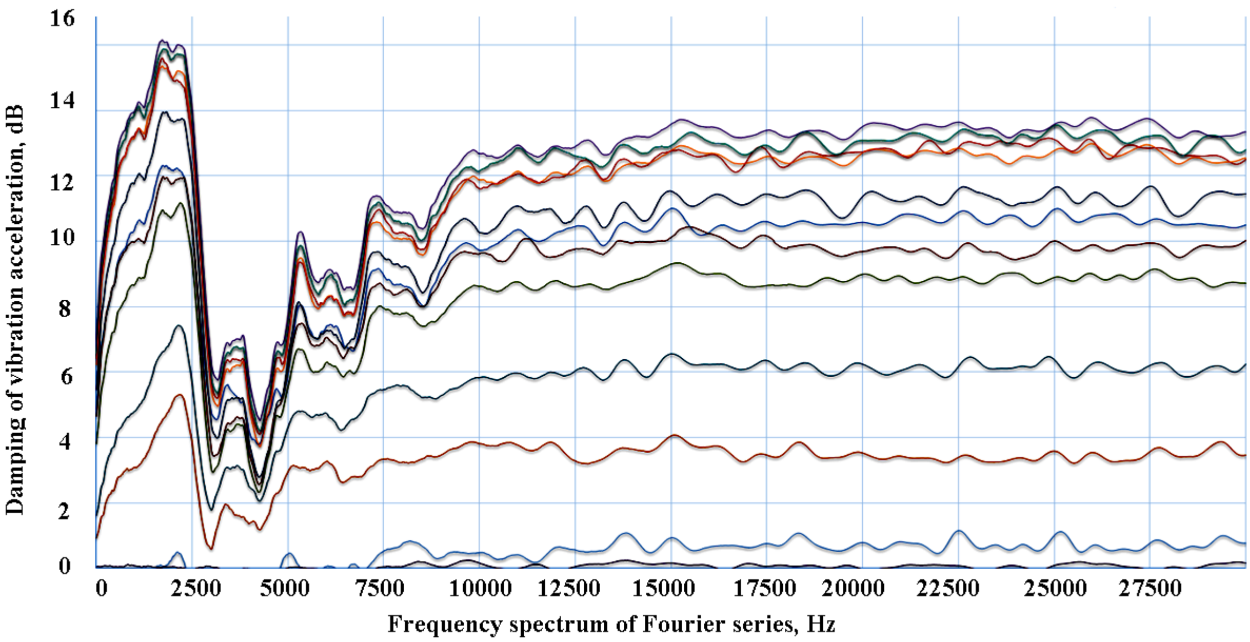



Figure 5 – Dependences of the averaged amplitudes of the vibration acceleration signal on the frequency spectrum of Fourier series and drum volume filling

Table 1. Dependence of vibration acceleration signal amplitudes on drum volume filling in the interval of the Fourier series frequency spectrum from 0 to 30000 Hz

| Time, h:m:s load t/h | 12:28:00 18 t/h | 12:33:00 16 t/h | 12:38:00 14 t/h | 12:44:00 12 t/h | 12:49:00 10 t/h | 12:54:00 8 t/h | 12:57:00 6 t/h | 13:01:00 4 t/h | 13:04:00 0 t/h |
|---|---|---|---|---|---|---|---|---|---|
| Frequency, Hz | Vibration acceleration signal amplitudes, dB | | | | | | | | |
| 5.86 | 2.83 | 6.02 | 6.54 | 7.61 | 10.51 | 10.50 | 10.36 | 10.00 | 9.86 |
| 11.72 | 2.92 | 6.15 | 6.57 | 7.45 | 10.18 | 10.05 | 10.13 | 9.40 | 9.48 |
| 17.58 | 2.64 | 6.17 | 6.49 | 7.02 | 9.68 | 9.57 | 9.88 | 9.15 | 9.46 |
| 23.44 | 2.81 | 6.24 | 6.61 | 7.67 | 9.54 | 10.10 | 10.27 | 9.13 | 9.30 |
| 29.30 | 2.63 | 5.94 | 6.77 | 7.82 | 9.67 | 9.95 | 10.04 | 9.28 | 9.37 |
| 35.16 | 2.44 | 5.93 | 6.51 | 7.48 | 9.63 | 9.27 | 9.37 | 9.00 | 9.10 |
| 41.02 | 2.35 | 5.41 | 5.62 | 6.94 | 8.68 | 8.41 | 8.58 | 8.07 | 8.24 |
| 46.88 | 2.52 | 5.19 | 5.77 | 6.81 | 8.03 | 8.29 | 8.43 | 7.75 | 7.88 |
| 52.73 | 2.70 | 5.56 | 5.48 | 6.84 | 8.38 | 8.38 | 8.46 | 7.92 | 8.00 |
| 58.59 | 2.38 | 5.11 | 5.10 | 6.40 | 8.07 | 8.22 | 8.24 | 7.47 | 7.49 |
| 64.45 | 1.91 | 4.61 | 4.71 | 5.87 | 7.89 | 7.60 | 7.69 | 7.31 | 7.41 |
| 70.31 | 2.22 | 4.87 | 5.22 | 6.29 | 8.01 | 7.69 | 7.98 | 7.63 | 7.91 |
| 76.17 | 2.70 | 5.19 | 5.78 | 6.68 | 8.22 | 8.32 | 8.58 | 8.34 | 8.60 |
| 82.03 | 2.53 | 5.16 | 5.68 | 6.59 | 8.47 | 8.48 | 8.57 | 8.81 | 8.90 |
| 87.89 | 2.52 | 4.93 | 5.33 | 6.75 | 9.03 | 8.62 | 8.55 | 8.79 | 8.72 |
| 93.75 | 2.59 | 5.67 | 5.65 | 6.72 | 9.44 | 9.14 | 9.16 | 8.96 | 8.98 |
| 99.61 | 2.41 | 5.86 | 5.67 | 6.71 | 9.25 | 9.32 | 9.36 | 9.25 | 9.29 |
| 105.47 | 2.44 | 5.70 | 5.65 | 7.16 | 9.63 | 9.46 | 9.62 | 9.51 | 9.67 |
| 111.33 | 2.98 | 6.21 | 6.41 | 7.54 | 10.25 | 9.93 | 10.01 | 10.03 | 10.11 |
| 117.19 | 3.08 | 6.20 | 6.73 | 7.76 | 10.80 | 10.20 | 10.12 | 10.47 | 10.40 |
| 123.05 | 2.66 | 5.91 | 6.18 | 7.49 | 9.99 | 10.36 | 10.31 | 10.17 | 10.12 |
| 128.91 | 2.02 | 5.31 | 5.57 | 6.93 | 9.07 | 9.56 | 9.66 | 9.14 | 9.24 |
| 134.77 | 1.82 | 5.12 | 5.22 | 6.99 | 8.99 | 9.10 | 9.13 | 9.08 | 9.12 |
| 140.63 | 2.00 | 5.61 | 5.59 | 7.23 | 9.77 | 9.43 | 9.68 | 8.99 | 9.24 |
| 146.48 | 1.91 | 5.50 | 5.79 | 7.23 | 9.91 | 9.59 | 9.56 | 9.72 | 9.69 |
| 152.34 | 2.09 | 5.42 | 5.52 | 6.86 | 9.75 | 9.51 | 9.52 | 9.96 | 9.96 |

As a result of the research, it was found that the most informative section of the degree of filling of the mill drum is the frequency spectrum of the Fourier series with amplitudes greater than 10000 Hz. This section of the spectrum is characterized by more uniform amplitudes of vibration acceleration signals. It allows to establish the optimal level of loading of the mill drum with the ground raw material.

When studying the relationship between the vibration acceleration signal and power consumption of the electric drive depending on the degree of its volume filling, equations (3) and (4) were used:

$$\Delta A = \frac{1}{n} \cdot \sum_{i=0}^{n} (A_0 - A_i), \tag{3}$$

where $A_0$ – amplitude of oscillation of the exhausted BDM, dB; $A_i$ – amplitude of oscillation of $i$-th frequency, dB;

$$\Delta N = \frac{1}{n} \cdot \sum_{i=0}^{n} (N_0 - N_i), \tag{4}$$

where $N_0$ – power consumption of the exhausted BDM, kW; $N_i$ – power consumption of $i$-th load, kW.

The data obtained are summarized in Table 2.

Table 2. Averaged values of amplitudes of vibration acceleration signal and power consumption of BDM from drum load

| Load, t/h | 18.1 | 16.1 | 14.0 | 12.0 | 10.1 | 7.9 | 6 | 4 | 0.3 |
|---|---|---|---|---|---|---|---|---|---|
| Power consumption, kW | 1406 | 1389 | 1372 | 1340 | 1329 | 1322 | 1291 | 1275 | 1254 |
| The average value of vibration acceleration, dB | 12.1 | 10.9 | 9.7 | 8.6 | 6.2 | 5.7 | 3.9 | 2.6 | 0 |

The dependence of the electric drive power consumption on the volume filling of the pulley is shown in Figure 6.

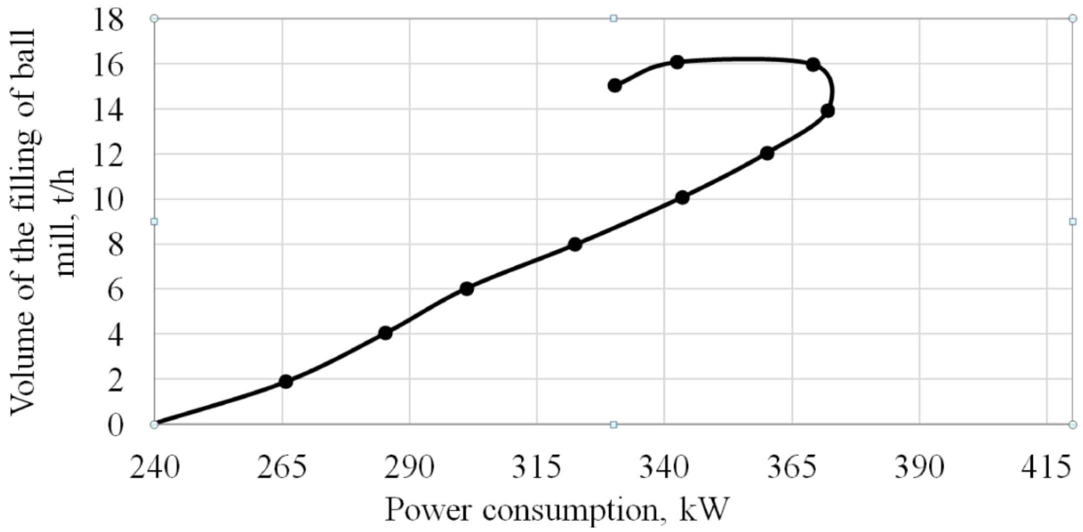



Figure 6 – Dependence of the power consumption on the volume filling of the BDM

The graphical dependence presented in Figure 6 illustrates the ambiguous dependence of the volumetric filling of the mill on the power consumption of the electric drive. It is expressed in the fact that at the load above 14 t/h and reaching the maximum volumetric filling of the mill drum, the power consumption of the electric motor of the ball mill decreases and gives false indications of filling. Further loading of the mill drum leads to blockage and complete stoppage of the ball mill. In industrial conditions, taking into account that the properties of the ground material in the process of operation change randomly, but at the same time the abrasion of grinding balls and wear of armor plates are preserved, the unit is forced to work at the underestimated loading of 10 t/h.

The conducted research on the vibration acceleration signal of the mill drum bearing support allowed us to study the character of the vibration acceleration signal amplitude variation in the whole range of volume filling of the mill, including its emergency section from 14 to 18 t/h. The dependence of the vibration acceleration signal amplitude on the volume filling of the mill drum determined by the experimental data is shown in Figure 7.

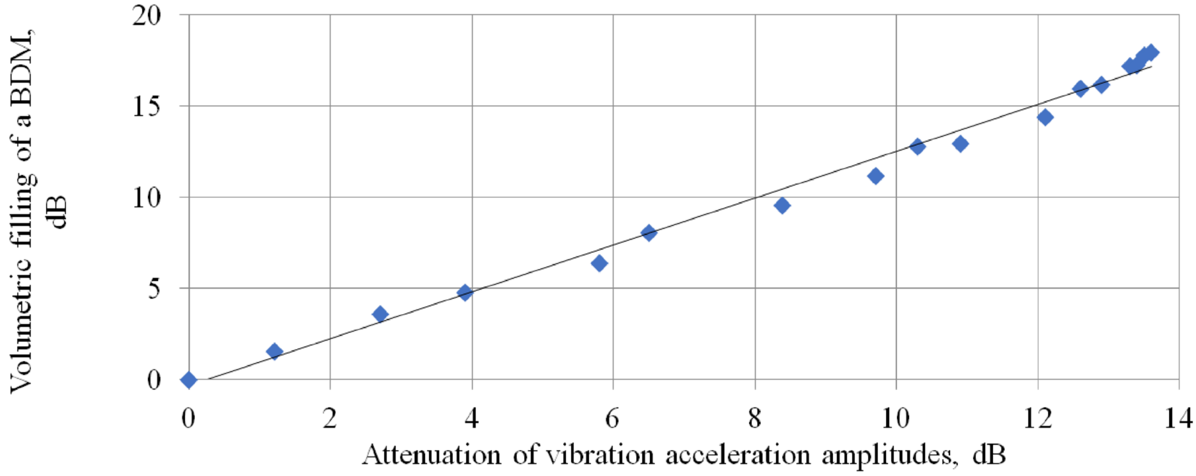



Figure 7 – Dependence of the vibration acceleration signal amplitude on the volumetric filling of the BDM

**4. Results and discussion**

Based on the conducted research the following results is made. The amplitude of the vibration acceleration signal of the mill drum bearing support is proportional to the amount of coal in the mill drum. It allows to carry out calculations of volumetric filling of the mill drum as a function of the consumed power of the electric drive, according to the equation:

$$\Delta V = \left(N_{0p} - N_{vp}\right) \cdot k_n, \tag{5}$$

где $N_{0p}$ – power consumption of the electric drive of the BDM, kW;

$N_{vp}$ – current power consumption of the actuator, kW;

$k_n$ – correction coefficient.

The amplitude of the vibration acceleration signal amplitude of the drum bearing support *A* of the mill depending on the volume filling *V* is determined according to the algorithm shown in Figure 8 (*f* – frequency of the vibration acceleration signal of the bearing support, Hz).

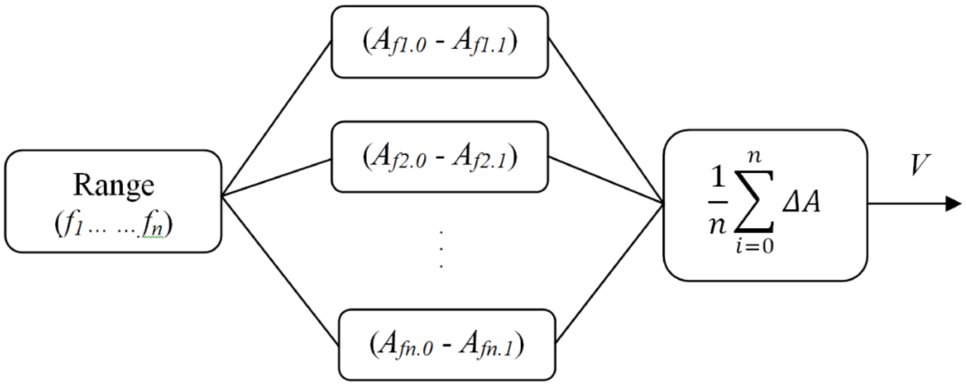



Figure 8 – Algorithm for determining the BDM filling level

The obtained data calculated by formula (5) using the algorithm for determining the level of filling of the mill drum (see Figure 8) are shown in Table 3.

Table 3. Results of research on vibration acceleration signal amplitude and electric drive power consumption from the volume filling of the mill drum

| Load, t/h | 0 | 2 | 4.0 | 6.0 | 8.0 | 10.1 | 12.0 | 13.9 | 15.9 | 16.1 | 18.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Power consumption, kW | 0 | 1.24 | 2.71 | 3.91 | 5.50 | 6.33 | 7.58 | 9.22 | 10.5 | 10.7 | 11.2 |
| Average amplitude value, dB | 0 | 1.2 | 2.6 | 3.9 | 5.7 | 6.5 | 8.6 | 9.7 | 10.2 | 10.8 | 12.8 |

The established dependences of the amplitudes of the vibration acceleration signal of the bearing support and the power consumption of the electric drive of the mill drum on its volume filling are presented in Figure 9.

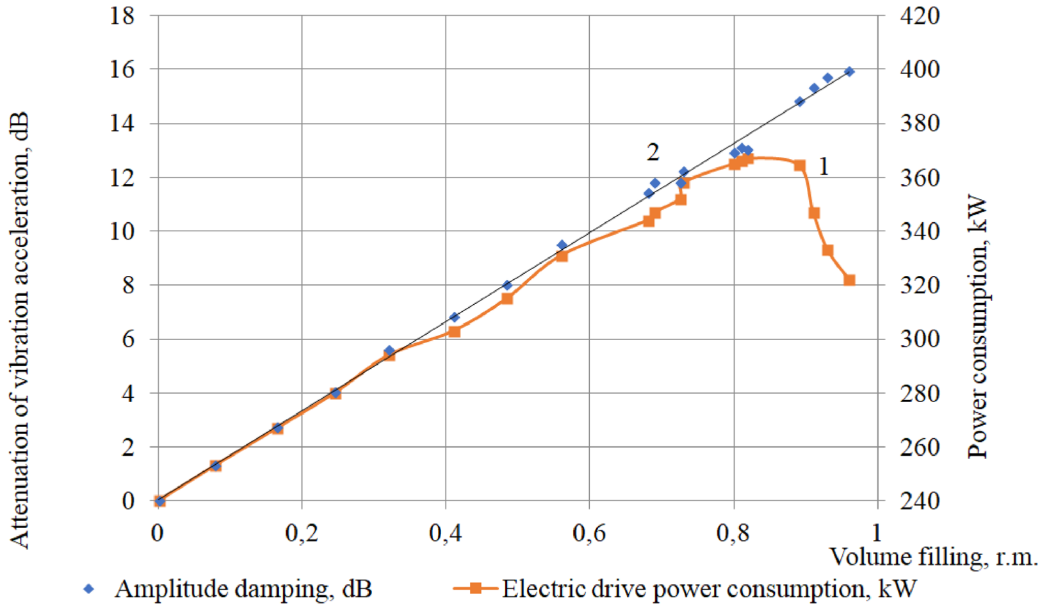



Figure 9 – Dependence of the vibration acceleration signal amplitudes and power consumption on the filling level of BDM in volumetric units

The analysis of the established dependences allows us to conclude that by the signal of vibration acceleration of the bearing support and by the power consumption of the electric drive it is possible to control not only the filling of the drum of the mill but also estimate the efficiency of the coal grinding process at different stages of its volumetric filling.

It has been established that the filling of the mill drum by the power consumption of the electric drive can be realized up to some limiting value, not more than 0.7 of the volume filling of the device (see Fig. 9, curve 1). Further increase of volume filling gives false readings on the level, which leads to blockage of the mill drum. At the same time, the value of the volume filling of the mill drum, expressed through the vibration acceleration signal of the bearing support, increases smoothly over the entire range of drum filling from 0.0 to 1.0 (see Figure 9, curve 2). This dependence clearly illustrates the reliability of the obtained information on the vibration acceleration of the mill drum support with the deviation from the approximating curve not exceeding 5–6%.

Experimental data on the study of the vibration acceleration signal of the support bearing of the mill drum show that the amplitude of the signal after its processing by the block of fast Fourier transform shows the real level of drum loading.

Thus, as a result of the conducted research it is established that the node of bearing support of the mill drum is determinant in the structural scheme of blocks for controlling the level of its volumetric filling. Measurement and processing of the vibration acceleration signal of the bearing support allows to automatize the control of the grinding process and control of the ball mill.

## 5. Conclusions

1. The dependence of the vibration-acceleration signal amplitude of the mill drum bearing support on the completeness of its loading with the grinding material has been experimentally established.

2. The established dependences of the amplitude of the vibration-acceleration signal amplitude of the bearing support and the consumed power of the electric drive of the mill drum on its volumetric filling with coal allow us to make a scientifically justified decision on the use of the vibration-acceleration signal of the bearing support as a determining parameter of the control system of the coal grinding process, in ball-drum mills.

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## ДОСЛІДЖЕННЯ РЕЖИМІВ І ПАРАМЕТРІВ ПРОЦЕСУ ПОДРІБНЕННЯ МІНЕРАЛЬНОЇ СИРОВИНИ У КУЛЬОВИХ БАРАБАННИХ МЛИНАХ

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**Анотація.** У статті наведено результати досліджень сигналу віброприскорення опори підшипника барабана кульового млина залежно від його навантаження при подрібненні мінеральної сировини. Проведено дослідження показань датчика вібрації, встановленого на опорі підшипника барабана млина та амплітуд сигналу віброприскорення від об'ємного заповнення барабана установки. Досліджувалися залежності амплітуд сигналу віброускорення від частотного спектра рядів Фур'є при різному об'ємному заповненні барабана млина в інтервалі навантаження від 0 т/год до 18 т/год. При дослідженні взаємозв'язку сигналу віброприскорення та споживаної потужності електроприводу барабана в залежності від ступеня його об'ємного заповнення, встановлені їх середні значення. За величинами усереднених чисельних значень амплітуд сигналу віброприскорення отримані графіки їх залежності від частотного спектру рядів Фур'є в діапазоні від 0 до 30000 Гц, встановлені залежності споживаної потужності млина і амплітуди сигналу віброприскорення від об'ємного заповнення барабана, розроблений алгоритм барабана млина, встановлені залежності сигналу віброприскорення та споживаної потужності від рівня заповнення млина в об'ємних одиницях. Встановлено, що ступінь заповнення барабана млина за споживаною потужністю електроприводу можна контролювати до 0,7 об'ємного заповнення барабана млина. У той же час, величина об'ємного заповнення барабана млина, виражена через сигнал віброприскорення опори підшипника, плавно зростає у всьому діапазоні заповнення барабана від 0,0 до 1,0. При цьому достовірність отриманої інформації з віброприскорення опори барабана млина має відхилення від апроксимуючої кривої, яке не перевищує 5–6%. Відстеження рівня заповнення барабана млина забезпечується сигналом датчика вібрації, що дозволяє підтримувати оптимальні показники по продуктивності, якості помелу і споживаній електроенергії. Отримані результати дають підставу використовувати сигнал віброприскорення в системі автоматичного керування процесом подрібнення вугілля як критерій оцінки ступеня заповнення барабана млина в процесі його експлуатації.

**Ключові слова:** кульовий барабанний млин, подрібнення, амплітуда сигналу віброприскорення, вугілля.