INFLUENCE OF THE BALL LOAD ON THE SPECIFIC POWER CONSUMPTION OF BALL MILLS

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ABSTRACT. The mill's output, and hence the specific power consumption, depend on the correct selection of the ball load. Both the increased and the decreased ball load lead to decreasing the mill's output which induces increase of the specific power consumption. At the optimum ball load of the mill, working in a closed loop, an increase in the circulating load can be allowed with a simultaneous increase in the mill's output, lowering the specific power consumption and improving the performance. To analyse the impact of the ball load on the specific power consumption, three-month data from 10 ball mills were processed. Experimental tests were also carried out for one mill to determine the specific power consumption when filling the mill with grinding bodies.

Key words: ball mills, optimum ball load, specific power consumption

ВЛИЯНИЕ НА ТОПКОВИЯ ТОВАР ВЪРХУ СПЕЦИФИЧНИЯ РАЗХОД НА ЕЛЕКТРОЕНЕРГИЯ НА ТОПКОВИ МЕЛНИЦИ

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РЕЗЮМЕ. От правилния избор на топковия товар зависи производителността на мелницата и следователно специфичния разход на електроенергия. Както завишения, така и занижения топков товар води до намаляване на производителността на мелницата, което предизвиква повишаване на специфичния разход на електроенергия. При оптимален топков товар на мелницата, работеща в затворен цикъл, може да се допусне повишение на циркулационния товар при едновременно увеличение на производителността на мелницата, снижавайки специфичния разход на електроенергия и подобрявайки технологичните показатели. За анализ на влиянието на топковия товар на специфичния разход на електроенергия са обработени данни за три месеца от работата на 10 топкови мелници. За една мелница са направени и експериментални изследвания за определяне на специфичният разход на електроенергия от запълването на мелницата със смилащи тела.

Ключови думи: топкови мелници, оптимален топков товар, специфичен разход на електроенергия

Introduction

By increasing the ball load the power consumption increases to maximum capacity (extremum) and after that lowers gradually (Fig. 1). This explains the fact that after increasing the ball load, the extremum, centre of load of grinding bodies is moving closer to the axle of rotation of the machine.

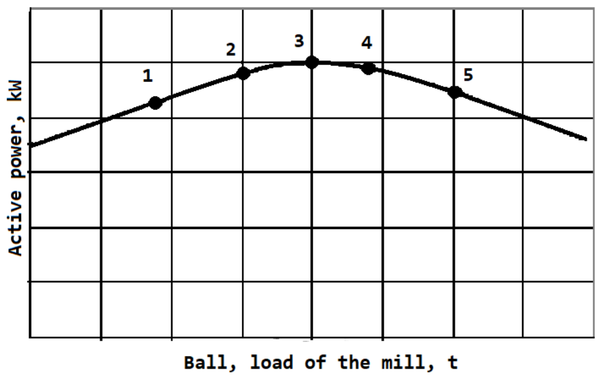

Fig.1. Dependence of the extracted active power on the ball load of the mill

It is well known that the waterfall mode of operation in the ball mill, the useful power *Po* includes the power to increase the grinding environment and to transfer the needed kinetic power.

$$P_0 = Mw \text{ , } W; \quad (1)$$

Where: *M* is the momentum, created by the grinding environment by the rotation of the drum, Nm;

w – actual angular velocity rad/s

$$M = G_{см}.I \text{ ,} \quad (2)$$

Where *Gсм* – the weight of the milling environment, N;

I – the distance between the centre of the load and the milling environment and the axis rotation of the drum, *m*.

The modes of work in (1) and (2) at (Fig. 1) are with unbalanced circulating load due to the lack of ball load.

It is typical of this section of the curve that with the increase of the ball load, the power gained by the electric motor increases.

In (3) the mill is supposed to work with stable circulating load and the ball load in this section of dependence is optimal.

The operation of the mill in later stages of ball load in (4) and (5) leads to a mode that is unstable circular load due to the overage of ball load and lowers the kinetic power of the grinding environment.

For this section of the curve it is specific that with the increase of the ball load, the active power produced by the electric motor decreases.

Experimental Tests

It is well known that the specific electricity consumption for ball mill grinding is closely connected with the technical process and depends on a number of factors: the weight of the ball mill, the size of the mill, the speed of rotation, the density of the pulp, the size of the end material, the lining of the mill, physical and mechanical properties of the ore, the efficiency of the mill, etc. Based on experimental tests, it was found that the main power in the ball mill is being consumed for lifting the ball load – approximately 80%. The increase of productivity of the mill leads to insignificant increase of exhausted power. The aim for increasing the productivity of the mills is apparent, and hence, the increase of the specific power consumption.

The productivity of the mill depends on the correct choice of ball load. Increasing and decreasing of the ball load leads to lowering the productivity of the mill and from there to increasing the specific power consumption. The size of the grinding bodies (balls) has to be taken under consideration in the productivity of the mill. The specific electrical consumption in the process of grinding of the ore can be determined most accurately by the electrical specifications.

Figure 2 shows the curves, determining the dependence between the size of the ball load and the exhausted power from the electric motor of a mill for a period of 12 days.

The data on the hourly distribution and the volume of the ball load for building the curve were taken by the SCADA system in the enterprise. After calculating the results from the measurements of the ball load, the hourly consumption norm of the balls was determined in relation to the alternation of the ball load in the mill during that time. In the same period data was extracted about the consumption of the electric motor of the mill, active power, recorded in the network analyser FLUKE. The curves in Fig.2 show that after every load with balls there is an active power jump registered. The increase of the active power is with approximately 9 kW per ton balls. During the work, the balls wear out, the electric load lowers and the used-up active power from the electric motor decreases. It is certain that if the ball dosage machine works and loads consistently the balls in the mill, the load schedule of the active power will be levelled which leads to economic power consumption.

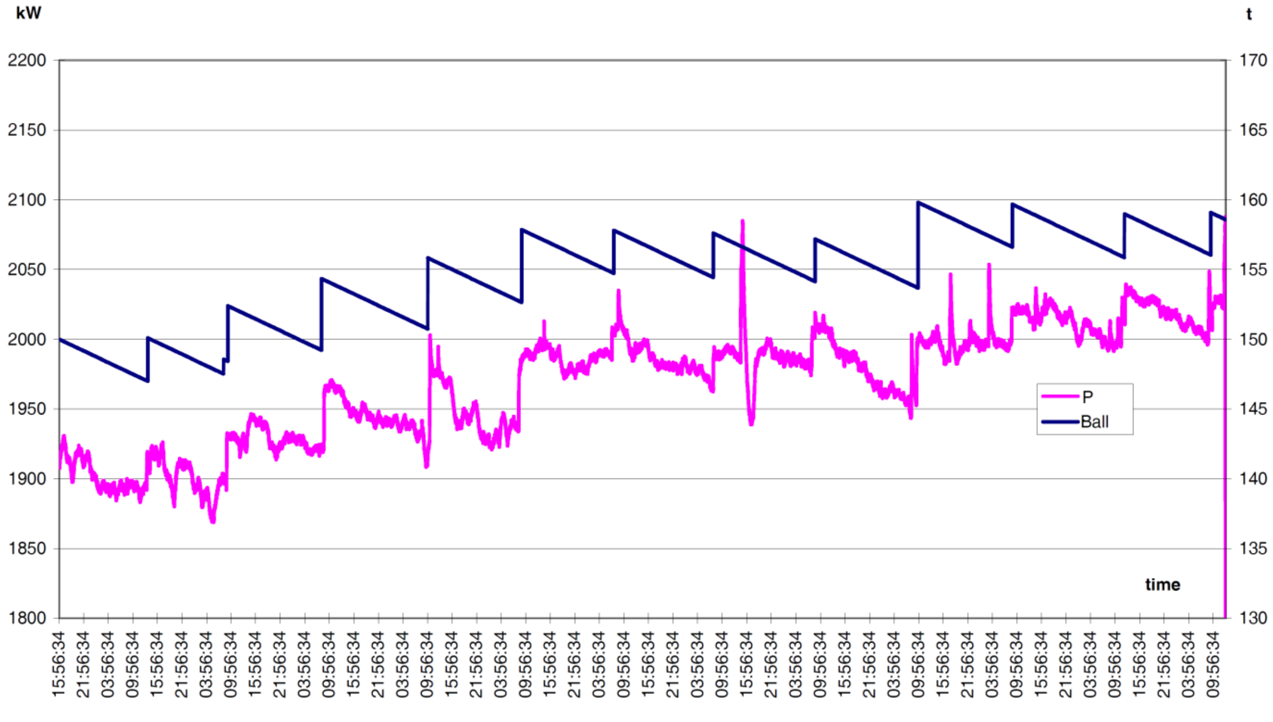

Fig. 2. Dependence of the active power consumed by the engine on the amount of ball load in the mill

Evidently, the perceived criteria for controlling ball dosage machines, namely the stator currant of synchronised electric motor averaged over a 30-minute interval, is not the most appropriate solution. In this sense, the stator current is not a unique criterion for loading the mill with balls or ore. The unique criterion for loading is the active power, consumed by the synchronised electric motor.

It is proposed that the control over the ball loading machines is to be provided when active power is monitored. In small intervals (the smaller the better) the active power is compared with the one that is set. The ball loading machine is turned on and loads the mill with portion of balls only if the ball load is in the left part of the extremum (3) of the curve, shown in graph 1. In approximately even load of ore this mode of control of the ball load, the work of the mill is ensured with optimal ball load (around the extremum in the curve in Graph 1) and will also decrease the power consumption.

The curves of active power and the ball load when starting the M4 mill after changing the lining are displayed in Fig. 3.

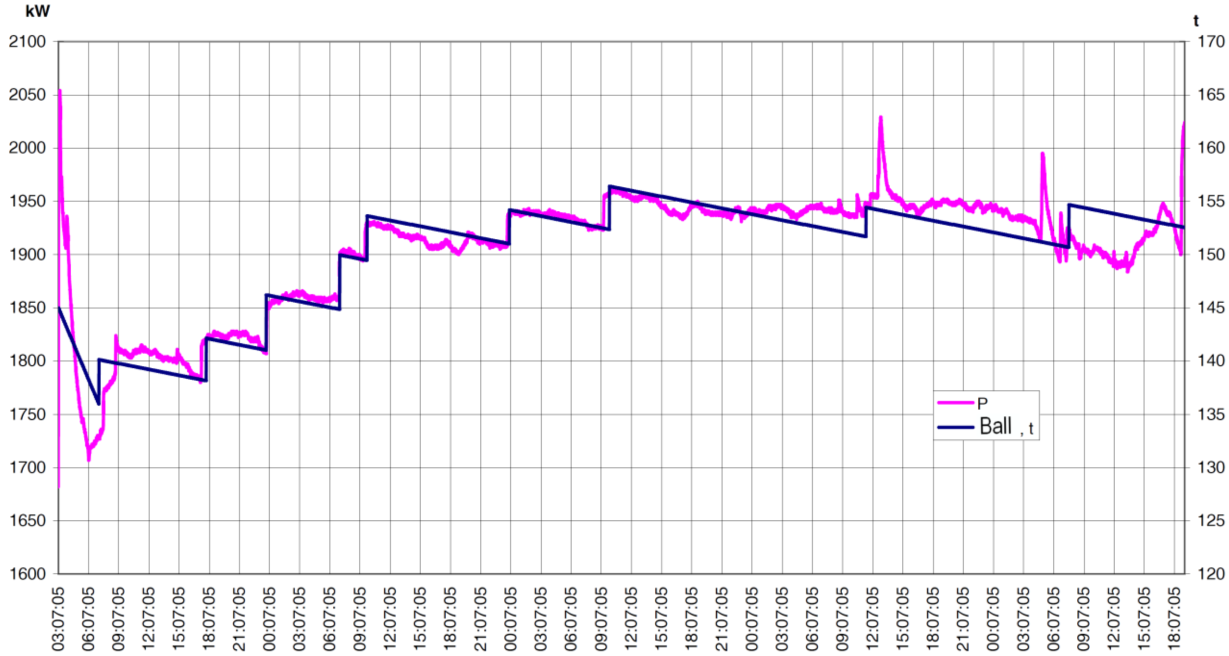

Fig. 3. Dependence of the active power consumed by the engine on the amount of ball load in the mill after changing the lining

At first there are rapid reduction engine's active power drop awey as a result of the filling of the lining of the mill with balls. The short intervals can also be seen during loading the ball load in the beginning in order to increase the effective balls involved in grinding. A period of set ball load is followed, around 155 tonnes (accepted 4514 in m³ – Minin and other, 2014). After the last shown load of balls it is obvious that the ball load has exceeded the optimal (point (3) in Graph 1) and lower power can be seen. Because of the proximity of the centre of gravity towards the axis of the drum, the mill does not reduce the active power, and the balls go into mixed speed mode with partial rewind and partial flight of the grinding bodies.

Afterwards due to the wearing out of the balls the circuit gradually increases. From this experiment the optimal ball load and the relevant active power can be determined. For mill unit M4, which is with new lining, the optimal ball load is 155 tonnes and the corresponding active power is 1950 kW.

Such dependence with expressed extreme exist and between the power from the electric motor and the quantity ore with consistent ball load.

The hourly load of the ore mill and the average hourly power with constant ball load are compared on Fig. 4. The fact registered by previous measurements is also confirmed - that with the increase of the load of the mill, the power drawn by the electric motor decreases. This shows that for the duration of measurements the working mode of the mill is after the extremum of the function P= F(Gсм), which means that the ball load is optimal or exceeds the optimum.

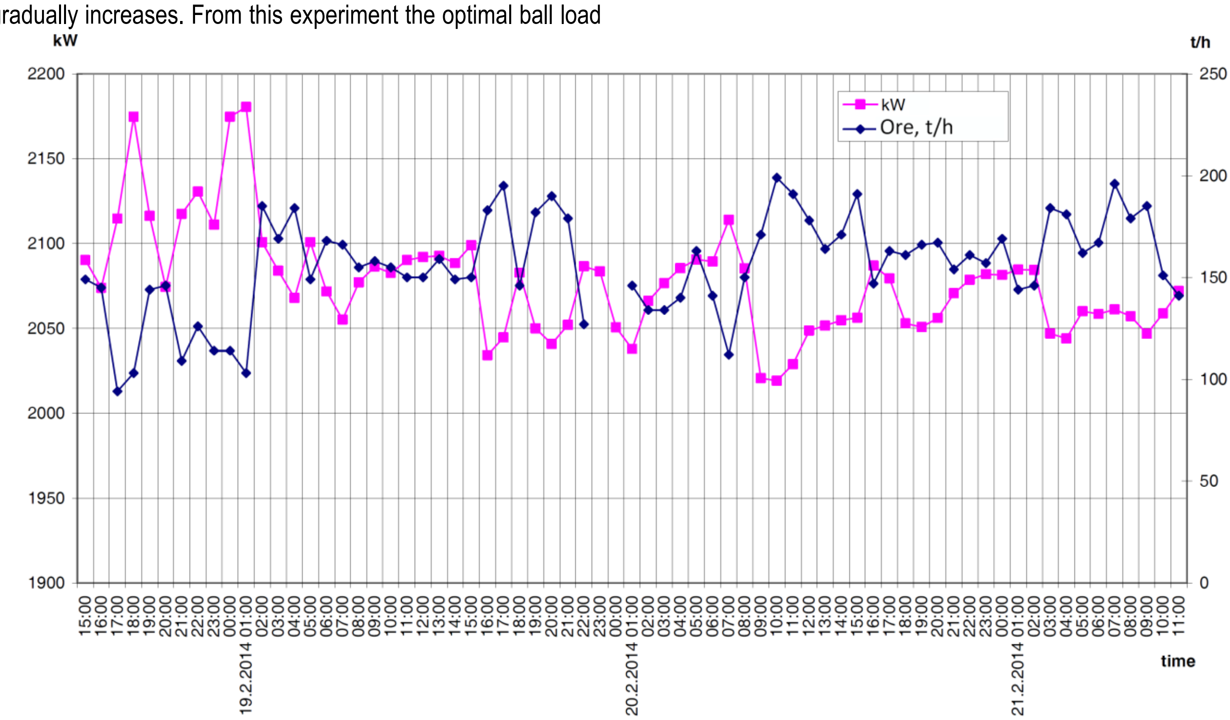

Fig. 4. Dependence between the exhausted active power and ore load

In order to analyse the influence of the ball load, the specific expense of electricity data has been processed in a period of 3 months across 5 mills. The end results are shown in Table 1.

Table 1.

Mill/ type balls	Monthly consumption of balls, t			Measurements 2013, bucket			Total balls	Ore from line	Ore	Produc-tivity	Time worked	Ball consum-ption	Energy	Average special cost	Hour power
	IV	V	VI	IV	V	VI	t	t	t	t/h	h	t/h	kWh	kWh/t	kWh
3 - steel	150	143	133	6	4	5	426	59000	220923	124.3	1777	0.2398	3357333	15.2	1889
4 - steel	141	138	143	11	4	9	422	69806	283141	148.6	1905	0.2215	3812398	13.5	2001
5 - steel	138	153	140	5	12	0	431	29817	219571	114.6	1915	0.2250	3744141	17.1	1955
6 - BU	114	123	136	0	6	4	373	46636	230906	127.7	1808	0.2063	3380748	14.6	1870
7 - BU	124	152	125	0	5	0	401	78940	288367	158.7	1818	0.2206	3521223	12.2	1937

The calculated average values of the specific electricity consumption based on the three month period confirm completely the results calculated during determining the energy performance. The lowest specific cost can be observed in mill №7, followed by №4. Mill №5 has the worst energy performance.

For the whole three-month period, a single ball measurement was performed at mill №7, with 31.5 % filling with balls, or 125 t balls (when 4650/m^3). For the period between 1st of April and 15th of May the consumption was between 200t balls and approximately the same amount also was added, which means that the mill for the period worked with 31.5% filling with grinding bodies. 20 tonnes were added, which means that the filling became 36.8%. The average specific cost for electricity during the three-month period is 12.2 kWh/t. Mill №7 has the biggest productivity (158.7 t/h) compared to the rest.

For the month of April four control measurements were conducted for mill №4, during which the mill was with fulfilment 35,9; 35,6; 35,9 and 37,4 % (between 141 and 148 t). The second place in terms of good energy consumption was mill №4 which also worked with a fill factor of less than the optimal 38%. For the period the specific power consumption was 13.5 kWh/t at an average output of 148.6 t/h.

Based on the above described dependence of the extracted power on the size of the ball load, it can be assumed that for the studied period, grinder №4 has the optimum ball load, since it has the highest hourly output (2001 kWh) and very good energy indicators.

Mill №5 is with the worst energy performance on 10th of April, on 12th of May control measurements were conducted on the ball load. The filling of the mill with grinding bodies was 35% (140 t) and 12t were added. In both cases a 38% fill is maintained with the added balls. For the tested period specific energy consumption of 17.1 kWh/t was recorded and the production rate was 114.6 t/h.

The comparison of the energy consumption of mill 5 and the maintained ball load allows the assumption that mill №5 worked with an excess of ball load during the testing.

Fig. 5 shows a comparison between the average power per hour and the specific power consumption during the hourly ball consumption.

Based on the analysis of the results the following assumptions can be made:

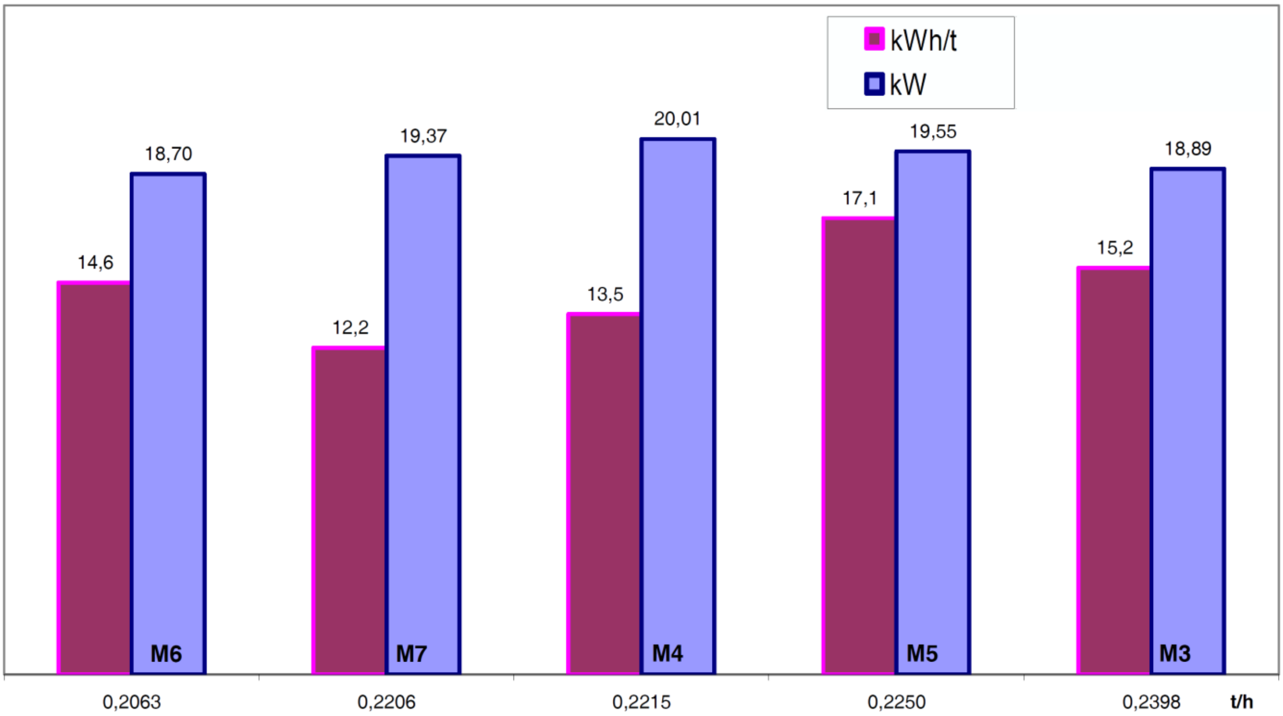

Fig. 5. Dependence between the specific consumption and hourly power of the balls consumption

1. Mill №7 worked very fast with optimal ball load and minimal ball load shortage.
2. Mill №6 worked with significant ball shortage. On 15th of May a control measurement was conducted on the balls in mill №6. The results showed the following: diameter 430 cm and height of the balls – 290 cm. This corresponds to 28,3 % filling or 114 t balls. This gives reason to assume that mill №6 has worked with an insufficiently balanced circulating load which, at roughly the same hourly working time, has led to nearly 20% lower production than mill №7 and increased the specific power consumption by 2,4 kWh/t.
3. Mill №5 has worked with an excess of ball load, average hourly power decreases due to the displacement of the centre of gravity of the grinding medium relative to the axis of rotation, the degree of equilibration of the circulation load is disturbed due to a decrease in kinetic energy. This has led to reduced productivity and increased specific electricity consumption.
4. Mill №3 like mill №5 worked with an excess of ball load and bad electric measurements. The measurements conducted in mill №3 on 29th of April and on 15th of May led to additional 24 t of balls on the first day with which the percentage and the fill rate was 37,1% and 16 t by the second day, which led to an increase of 37,6%.

The conducted analysis on the influence of the ball load of the energy parameters of the milling aggregates gives reason to conclude that in order to achieve good energy indicators, a research to optimise the ball load is needed. In this sense, we believe that the aove-mentioned experiment proposed by us will lead to significant positive results.

From the table above it can also be seen that the consumption of ball load of the type BU is lower than the oneused in type "Steel" with average 0,0153 t/h.

Conclusion

The results from the conducted experiments give reason to make the following conclusions.
- The drawn active power of the ball mill electric motor is not a unique indicator of the mill load;
- In the continuous operation of the mill, the balls in it are worn out and their quantity is reduced. As a result, the electricity consumption and mill performance are altered;
- The wear of the balls is a reduction of the diameter and shape under the abrasion of the ground ore. As a result of this process, the balls in the mill are of different size and the grain size of the ball filling greatly affects the work of the mill;
- The size the grinding bodies directly affects the power consumption of the mill's motor. With the change in the structure of the ball filling, the centre of gravity of the grinding medium, and respectively, the resistance moment, which must overcome the electric motor, also change.

References

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