Annual of the University of Mining and Geology "St. Ivan Rilski"
vol.44-45, part III, Mechanization, electrification and automation in mines, Sofia, 2002, pp. 37-41

RESEARCH OF THE PROCESS OF REFINEMENT AT CENTRIFUGAL ROLLER MILL WITH MEANS OF DIMENSIONAL ANALYSIS

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SUMMARY

The results of laboratory examinations with centrifugal roller mills (CRM) are analyzed and on the basis of the accumulated experience conclusion are made for introduction of this kind of mills in production. In this paper the based model of process of grinding (refinement) with CRM is constructed and conclusions with means of dimensional analysis are made.

An example is presented of construction of a mill with ruling skidding of the grinding rollers, which corresponds to the boundary parameters of the model.

The deduced dependencies would be used to take optimal decisions at designing.

Key words: dimensional analysis, centrifugal roller grinding mills, optimum projection, optimum experiment, similitude, physical modeling

INTRODUCTION

Centrifugal roller mills (CRM) are machines for grinding. They use centrifugal forces created by relatively fast motion of grinding rollers. In comparison with rod and ball mills the use of fast CRM is characterized with:

- Smaller capacity and weight of mills;
- Better productivity;
- Smaller power consumption;
- Smaller wearing out of working parts;
- Higher universal for grinding of materials with different qualities.

More considerable problems in the process of maintenance of CRM:

- Fast and non regular outwearing on the grinding rollers;
- Decreasing the pressure of rollers on the materials with increasing of wearing on grinding rollers.

In the paper by Chalashkanov (1979) a profound analysis of the process of grinding is made on the base of theory of similarity and big number of experiments with laboratory CRM. There is a tendency of being slow of the advance of theory in comparison with the applicatin of CRM. D. Obreshcov and collective (Obreshcov D., 1965, Obreshcov D. et all., 1973) have made an attempt to accept centrifugal roller mills in manufacture. Base work was made on the tendency of increasing wearing resistance of the rollers. The process of wearing is described with a complicated system of differential equations, use of which meets some difficulties. This process of research is realized with big number of experiments with laboratory CRM. In the paper by Chalashkanov (1979) preferences to empirical research of the process of grinding are given.

THE PURPOSE

To apply a well-founded model of the process of a refinement is offered in this paper, created on the base of great number of experiments and conclusions by Chalashkanov (1979) and methods of dimensional analysis by Dimitrov (1998, 1999).

To apply a method for full use of the information about the working process of CRM, thus to realize rational simulation.

SCHEMATIC MODEL OF GRINDING WITH CRM

The process is characterized with two elements which are in dynamic condition:

- Rollers;
- Material of grinding.

The material and the rollers influence each other and as a result occurs destruction, fast fragmentation of a material and gradually wearing of the rollers.

The motion of the material from upward to down is under the action of the weight and at the same time it scrolled by the rotor.

The rotary motion of the rollers exists as a result of motion of the rotor in relation to the drum and at the same time they are skidding. The movement of each roller can be presented as a sum of free rotation without skidding at the given moments, alternatively replaced from a status of the block of a roller.

In definite conditions the status of process can be near to one of combinations (I.A, II.A), (I.A, II.B), (I.B, II.A) and (I.B, II.B) (Fig.1). During the usual work of CRM the dynamic process with dynamic elements (rollers and grinding material) is functioned. Their movement can be described as a superposition. The wearing can be represented as a process that is compounded of I.A and I.B, and process of a refinement - IIA and IIB.

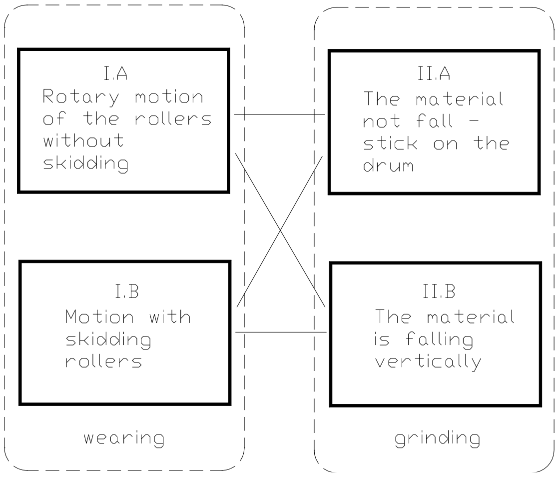

Figure 1. Schematic model of grinding with CRM

In addition, giving the wear process of rollers, it is necessary to think that at their cylindrical form and free movement, owing to free motion on the grinding material is realizing pushing away from a drum and after that strong impact on him at borders. This dynamic process is named an intersection of rollers. In result of that the wear process in borders of roller is fast.

SIMULATION OF WEARING PROCESS OF THE ROLLERS

By Chalashkanov (1979) and other authors the wearing process of the rollers of CRM depend on:

- Physicochemical properties of the grinding material;
- Type of working surfaces of the grinding mill;
- Thermal properties and temperature of the working parts;
- Geometrical measures, speed of motion and time for work.

d_p, h_p - Diameter and height of one roller,m:

a_p - Number of rollers on a level;

k_{eT} - Number of levels;

D_k, H_k - Diameter and height of the barrel of the grinding mill, m;

w - Angular velocity of the rotor, s^{-1};

t - Duration of work.

For counting the wearing is introduced value J - speed of wear, that expresses the capacity of separated material from each roller for a unit time m^3/s .

- Rules defining speed of the wear process of the rollers (in short wear) J :
- The wear depends on right direction from pressing force P of each roller on the barrel;
- It depends on general working surface and continuity T_a of work before amortization of rollers;
- On frequency of effects by grinding material on a unit area from surface of the rollers;
- The wear is bigger in borders of the rollers because of specific way of motion (crossing of axis) of the rollers.

For full description of a process it is not enough to be expressed analytical dependence between its parameters. It is necessary to clarify and involvement of each of the parameters as physical quantity, expressed from physical dependence and dependence that is deriving from the subject of the task (we'll call it subject dependence) (Dimitrov, 1998). Under physical dependence we understand the presentation of the formulas of the parameter's dimension by some grounded physical quantities. This dependence is manifested as the grounded tendency and it is possible to separate it from randomness and manifestation of an empirical dependence. The subject dependence is link between the physical quantities, which appears from the subject of the task - concrete application in certain practical area. This type of dependence adds to the information from physical and empirical dependence.

From point of view of possibilities to apply the dimensional analysis by Dimitrov (1998) a process is named simple if it is described by analytical dependence, represented with exponent monomial and complex process when it is described with sum of exponent monomials. For the application, which we make, we admit that the processes are represented as a superposition of simple processes.

According to the perceived from us model of a refinement (fig.1), the process of wear is superposition of the free rotation of the rollers without skidding and work with the block of rollers.

For description of the process we use dimensional analysis. In original consideration, we divide decisive parameters of the processes on compulsory and which possibly participate.

The system of physical quantities include:

- $P = F_u$ - Normal pressuring force of each of rollers;
- $\frac{G_p}{g}$ - Average mass of rollers;
- $S = \pi d_p h_p a_p k_{eT}$ - working area under influence in moment t of work;

In each simple process takes part some of physical quantities:

t - Time for work $t \in (0.T_a)$, where T_a mean time for amortization of the rollers under certain conditions. The roller is amortized at reaching average size $d_a = 50mm$.

$v = \omega D_k$ - Linear speed of rotor in relation to barrel.

When working with the block of the rollers, the wear depend in right direction by:

h_p - Height of the roller – describes influence of crossing of axis of the rollers on wearing.

We use also specific for a dimensional analysis a method for choice of basic parameters of dimension, which give dependence between some of parameters of the process:

$$[P]=\frac{L_1 M}{T^2},\quad \left[\frac{G_p}{g}\right]=M,\quad [S]=L_2^2,$$

$$[v]=\frac{L_2}{T} \text{ and } [t]=T.$$

At rotation without skidding $[J_1]=\frac{L_1L_2^2}{T}$,while at work with block of rollers $[J_2]=\frac{L_1L_2^2}{T}$ or $[J_2]=\frac{L_1L_2L_3}{T}$ depending on if h_p takes part.

In dependence of which of the quantities t or v takes part in system of physical quantities, are received two types generalized schemes sch.1 (fig.2) and sch.2 (fig.3)

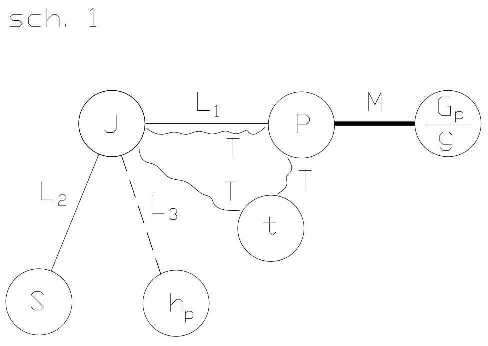

Figure 2. Scheme of the dimensions – sch. 1

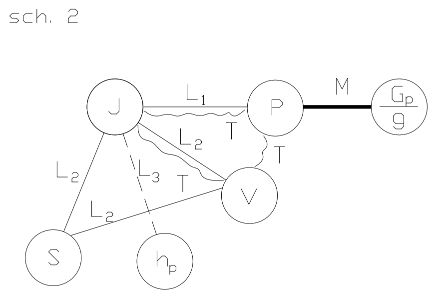

Figure 3. Scheme of the dimensions – sch. 2

Schematic the generalized equivalencies are:
A. At the rotation without skidding

$$[J_1]=[P]^{x_1}\left[\frac{G_p}{g}\right]^{x_2}[S]^{x_3}[z]^{x_4} \qquad (1) \text{ and}$$

B. Work with the block of rollers

$$[J_2]=[P]^{x_1}\left[\frac{G_p}{g}\right]^{x_2}[S]^{x_3}[z]^{x_4}[h_p]^{x_5}, \qquad (2)$$

where with z is denoted one of the quantities t or v.

Therefore are received 2 x 2 = 4 variants for the process. The structural formulas for the simple processes A. and B. are given in table 1.

Table 1: Structural formulas of the simple processes

A. sch.1:	B. sch.1:
$J_1=C_1\frac{gP}{G_p}S\cdot t$	$J_2=C_2\frac{gP}{G_p}S^{\frac{1}{2}}\cdot th_p$
A. сх.2:	Б. сх.2:
$J_1=C_1\frac{gP}{G_p}\cdot\frac{S^{\frac{3}{2}}}{v}$	$J_2=C_2\frac{gP}{G_p}\cdot\frac{Sh_p}{v}$

The choice of the appropriate variant is realized by experimental way. Also there are the following considerations for choice of variants A. sch.1 and B. sch.2 - the working surface S is proportional to the number of effects of the particles of a grinding material on unity of this area - proportional on the speed of wearing.

Therefore the structural formula of the wearing is:

$$J=C_1\frac{gP}{G_p}S\cdot t+C_2\frac{gP}{G_p}\cdot\frac{Sh_p}{v} \qquad (3)$$

From $P=F_ц=\frac{G_p}{g}\cdot\frac{D_к-\tilde{d}_p}{2}\cdot\frac{v^2}{D_к^2}$, $v=D_к\cdot\omega$ and $\tilde{d}_p=L(t)$, $t\in(0,T_a)$ is receive

$$J=\frac{\pi}{2}\frac{h_p}{D_к}\omega a_p k_{ет}\left(C_1 D_к\,\omega+C_2 h_p\right)x$$
$$x\,[D_к-L(t)]L(t) \qquad (4)$$

Let $\Delta V=\pi\left[\left(\frac{d_p}{2}\right)^2-\left(\frac{\tilde{d}_p}{2}\right)^2\right]h_p a_p k_{ет}$ is average volume of a material, detached from the work parts of the rollers for the period t. Here d_p is the initial diameter, and $\tilde{d}_p=L(t)$ is the average diameter of rollers in moment $t.L(T_a)=d_a=50$ mm.

Then $J=\frac{\partial\Delta V}{\partial t}=-\frac{\pi}{2}L(t)L'(t)h_p a_p k_{ет}$ and after replacement in the structural equation is received

$$\ln\frac{D_k-L(t)}{D_k-d_p}=C_1\frac{\omega^2 t^2}{2}+C_2\frac{\omega t h_p}{D_k} \qquad (5|$$

For defining of constants C_1 and C_2 is used data which refers to the grinding of dolomite. The data is divided into experimental and test parts (table. 2).

Table 2: Data for calculate of wearing

T_a	h_p	d_p	ω	D_k	d_a
Experimental data					
1260	150	70	100	250	50
1400	120	70	80	250	50
2120	90	90	60	250	50
2480	90	90	80	250	50
1920	45	90	100	250	50
2220	45	90	80	250	50
2010	45	90	80	250	50
2480	45	70	100	250	50
Test data					
2010	90	70	80	250	50
2640	90	90	60	250	50
2460	45	70	80	250	50
1720	90	90	100	250	50

The experimental data is used for calculation of C_1 and C_2 by method of the least squares, and test data – for defining of errors.

The values $C_1 = 3.4 \cdot 10^{-11}$ and $C_2 = 1.4 \cdot 10^{-5}$ received. The mean relative error for test data is 4%.

DEFINITION OF THE USEFUL POWER OF MILL

For deducing the formula for the power, the scheme on fig.1 can baused and a system of parameters, including grounded quantities for wearing J and efficiency of the mill Q. Because the useful work for grinding is related to the work wearing of the rollers, power also can be represented as a superposition $N = N_1 + N_2$ of power N_1 at free rolling of the rollers and power N_2 at working with the block of rollers. The corresponding simple processes have schemes of dimensions, which are obtained from the properties given with the respective schemes of wearing with addition of new parameters (fig.4 and fig.5).

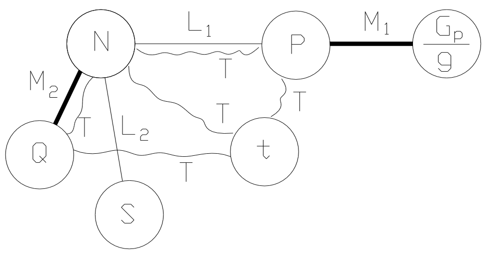

Figure 4. Scheme for determination of power corresponding to sch. 1

We add the data from table 3 to that from table 2, including: the power N, efficiency Q and working surface S at mean diameter $d_{cp} = \dfrac{d_p + d_a}{2}$ of a roller.

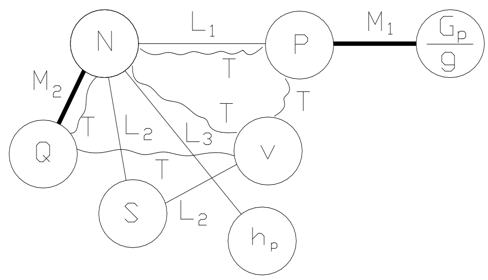

Figure 5. Scheme for determination of power corresponding to sch. 2

Table 3: Data for calculating of power

N	Q	S	d_{cp}
Experimental data			
7	0.1	200000	60
4	0.1	100000	60
2	0.1	79168	70
4	0.1	78168	70
4	0.1	59376	70
2.5	0.1	29688	70
3	0.1	39584	70
2	0.1	25447	60
Test data			
4	0.1	59375	70
2	0.1	76341	90
2.5	0.1	29688	70
8	0.1	300000	90

The structural formula is

$$N = C_1 \frac{gPQS^{1/2}}{G_p} + C_2 \frac{gPQS}{G_p h_p} \tag{6}$$

From the experimental data are received $C_1 = 1.8 \cdot 10^{-7}$ and $C_2 = 2.2 \cdot 10^{-9}$ and the mean relative error for the test data is 10 % .

CENTRIFUGAL ROLLER MILL WITH SKIDDING ROLLERS

The different boundary states included in schematic model (fig.1) are simple processes, which in actual applications do not meet separately. In the most often met construction of a centrifugal grinding mill the motion of the rollers is provoked from the motion of the rotor in relation to the barrel. At which the process of grinding has weakly manifested skidding - status I.B. In some cases for more efficient grinding of material is necessary to combine pressure with rubbing. Fig.6 represents CRM working in this way.

The principle of work of the grinding mill is given as follows: Material is fed throush the hole 1 by gravitation. It is distributed uniformly on the barrel of the mill by blades 2 and is grinded with rollers 3, pressed on the barrel 4, under the action of a centrifugal force, which is provoked from rollers rolling on the internal cylindrical surface of the barrel. The rollers have bearings to slippers 5 (on which they have axial motion), so they gain two independent motions. The rollers roll around their axis by the electric motor through reducer 6 with the universal coupling 7. On the other hand the barrel of the reducer 6 receives compulsory rotary motion from reducer 8. As a result of superposing from these two motions, the roller affects pressing and rubbing on a particle from the grinding material. By this method is received considerably refine product in comparison with the mills with cleanly rotary motion of rollers.

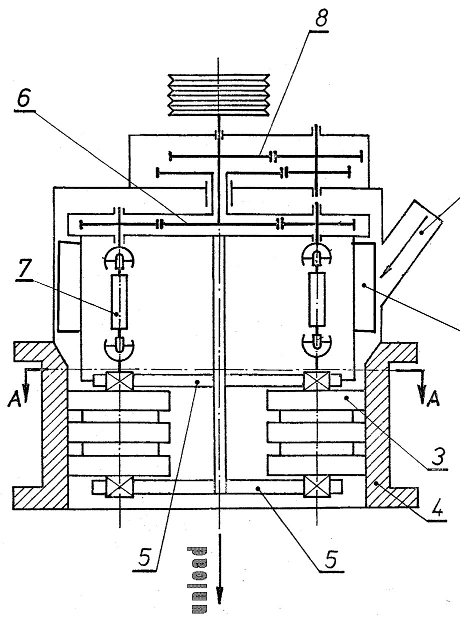

Figure 6. CRM with control on the skidding of the rollers

The mill is intended for high quality and dry refinement of ore and nonmetal minerals. It is possible to be used for experimental research of the schematic model on fig. 1.

CONCLUSION

The offered schematic model gives a possibility for applying of dimensional experiment by deducing of dependencies between the parameters.

The given example of CRM with control on the skidding of the rollers and received results for the error (4% and 10%) prove the correctness of the schematic model (fig.1).

The construction on fig.6 confirms the equality of the states I.A and I.B of the process of grinding, that is not manifested at the customary constructions of CRM.

The considered here common model of the grinding process and offered method of experimental research will found application at theoretical explanation of processes, which accompany with a grinding and in a practical construction of effective CRM

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Recommended for publication by Department of Mathematics, Faculty of Mining Electromechanics