ALGORITHM FOR OPTIMIZING THE ROLL FORM IN CENTRAL BAR ROLL MILLS

Simeon Sezonov

University of Mining and Geology "St. Ivan Rilski", 1700 Sofia, sezonov_si@abv.bg

ABSTRACT: The article investigates the change of the roll shape of a centrifugal roller mill in its wear during the process of operation. An optimal shape is sought to compensate for the reduction in the roll mass by increasing its working area. A solution to the task is used as a result of the grinding theory with maintaining a constant grain size of the product, which determines the optimum change of the longitudinal profile of the roll resulting from the working process. In this connection, an algorithm has been developed to calculate the current height of the worn portion of the roller. It consists of eight steps. It sets the starting center radius, the current radius of the weft pulley, and the minimum allowable radius. In addition, an algorithm has been developed to determine the co-ordinates of points from a curve that describes the worn portion. It is applied at a set height of the worn part and consists of six steps.

The first algorithm has been numerically tested using the Excel product. This solution complements the analytical expressions of the task of form modification. The proposed algorithms can be used by engineers to select optimum sizes for roll the from a cylindrical roller mill. A numerical example is attached.

Keywords: centrifugal roller mill, optimum roll profile, stresses.

АЛГОРИТЪМ ЗА ОПТИМИЗИРАНЕ ФОРМАТА НА РОЛКАТА В ЦЕНТРОБЕЖНО РОЛКОВИТЕ МЕЛНИЦИ

Симеон Сезонов
Минно-геоложки университет "Св. Иван Рилски ", 1700 София, sezonov_si@abv.bg

РЕЗЮМЕ: В статията се изследва промяната на формата на ролката в центробежно-ролкова мелница при износването й в процеса на работа.

Търси се оптимална форма, която да компенсира намаляването на масата на ролката чрез увеличаване на работната й площ. Използва се решение на задачата като резултат от теорията на смилането при поддържане на постоянен зърнометричен състав на продукта, при което се определя оптималното изменение на надлъжния профил на ролката в резултат на реализирането на работния процес. Във връзка с това е разработен алгоритъм за изчисляване на текущата височина на износената част на ролката. Той се състои от осем стъпки. В него са зададени начален радиус на масовия център, текущ радиус на износващата ролка и минимален допустим радиус. Освен това е разработен и алгоритъм за определяне на координатите на точки от крива, описваща износената част. Той се прилага при зададена височина на износената част и се състои от шест стъпки.

Първият алгоритъм е числено тестван с помощта на продукта Ексел. Това решение допълва аналитичните изрази от задачата за формоизменението. Предложените алгоритми могат да се използват от инженери за избор на оптимални размери на ролката от цилиндрично-ролкова мелница. Приложен е числен пример.

Ключови думи: центробежно-ролкова мелница, оптимален профил на ролката, напрежения.

Introduction

One of the most common grinding machines operating in inertia is the centrifugal roller mill. It guarantees higher performance than conventional gravity-based mills. This is accompanied by rapid wear of the rollers. The degree of grinding is proportional to the number of impacts. To increase their frequency, it is recommended that the work area at the height of the roller be increased. In this connection, the task of modulating the longitudinal profile of the roller is investigated.

One solution is described in Stoev et al. (1982). Based on the grinding theory, a detailed derivation of the analytical dependencies that determine the ultimate wear height of the rollers is described.

The main purpose of this work is to present an algorithm for determining the height and curve of the worn part of the roll. By using it and by using popular program tools, values for a real roller from a cylindrical roller mill are obtained in the article.

Exposition

1. Description of the task of the form modification

When studying the shape of the roller, the Rittinger theory of grinding is preferred. According to it, work in shredding should be proportional to the newly formed surface. According to this theory, the grinding of the material is realized after a sufficiently large elastic deformation, i. e. absorbing a certain amount of "elastic" energy from the body volume.

In recent years, new technologies, schemes and grinding machines have been developed. These are technologies (Parashkevov, 1969) in which high-speed machines and centrifugal forces are used for grinding. For these cases, the simple work of the deformations of a single piece will be proportional to the change in the volume of this piece, raised to the third degree. In order to maintain a constant grain size, it is necessary that the product of the number of deformation cycles of the roll at the intersecting force of the roller be constant.

In order to maintain the grain size composition, according to the Rittinger theory of grinding (Stoev et al., 1982), the condition must be fulfilled:

$$\left[\pi r^2 H + 2\pi\varphi(0)\right]RH = \left[\pi y^2(x)(H+2x) + 2\pi\varphi(x)\right](r_o - y)(H+2x) \tag{1}$$

where $\varphi(x) = \int_x^h y^2(x)dx$; $\varphi(0) = \int_0^h y^2(x)dx$;

$r_o = R + r$.

The initial conditions are: $y(0) = r$ and $y(h) = r_k$.

Equation (1) is obtained by meeting the requirement of unchangeability of the product at the initial point and at an arbitrary point in time. Multipliers in this product are: the roll volume, the radius of the mass center, and the radius of the cylindrical part. In (1), the following symbols are defined, which are illustrated in Figure 1:

R - starting radius of the mass center;

H - initial height of the cylindrical section of the roll (working height);

r - current radius of the wear roll;

h - maximum height of the wearing roller;

$y(x)$ - function of the curve describing the worn portion of the roller (Fig. 1);

r_k - minimum tolerable radius.

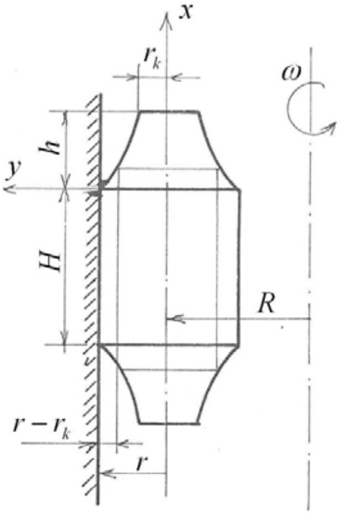

Fig. 1. Roll of the mill

If $x = h$ и $y = r_k$ are substituted in (1), it is obtained:

$$D = r_k^2 B_1 (H + 2h), \tag{2}$$

where

$B_1 = r_o - r_k$.

Equation (1) is processed and a Bernullium-type equation (Stoev et al., 1982) is reached:

$$t' = f_1(y)t + f_2(y)t^3, \tag{3}$$

where

$f_1(y) = -(r_o - y)^{-1}$; $\quad f_2(y) = -\dfrac{2(r_o - y)}{D}$;

$t(y) = H + 2x$.

Equation (3) integrates into squares (Korn, G., Korn, T, 1970). For this purpose, we exchange $\bar{t} = t^{-2}$ and receive:

$$\bar{t}' + 2f_1(y)\bar{t} = -2f_2(y), \tag{4}$$

which is a linear differential equation of first order.

The solution to (4) is equated to $(H + 2x)^{-2}$ and produces:

$$x = -\frac{H}{2} + \frac{B_4}{2(r_o - y)}, \tag{5}$$

where

$$B_4 = \frac{1}{\sqrt{B_2 + \dfrac{4}{D}\left[r - y + (r_o - y)\ln\left(\dfrac{R}{r_o - y}\right)\right]}};$$

$B_2 = H^{-2}R^{-2}$.

In this equation, $x = h$ and $y = r_k$ are replaced and after processing, this expression is to be solved:

$$(H + 2h)^2 = \frac{1}{B_2}\left(\frac{1}{B_1^2} - B_3\right), \tag{6}$$

where

$$B_3 = \frac{4}{r_k^2 B_1}\left[r - r_k + B_1 \ln\left(\frac{R}{B_1}\right)\right].$$

2. Algorithms for determining the height limit of the roll wear

The resulting expressions are used to determine the height of the worn part of the roller and the coordinates of points of that part at different heights. For this purpose, equations (5) and (6) need to be processed. The second equation determines the current height of the worn part h_i:

$$h_i = -\frac{H_i}{2} + \sqrt{\Delta B_i}, \tag{7}$$

where

$\Delta B_i = B_5 B_{2,i}^{-1}$; $B_5 = B_1^{-2}$; $B_{2i} = H_i^{-2}R^{-2}$.

In equation (7), the index i is an integer and takes an initial value of 0, and increases to a value n.

For specific values of h_i and H_i from equation (5), the coordinates of the points j, whose total number is m (Fig. 2), are determined. For this purpose, we replace x with x_i^j,

H with H_i and y with y_j. The following expression is obtained:

$$x_i^j = -\frac{H_i}{2} + \frac{B_{5,i}}{2B_{2,i}B_{6,i}^j}, \tag{8}$$

where

$$B_{2,i} = H_i^{-2}R^{-2}; \qquad B_{5,i} = H_i + 2h_i;$$

$$B_{6,i}^j = \sqrt{B_{2,i}\left(B_{5,i}\right)^2 + B_{3,i}^j};$$

$$B_{3,i}^j = \frac{4}{r_k^2 B_1^j}\left[r - r_k + B_1^j \ln\left(\frac{R}{B_1^j}\right)\right]; \; B_1^j = r_o - y_j.$$

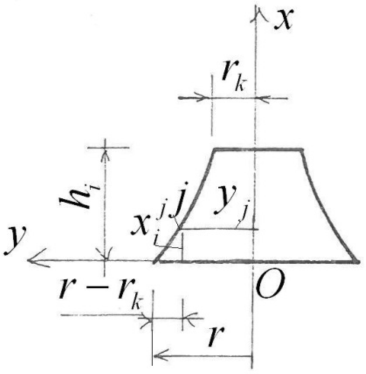

Fig. 2. Worn Roll View

In equation (8), the coordinate y_j participates, which is determined by

$$y_j = r - \Delta z_1\left(r - r_k\right)j, \tag{9}$$

where

$$\Delta z_1 = \left(m+1\right)^{-1}.$$

Equation (7) is basically in the algorithm for obtaining the limit value of the worn portion h_i. It sets the starting height of the cylinder H_o and the height increase ΔH. The algorithm is described in the following steps:

Step 1: Set the values of H_o, R, r, r_k, ΔH, n and m.

Step 2: Calculate the coefficients B_1, B_3 and B_5.

Step 3: The counter i is zero.

Step 4: Calculate $B_{2,i}$, ΔB_i and the height h_i.

Step 5: Activate a subroutine (Figure 4).

Step 6: The counter i is incremented by one.

Step 7: Check that the reading i is not greater than the set value n $(i > n)$. If this is the case, it ends with the first part of the algorithm (end).

Step 8: If the reading i is less than the set value n $(i < n)$ and the height is increased by ΔH, it goes to step 4.

The flow chart of the algorithm is given in Figure 3.

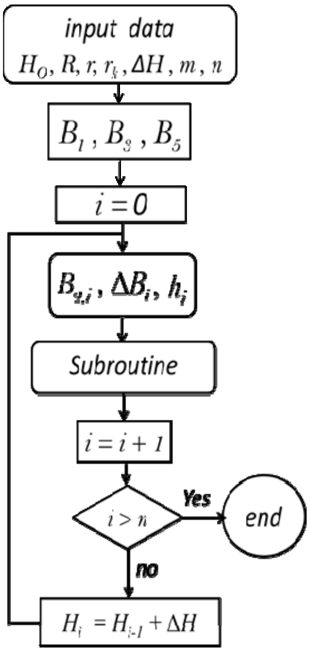

Fig. 3. Flow chart of the algorithm

Expression (8) is the basic in the subroutine algorithm described in the following steps:

Step 1: Set the counter j value 1.

Step 2: Set the value of m.

Step 3: Calculate y_j and x_i^j.

Step 4: The counter j is incremented by one.

Step 5: Verify that the counter value j is greater than m. If this is the case, the subroutine is finalized.

Step 6: If j is less than m, we assume that the roll is divided into layers Δz_j, grows with the next layer Δz_1 and passes to step 3.

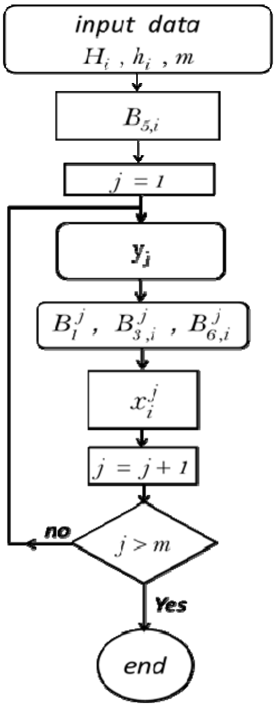

Fig. 4. Flow chart of subroutine program

The described algorithm applies to thirteen points and is illustrated by the flow chart given in Figure 4.

3. A numerical example

The roll with cross section from figure 1 is being considered. The input data are given in Table 1.

Table 1.
Input data

parameter	multiplier	dimension	value
H_o	–	mm	90
R	–	mm	120
r	–	mm	35
r_k	–	mm	15
B_1	–	mm	140
B_3	10^{-2}	mm	– 2.034
n	–	mm	3
m	–	mm	3
ΔH	–	mm	1

By observing the algorithm without the subroutine, the results obtained are presented in Table 2.

Table 2.
Results

parameter $\rightarrow$ point i $\downarrow$	H_i	B_{2i}	ΔB_{1i}	h_i
multiplier		10^{-4}		
dimension	mm		mm	mm
0	70	1.42	179.539	32
10	80	1.09	234.500	37
20	90	0.857	296,789	41
30	100	0.694	366.407	46
40	110	0.574	443.352	50
50	120	0.482	527.625	55
60	130	0.411	619.227	59
70	140	0.354	718.157	64
80	150	0.309	824.415	69
90	160	0.271	938.001	73
100	170	0.240	1058.915	78
110	180	0.214	1187.157	82
120	190	0.192	1322.728	87

It can be seen from the table that a linear increase in the height of the cylindrical part of the roll H_i results in a non-linear increase in the worn portion of the roller h_i.

4. Key findings

The results of the work can be summarized as follows:

– the analytical expressions for determining the height of the worn part of the roller of a centrifugal mill are verified and refined;

– two algorithms are proposed for calculating the magnitudes described;

– the first algorithm is numerically tested.

The presented solution is a completed version of the developed analytical expressions from the task of changing the shape of the roll.

Conclusion

In order to find the optimum height of the worn part of the roll, a roll change task is formulated. An algorithm consisting of eight stages has been developed for it. The Excel application is used to produce numerical values. An algorithm for determining the wear curve is also given. It applies to a set height and is described in six steps.

The proposed analytical expressions and algorithms can be used by designers to select rolls in centrifugal roller mills.

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