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Matrix Modeling of Technological Systems Grinding with Closed Circuit Ball Mill

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Abstract: Presented promising application of technological systems grinding cement clinker and additives on the basis of the closed circuit ball mills. Matrix model transformation a grain structure in closed circuit ball mills with design features included in the flow chart of elements allowing to predict grinding process parameters (performance, power consumption, quality of the finished product, etc.) represented.

Key words: Ball mill · Matrix of grinding · Separator · Aero material flows

INTRODUCTION

Improving the efficiency of cement production is possible by improving the technological everyone conversions [1, 2]. One of the major in the production of cement is a fine grinding cement clinker and additives in various types of grinding devices. Despite the large number of modern mills, some of the most simple in construction and maintenance is ball mills, which are able to obtain a finished product of the different properties of clinker [1, 3, 4]. However, the absence of a generalized method of calculating the entire grinding line complicates both designing and the modernization and operation of technology systems on the basis of grinding ball mills to produce a quality product with a minimum of energy consumption for grinding [5-7].

Closed grinding systems are complex groups of elements and subsystems, interconnected material and aero material flows. The basic element of system is a ball mill, the efficiency of which is characterized by (a lower triangular) grinding *P* matrix, each element of which p_{ij} is equal to share of j^{th} fraction of the material entering the mill, which after grinding passes in the i^{th} fraction to the original product separator [8]. Separator operating is characterized by a diagonal matrix separation *Se*, each element of which se_{ij} shows the of share of the j^{th} fraction of the original material, which translates into the same fraction of the finished product:

$$Se_{ii} = \frac{Q_2 \Delta D_i^2}{Q_1 \Delta D_i^2} \tag{1}$$

Points with coordinates (d_j, 1-se_{ij}) define the curve Tromp for the separator. Aspiration take-out, operation of the aspiration shaft, cyclones for the deposition of cement and dust cleaning, bag filters and so on are characterized by similar matrixes factional passes (breakthrough). The fractional compositions of the various material flows denote column vectors *f* with appropriate index. Their elements are $f_i = \Delta D_i$ is equal relative to share of i^{th} fraction of material (i = 1, 2,... m, where the serial number m corresponds to the finest fraction of the material). The number of fractions of the material m determines the size of the matrixes of grinding and the faction passes.

System of material and aero material flows in the grinding flow chart ball mill-classifier (GFC "BM-S") are shown in Fig. For each device are: the matrix transformation of dispersion, the vectors of dispersed composition and size of incoming and outgoing flows of material and process air. The mass conservation conditions are carried out for each machine and the system as a whole:

$$Q_c = Q_2 + Q_t, \tag{2}$$

$$Q_{ab} + Q^{(1)}_{cb} + Q^{(2)}_{cb} = Q_{bb}. \tag{3}$$

Here Q_t - mass flow discharge of material into the atmosphere; Q_{ab}, $Q^{(1)}_{cb}$, $Q^{(2)}_{cb}$ и Q_{bb} - aspiration air mass flow rates, air drawn to the line "mill-aspirated shaft-cyclones-filter" in the chart "separator-cyclones" and also a full flow of dusty air, discharged into the atmosphere.

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The task of the matrix modeling the grinding system is to determine size and dispersion of material flow through the load mill characteristics Q_c and f^c and the transformation matrix particle size distribution in the mill, separator, cyclones and filters.

The matrix model of the closed grinding circuit (represented stepwise) will receive from the base of balance equation i^{th} narrow faction material during its mechanical processing in the elements and nodes of the system [3, 9].

Mixing the original material and grit entering the mill:

$$Q_c + Q_k = Q_m; \tag{4}$$

$$Q_c f_i^c + Q_k f_i^k = Q_m f_i^m. \tag{5}$$

Dividing both sides of equation (5) on the $Q_m = Q_1$, we get:

$$\frac{1}{k_c} f_i^c + \left(1 - \frac{1}{k_c}\right) f_i^k = f_i^m \tag{6}$$

where $k_c = Q_1/Q_2 = Q_m/Q_c$ - circulation rate.

Grinding the material in a ball mill:

$Q_m = Q_1$,

$$f_i^1 = \sum_{j=1}^{m} P_{ij} f_j^m = \frac{1}{k_c}\sum_{j=1}^{m} P_{ij} f_j^c + \left(1 - \frac{1}{k_c}\right)\sum_{j=1}^{m} P_{ij} f_j^k = \frac{1}{k_c} f_j^{oc} + \left(1 - \frac{1}{k_c}\right)\sum_{j=1}^{m} P_{ij} f_j^k. \tag{7}$$

Here,

$$f_j^{oc} = \sum_{j=1}^{m} P_{ij} f_j^c \tag{8}$$

the content of the i^{th} fraction in the product at the open circuit grinding mill.

Forming of aspiration removal of the material is characterized by the matrix $A = (a_{ii})$ [10]:

$$Q_1 f_i^1 a_{ii} = Q_a f_i^a, \tag{9}$$

where Q_a - the value of the aspiration removal of material; f_i^a - the content of the i^{th} fraction of the material suspended in the air aspiration. Summing both sides of all factions ($1 = i = m$), we find the value and dispersion of aspiration removal:

$$Q_a = Q_1 \sum_{i=1}^{m} f_j^1 a_{ii} \tag{10}$$

$$f_i^a = \frac{f_i^1 a_{ii}}{\sum_{i=1}^{m} f_i^1 a_{ii}}. \tag{11}$$

Because of the of aspiration removal changing number and dispersion of material coming out of the mill [11, 12]:

$$Q_1 f_i^1 (1 - a_{ii}) = (Q_1 - Q_a) f_i^{(1)}, \tag{12}$$

where $f_i^{(1)}$ - the contents of i^{th} fraction to the grinding product exiting the mill.

The deposition of suspended material in the aspiration-coagulation shaft described by the matrix:

$$Q_a f_i^a s_{ii} = (Q_a - Q_s) f_i^s; \tag{13}$$

$$(Q_1 - Q_a) f_i^{(1)} + Q_a f_i^a (1 - s_{ii}) = (Q_1 - Q_a + Q_s) f_i^{(2)}, \tag{14}$$

where Q_s - mass flow of the material deposited in the aspiration shaft; $f_i^{(2)}$ - the content of i^{th} fraction in the material exiting the aspiration shaft.

Cleaning the aspiration air in the cyclone characterized by a matrix of fractional breakthrough $C = (c_{ii})$:

$$(Q_a - Q_s) f_i^s c_{ii} = (Q_a - Q_s - Q_y) f_i^{ym}; \tag{15}$$

$$(Q_a - Q_s) f_i^s (1 - c_{ii}) = Q_y f_i^{yk}, \tag{16}$$

where Q_y - mass flow of material deposited in the cyclone; f_i^{ym}, f_i^{yk} - content of i^{th} fraction in the material particles that are carried along with the air from the cyclone and precipitated in it.

The merging of material flows after cyclones:

$$(Q_1 - Q_a + Q_s) f_i^{(2)} + Q_y f_i^{yk} = (Q_1 - Q_a + Q_s + Q_y) f_i^{(3)}. \tag{17}$$

The merging of material flow at the inlet of the filter:

$$(Q_1 - Q_s - Q_y) f_i^{ym} + (Q_o + Q_{oc}) f_i^o = Q_{bf} f_i^f, \tag{18}$$

where $Q_{bf} = (Q_a - Q_s - Q_y + Q_o - Q_{oc})$ - the flow of material entering into the filter; f_i^f - the contents of the i^{th} fraction in it; Q_o - the flow of material coming out together with the

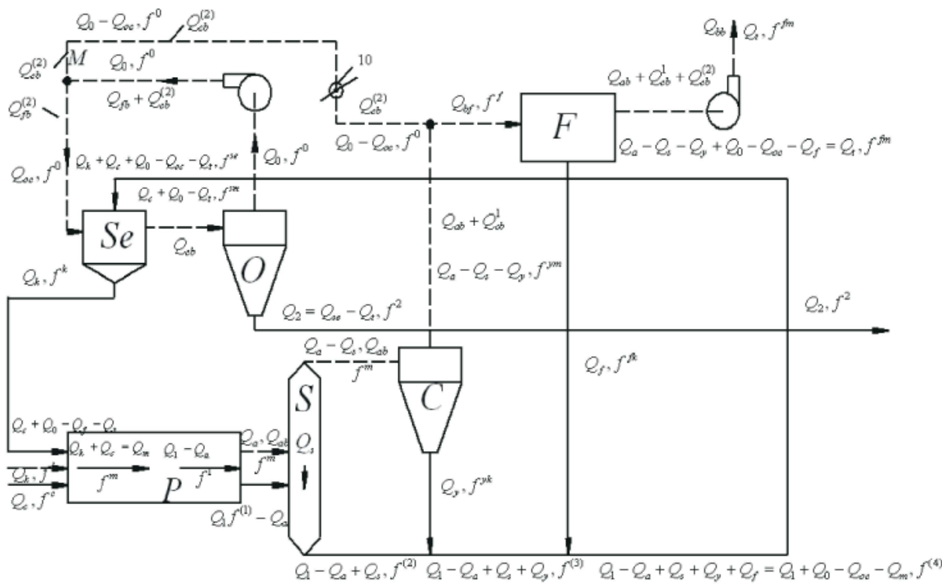

Fig. 1: The scheme of the material and aerodynamic flows in the flow chart of grinding "Ball mill-separator" with the returning of dust cleaning products in the original material

air from the cyclone-precipitators. This flow at a point M (Fig. 1) branches in proportion to divide the airflow:

$$\frac{Q_o - Q_{oc}}{Q_{oc}} = \frac{Q_{cb}^{(2)}}{Q_{fb}} = p$$

Hence

$$Q_{oc} = \frac{Q_o}{1+p} \qquad (19)$$

where Q_{oc} - flow of material entering to the separator with a separating air; p - the ratio of the leakage rate in the chart "Separator-cyclone-precipitators" to the volume of air separation.

Cleaning the dust-laden air in the filter is characterized by a matrix of fractional breakthrough of particles $F = (f_{ii})$:

$$Q_{bf} f_i^f f_{ii} = (Q_{bf} - Q_f) f_i^{fm} = Q_\delta f_i^{fm}; \qquad (20)$$

$$Q_{bf} f_i^f (1 - f_{ii}) = Q_f f_i^{fk}. \qquad (21)$$

Here Q_f - mass flow of deposited material in the filter; f_i^f, f_i^{fk} - the relative contents of the i^{th} fraction of particles in depositing and going out material with the air from the filter.

Summing both sides of equation (20) for all the factions, we find the power and content of all fraction of the dust emission to the atmosphere:

$$Q_t = Q_{bf} \sum_{i=1}^{m} f_j^f f_{ii} \qquad (22)$$

$$f_i^{fm} = \frac{f_i^f f_{ii}}{\sum_{i=1}^{m} f_i^f f_{ii}}. \qquad (23)$$

The merging of material flows after the filter:

$$(Q_1 - Q_a + Q_s - Q_y) f_i^{(3)} + Q_f f_i^{fk} = (Q_1 - Q_a + Q_s + Q_y + Q_f) f_i^{(4)} =$$
$$= (Q_k + Q_c + Q_o - Q_{oc} - Q_t) f_i^{(4)}. \qquad (24)$$

The merging of material flow at the inlet to the separator:

$$(Q_k + Q_c + Q_o - Q_{oc} - Q_t) f_i^{(4)} + Q_{oc} f_i^o = (Q_k + Q_c + Q_o - Q_t) f_i^{se}, \qquad (25)$$

where f_i^{se} - the content of the i^{th} fraction of the material entering in the separator.

Separation of the material in the separator described by the matrix classification $Se = (se_{ii})$:

$$(Q_k + Q_c + Q_o - Q_t) f_i^{se} se_{ii} = (Q_c + Q_o - Q_t) f_i^{cm}; (\qquad 26)$$

$$(Q_k + Q_c + Q_o - Q_t) f_i^{se} (1 - se_{ii}) = Q_k f_i^k. \qquad (27)$$

Summing both sides of these equations for all the factions, we get:

$$Q_c + Q_o - Q_t = (Q_k + Q_c + Q_o - Q_t) \sum_{i=1}^{m} f_j^{se} se_{ii} \; ; \tag{28}$$

$$Q_k = (Q_k + Q_c + Q_o - Q_t) \sum_{i=1}^{m} f_j^{se}(1 - se_{ii}) \; ; \tag{29}$$

$$f_i^k = \frac{f_i^{se}(1 - se_{ii})}{\sum_{i=1}^{m} f_i^{se}(1 - se_{ii})}. \tag{30}$$

The deposition of cement in cyclone-precipitators characterized by a matrix $O = (o_{ii})$:

$$(Q_c + Q_o - Q_t) f_i^{sm} o_{ii} = Q_o f_i^o; \tag{31}$$

$$(Q_c + Q_o - Q_t) f_i^{sm} (1 - o_{ii}) = (Q_c - Q_t) f_i^2 = Q_2 f_i^2. \tag{32}$$

Summing both sides of these equations for all the factions, we get:

$$Q_o = (Q_c + Q_o - Q_t) \sum_{i=1}^{m} f_j^{sm} o_{ii} \; ; \tag{33}$$

$$f_i^o = \frac{f_i^o o_{ii}}{\sum_{i=1}^{m} f_i^{cm} o_{ii}} \tag{34}$$

$$Q_2 = (Q_c + Q_o - Q_t) \sum_{i=1}^{m} f_j^{sm}(1 - o_{ii}) \tag{35}$$

$$f_i^2 = \frac{f_i^{sm}(1 - o_{ii})}{\sum_{i=1}^{m} f_i^{sm}(1 - o_{ii})}. \tag{36}$$

For the closure of the matrix equation (7), which is the basis of the model of grinding is necessary to express the dispersion of grit through the dispersion of the original material. This is feasible, since point 11 reverse transformation. Substituting into equation (27) the relation (25) and then in (24) we get:

$$\begin{aligned} Q_k f_i^k = {} & (1 - se_{ii})\, Q_{oc} f_i^o + (1 - se_{ii})(Q_{oc} - Q_a) f_i^{(1)} + \\ & (1 - se_{ii})\, Q_a f_i^a (1 - s_{ii}) + (1 - se_{ii})(Q_a - Q_s) f_i^s (1 - c_{ii}) \\ & (1 - se_{ii})(1 - f_{ii})(Q_a - Q_s - Q_y) f_i^{ym} + (1 - se_{ii})(1 - f_{ii})(Q_o - Q_{oc}) f_i^o. \end{aligned} \tag{37}$$

Then with the help of equations (8)...(12) and (18) we get:

$$Q_k f_i^k = \frac{(1 - se_{ii})(1 + (1 - f_{ii})?)}{1 + P} f_i^o Q_o + \\ + (1 - se_{ii})(1 - s_{ii} a_{ii} f_{ii} c_{ii}) f_i^1 Q_1. \tag{38}$$

From the expression (38) we must also exclude the value $f_i^o Q_o$. To do this, perform a similar inverse transformations, starting with point 12. With the help of expressions (25) and (24) the relation (31) is:

$$\begin{aligned} Q_o f_i^o &= (Q_c + Q_o - Q_t) f_i^{sm} o_{ii} = (Q_k + Q_c + Q_o - Q_t) f_i^{se} se_{ii}\, o_{ii} = \\ &= se_{ii}\, o_{ii} (Q_k + Q_c + Q_o - Q_{oc} - Q_t) f_i^{(4)} + se_{ii}\, Q_{oc} f_i^o. \end{aligned} \tag{39}$$

Next using (8)...(17), (20), (23) we get:

$$Q_o f_i^o = \frac{se_{ii} o_{ii} (1 - s_{ii} a_{ii} f_{ii} c_{ii})(1 + ?)}{1 + P - se_{ii} o_{ii} (1 + (1 - f_{ii})?)} f_i^1 Q_1. \tag{40}$$

Substituting equation (40) into (39) we get:

$$Q_k f_i^k = \frac{(1 - se_{ii})(1 - s_{ii} a_{ii} f_{ii} c_{ii})(1 + ?)}{1 + P - se_{ii} o_{ii} (1 + (1 - f_{ii})?)} f_i^1 Q_1. \qquad 1(41)$$

Dividing both sides of equation (41) on Q_k, we get:

$$f_i^k = \frac{1}{1 - \frac{1}{k_c}} \frac{(1 - se_{ii})(1 - s_{ii} a_{ii} f_{ii} c_{ii})(1 + ?)}{1 + P - se_{ii} o_{ii} (1 + (1 - f_{ii})?)} f_i^1. \tag{42}$$

Summing both sides of equation (42) for all the factions and given that, $\sum_{i=1}^{m} f_j^k = 1$ we get:

$$\frac{1}{k_c} = 1 - \sum_{i=1}^{m} \frac{(1 - se_{ii})(1 - s_{ii} a_{ii} f_{ii} c_{ii})(1 + ?)}{1 + P - se_{ii} o_{ii} (1 + (1 - f_{ii})?)} f_i^1. \tag{43}$$

Substituting (42) and (43) into equation (36) after simple transformations we obtain:

$$f_i^1 = f_i^{oc} - \sum_{j=1}^{m} \left(f_j^{oc} - P_{ij} \right) \frac{(1 - se_{jj})(1 - s_{jj} a_{jj} f_{jj} c_{jj})(1 + ?)}{1 + P - se_{jj} o_{jj} (1 + (1 - f_{jj})?)} f_j^1. \tag{44}$$

Here $f_i^{oc} = \sum_{j=1}^{m} P_{ij} f_j^1$ - calculated (by the grain structure of original material), the quantities that determine the particulate composition of the product after grinding, resulting in an open circuit. Elements of the matrixes characterizing the operation of ball mill p_{ii}, aspiration a_{ii}, aspiration shaft s_{ii}, cyclone to clean the aspiration air c_{ii}, filter f_{ii}, separator se_{ii}, cyclone separators, o_{ii}, as well as air leakage rate p must be specified.

Then from the matrix equation (44) can be obtained system of m equations with known coefficients, the solution of which gives the dispersed composition of f_i^1 a closed circuit system load of the grinding circuit based on a ball mill. Knowing the values with the f_i^1 help of (43) can find the load on the separator defined by the coefficient k_c. By given a load mill Q_{se} and circulation rate k_c find $Q_1 = Q_c\ k_c$. Then by (20) and (31) we find the aspiration removal of material Q_a, the composition of entrained material coming out of the mill in the grinded state:

$$f_i^{(1)} = \frac{Q_1 f_i^1 (1 - a_{ii})}{Q_1 - Q_a}. \quad (45)$$

Similarly, passing all of the following items can be written equations for the size and particulate compositions of other flows, including for the finished product (35), (36), grains (27), (28) and for containing dust emission to the atmosphere (21) and (23).

The relations (4)…(44) comprise a matrix model GFC based on closed circuit ball mill with a return to the original for the separation the material dust cleaning products. Applying the above model of the transformation of the particle size distribution grinding and separation products, knowing the properties of grinded clinkers, we can predict the quality of the cement and technological parameters for plants included into the flow chart of grinding.

Taking advantage of the above-proposed method of converting grain size distribution can return stroke, ask all the necessary output data (qualitative and quantitive parameters, grinding plant capacity, etc.), to pick up all the equipment necessary to provide the desired product range.

RESULTS

Developed a matrix model transformation particle size distribution material of the basic types of closed circuit flow chart grinding allowing to specify the characteristics of the raw materials, a mill, a separator and dust collector predict system performance and grain size distribution of the finished product, as well as parameters of the material and aero material flow system.

To study the influence of major design and technological parameters of the grinding flow chart on and dispersing performance characteristics of the finished product, complete process modeling grinding flow chart "Ball mill- separator".

The analytical expressions of dispersion of the finished product through the parameters of the grain size distribution of the original material and technological parameters of ball mill and the separator obtained. They allow the co-regulation of their operation modes for maximum performance of the product specified quality.

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