OPTIMIZATION AND METHOD OF DRAWING CONTROL IN BLOCK CAVING AT TONGKUANGYU MINE①

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ABSTRACT The principles of the middle-and long-term production planning for the block caving at Tongkuangyu mine, the optimization of drawing control under the overlying rock, the numerical method for the stope model, and the method used to put the drawing control into practice were described systematically.

Key words block caving method drawing control computer-based production planning drawing optimization

1 INTRODUCTION

The researching orebody belongs to a super-large porphyry copper deposit at Tongkuangyu mine, whose horizontal thickness is 80~ 200 m, dip angle 45° and grade of copper 0.672% in average. The original design used the sublevel caving without sill pillar. However, the technical innovation in mining method was conducted in the late of 1980s, that is the block caving, which advances from east to west with a caving layer of 120 m in height, has been used for instead the sublevel caving without sill pillars. The bottom structure for ore removal via. the draw-cone—slusher drift was employed, and the ore was loaded directly in to the truck on the haulage level by a 90 kW slusher.

Since the large-sized block caving and the 120 m height level ore drawing (Hereafter drawing) under over lying rock was introduced for the first time in China, there was no domestic experience could be referred, therefore special computer software for the drawing control was developed by the author, which resulted in the work of both middle- and long-term production planning and short-term drawing control instructing was done by computer, and the optimized drawing under the overlying rock has been achieved by controlling the interface of ore and rock. All these works are presented in this paper.

2 BASIC PRINCIPLES OF DRAWING CONTROL

2.1 Equally proportioned even drawing

The middle- and long-term production planning on the block caving at Tongkuangyu mine was based on the principles of equally proportioned even drawing, which means that the draw-out quantity at each drawpoint is assumed to be the column body corresponding to the area borne by the drawpoint, and the column body is evenly depressed in the process of drawing; but the draw-out quantity at each drawpoint in any control period is directly proportioned to the stored quantity of the caved ore at this drawpoint, and the drawing proportion for all drawpoints in the control period is equal. The mathematical model is as follows:

$$Qf_i = \frac{(\alpha_i \cdot Qd_i - Qp_i)\,Q}{\sum_{j=1}^{R}(\alpha_j \cdot Qd_j - Qp_j)} \qquad i = 1, 2, \cdots R \tag{1}$$

where R —numbers of drawpoints for simultaneous operation; Qf —ore quantity based on production planning, t; Qd —quantity of ore borne by drawcone, t; Qp —quantity of drawn ore, t; Q —total output of stope in the period of production planning, t; α —exponent of drawpoint for the production planning.

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In Eqn. (1) Qf_i must satisfy the following definite conditions that when $Qp_i/(Qd_i)$ is less than or equal to 5, 10, 20, 30, 40 and 50 respectively, then Qf_i is less than or equal to 30, 40, 50, 60, 70 and 80 correspondently; but when $Qp_i/(Qd_i) > 50$, then $Qf_i = 100$. The first row of drawcones closing to the undercut advance line was taken as 0, and the second row of drawcones was taken as 0.1, then each row of drawcones was taken by increment 0.1~ 0.15 (if $\alpha > 1$, all of them are taken as 1).

2.2 Assessment of drawing ore grade for the production planning

As for the middle- and long-term production planning, ore tonnage and grade are determined according to Laubscher's grade assessment[1], its basic concept is that the column drawing ellipsoid borne by a drawpoint is considered to have waste entered in the process of ore drawing. When the entire ore borne is assumed to be drawnout, total quantity of waste entered is equal to the quantity of drawn ore after waste entered is begun, and the percentage of waste entered is increased linearly.

According to this grade assessment, the grade model for 10 m^3 block and the grade of initial dilution point, the diagram of value assessment for the drawn ore from any drawcone at Tongkuangyu mine was made (Fig. 1), in which the grade of initial dilution point $C_1 = 57.5\%$ is the value taken from the drawing test; and that of the drawing end-point $C_2 = 142.5\%$ is the calculated value based on the assumption, C_0 is the grade of the assessment point for the production planning, G_i is the geological grade for i-th 10 m^3 block, G_0 is the grade of overlying rock.

Take the mid-value of ore quantity for the production planning as the grade assessment point when calculating its grade C_0, i.e.

$$C_0 = \frac{1}{Qd}\left(\frac{Qf}{2} + Qp\right) \qquad (2)$$

The calculation method of grade for the production planning and based on Fig. 1 is as follows: make a vertical seqment through the point C_0 and suppose its length to be one unit; take the length l_i segmented by each grade block-zone

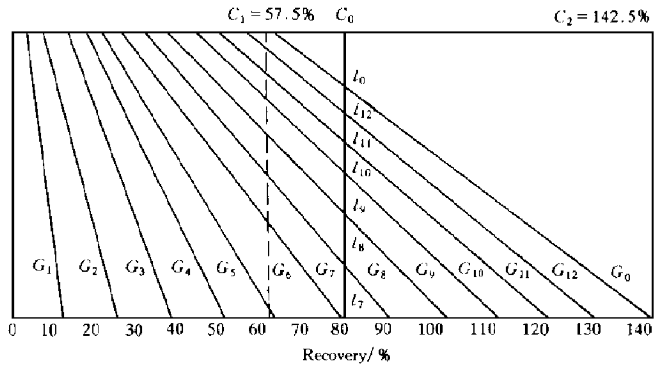

Fig. 1 Grade value assessment diagram for ore drawing at Tongkuangyu mine

G_i as the weight factor, then calculate the average grade of ore quantity for the production planning according to the weighted average method. The grade g of the point C_0 shown in Fig. 1 is:

$$g = l_0 G_0 + \sum_{i=7}^{12} l_i G_i \qquad (3)$$

2.3 Model of drawing control

The key task of drawing control under the overlying rock is to reduce the ore loss and dilution in the process of drawing as soon as possible, those under the overlying rock are attributed to the entry of waste at the contact surfaces of ore and rock. The waste entry is constrained by two main factors: the first is the contact area of ore and rock, the second is the mechanical characteristics of the caved ore and rock. The extent controlled by the later factor is asually very small in the process of drawing, for any specific drawing stope, therefore, the mechanical characteristics of the caved ore and rock, related to the drawing control, can be used as the invariant factors. The factor which can constrain the waste entered in the process of drawing and can be controlled by the drawing sequence is the area the contact surfaces between ore and rock, which is made to be in a state of the minimum so that the waste entry reaches to the least.

Through computer simulation, it has been shown that the significant effecting diameter of the short-term drawing quantity, on the surface of contact at any drawing point is 25 m under the conditions of production requirement and level height at Tongkuangyu mine. It can be considered that, therefore, the optimal drawing quantity at any drawpoint is the minimal one to which the contact surface area of the zoned ore and rock, in the range of 25 m in diameter aroung drawcones reaches minimum:

$$\min S = f(x(Qf), y(Qf), z(Qf)) \quad (4)$$

where S is the contact surface area of the zoned ore and rock, m^2; $x(Qf)$, $y(Qf)$ and $z(Qf)$ express the space state at any point on the contact surface of ore and rock, and those are the functions of drawn quantity Qf.

Eqn. (4) is the control model of ore-rock contact area. According to this model, the optimal drawing control under the overlying rock can be obtained. However, some unexpected problems often occur in the process of ore drawing, for example, the blockage, damage and maintenance of drawcones, the requirement of pressure release for the bottom structure, the production requirement and so on. The quantity of ore drawing at these special drawpoints is satisfied according to the preferential principle, and the production requirement is met by the method of coefficient control.

2.4 Motion equation of ore and rock particles

The contact surface of ore and rock consists combined of the surfaces of the caved ore and rock particles, thus their motion equation in the process of drawing is the theoretical basis for the drawing control dealing with Eqn. (4). Being aimed at the block caving at Tongkuangyu mine, therefore, the drawing experiment of a high-level physical model was made. The test results showed that the drawing material under the condition of low-level drawing has an approximate ellipsoid. However, the ellipsoid progressively becomes big on the upper and small on the lower with the increase of drawingheight. According to this experimental phenomenon, the rotational abutting ellipsoid model was established, i. e. the drawing material was fit into a rotational abutting ellipsoid, of which the two minor half-axes were similar but the major half-axes were not equal certainly[2]. The ellipsoid surface equation can be expressed as:

$$x^2 + y^2 = b^2[1 - \beta^2(z/a - 1)^2] \quad (5)$$

where $\beta = \begin{cases} 1 & 0 \leqslant z \leqslant a \\ a/(h-a) & a < z \leqslant h \end{cases}$

and a, b, h are the shape variables of ellipsoid, i. e. lower major half-axis, minor half-axis and the height of the ellipsoid respectively. And a, b are the variables related to h and the mechanical characteristics of the caved ore and rock, and are determined by the drawing ellipsoid test. Under the condition of ore and rock caving at Tongkuangyu mine:

$$\left.\begin{aligned} a &= 0.58458h^{1.02301} \\ b &= 0.23111h^{0.86219} \end{aligned}\right\} \quad (6)$$

According to the assumption of abutting ellipsoid drawing and its surface Eqn. (5), the basic equation of particles motion of ore and rock caved was derived:

$$\left.\begin{aligned} X &= \frac{ab}{\sqrt{a^2u^2 + \beta^2b^2v^2}}X_0 \\ Y &= \frac{ab}{\sqrt{a^2u^2 + \beta^2b^2v^2}}Y_0 \\ Z &= a + \frac{abv}{\sqrt{a^2u^2 + \beta^2b^2v^2}} \end{aligned}\right\} \quad (7)$$

where $u^2 = X_0^2 + Y_0^2$, $v^2 = (Z_0 - a_0)^2$, X_0, Y_0, Z_0 indicate the initial space state before the particles move.

According to Eqn. (7), and being combined with Eqns. (5) and (6) as well as the volume formula of drawing ellipsoid $Q = (2/3)\pi b^2h$, the iteration method can be used to determine the space state of any particle point at the contact surface in the process of drawing.

3 DIGITALIZATION OF STOPE MODEL

3.1 Numerical model of stope drawcones

The establishing of the numerical model of stope drawcones is aimed at making the computer process the relative data according to the regularity of stope drawcones distribution. In Tongkuangyu mine, the main drawcones were evenly distributed in the form of block, the drawcone spacing was 10 m × 10 m, with a good regularity, and the positioning can be carried out by numbers of cross drift, slusher drift and drawcones. Therefore, the matrix was used directly to describe the distribution of stope drawcones, which was formed into the regular quadrangle by use of suppositional modelling. Suppose the number of any drawpoint to be b_{ij}, then the matrix $\{B\}$ with one line N and rank M completely characterizes the regularity of stope drawcones distribution:

$$\{B\} = \begin{vmatrix} b_{11}, & b_{12} \cdots b_{1M} \\ b_{21}, & b_{22} \cdots b_{2M} \\ \cdots\cdots & \cdots\cdots \\ b_{N1}, & b_{N2} \cdots b_{NM} \end{vmatrix} \tag{8}$$

where the numbers and the relative location on the plane of drawcones on the i-th line and the j-th rank are determined only by b_{ij}. The drawing parameters matrix, such as matrix of exponent for the production planning $\{\alpha\}$, matrix of ore quantity for the production planning $\{Qf\}$, matrix of ore quantity borne $\{Qd\}$ and matrix of ore quantity drawn $\{Qp\}$ etc, for drawcones, can be constructed relatively. The processing of drawing parameters for the single drawcone, therefore, is turned into the processing of drawing parameters matrix for stope drawcones.

3.2 Digitalization of ore and rock contact surfaces

The contact surfaces borne by each drawcone were divided into 8 subunits in area. The unit model for ore and rock contact surfaces is shown in Fig. 2

Suppose the coordinate system for zoning contact surfaces to be $X - Y - Z$, then the space state of any node $B(I, J)$ on the contact surfaces under this coordinate system is

$$\left.\begin{aligned} X_{ij} &= 5(i - I) \\ Y_{ij} &= 5(j - J) \\ Z_{ij} &= \frac{\sum\limits_{t=0}^{1}\sum\limits_{k=0}^{1} \dfrac{Qc([\frac{i+t}{2}],[\frac{j+k}{2}])}{100\gamma_{ot}}}{\sum\limits_{t=0}^{1}\sum\limits_{k=0}^{1}\mu} \end{aligned}\right| \tag{9}$$

where

$$\mu = 1, \text{ when } Qc([\frac{i+t}{2}],[\frac{j+k}{2}]) \neq 0$$

and $\mu = 0$, when $Qc([\frac{i+t}{2}],[\frac{j+k}{2}]) = 0$

where i, j are the line and rank sequence of the nodes of unit model for ore and rock contact surfaces in the nodal matrix; Qc is the quantity of ore stored in drawcones and $Qc = \alpha Qd - Qp$; γ is the bulk volume weight of the caved ore.

The area of the zoning contact surfaces:

$$S = \sum_{i=n_0}^{n_1-1}\sum_{i=m_0}^{m_1-1}\Omega_{ij} \tag{10}$$

where $n_0 = 2I - 5$, but $n_0 \geqslant 1$;
$n_1 = 2I + 5$, but $n_1 \leqslant N$;
$m_0 = 2J - 5$, but $m_0 \geqslant 1$;
$m_1 = 2J + 5$, but $m_1 \leqslant M$;

$$\Omega_{ij} = \sum_{t=1}^{2}[P_{ij}^{(t)}\prod_{k=1}^{3}(P_{ij}^{(t)} - d_{ij}^{(t,k)})]^{\frac{1}{2}}$$

and $d_{ij}^{(t,k)}$ is the length of side for the triangle unit on the contact surfaces.

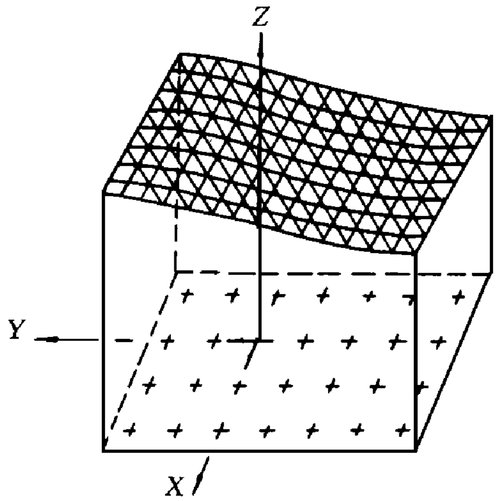

Fig. 2 Unit model for ore and rock contact surfaces

4 OPERATIVE METHODS FOR DRAWING CONTROL

As for the block caving at Tongkuangyu mine, the drawpoints of simultaneous drawing are considerable (up to several hundreds). Therefore, the computer was used for the drawing control which was carried out by the middle- and long-term production planning, the short-term production planning and the daily or ten-days drawing control instruction. The latter two were mainly responsible for carrying out the optimized monthly production planning, daily or ten-days drawing control instruction, those drawing are performed beneath the contact surface of ore and rock.

4.1 Middle- and long-term production planning

According to the deposit model, the production requirement, the undercut rate, and in the light of the equal-scale even drawing principle and Laubscher's grade assessment, the middle- and long-term production plan was worked out. The period of production planning was one quarter of a year, and the time limit of middle- and long-term production planning was 3 ~ 5 years.

The main targets of middle- and long-term production planning were to plan the undercut advance schedule satisfying the production requirement, and work out the drawn quantity and metal content for drawcones, slusher drifts, cross drifts and stopes in the time limit of production planning.

The computer-based middle- and long-term production planning methods are as follows:

(1) Establish the numerical model of stopes and the sequential file $\{B\}$, $\{Qd\}$;

(2) According to the basic principle that the area of undercut is about 1 800 m^2 per quarter, determine the undercut advance line quarterly;

(3) Establish the exponent matrix $\{\alpha\}$ of production planning. After the inputing with an exponent of production planning of 0. 1, of drawcone number the exponents of production planning for other drawcones are determined automatically by the computer;

(4) Calculate quarterly total output Q of stope: $Q = \sum_{i=1}^{k_0} Qq_i$, where k_0 is the numbers of cross drifts for haulage putting into operation; Qq_i is the quarterly output of cross drifts for haulage, which is determined by the equation:

$$Qq_i = \sum_{j=1}^{nq} \eta \cdot QC_j \quad \text{but } Qq_i \leqslant Qm,$$

where nq is the numbers of the operating drawcones in the cross drifts for haulage; Qm is the quarterly hauling capacity of cross drifts, 265 × 10^3t according to the design; η is the coefficient of quarterly:

$$\eta = \begin{cases} 3/7 & Qc > 1\,000 \\ 1 & Qc \leqslant 1\,000 \cap \alpha \geqslant 1 \end{cases}$$

(5) Calculate the ore quantity of production planning for drawcones according to Eqn. (1) and check the drawn ore quantity of drawcones;

(6) Check the drawn ore quantity of drawcones according to the maximal capacity of ore removal by slusher;

(7) Calculate the metal content of production planning according to Eqn. (3). The calculation is finished by subprogram.

4. 2 Short-term production planning

The short-term production planning used month as the period of production planning, and its targets conformed to those of the middle- and long-term production planning. However, the short-term production planning was required to combine the practical conditions of mine production closely, therefore, it was conducted not only annually but also monthly, that is to say, the output plan for the coming month will be worked out at the end of former month according to the practical production status. The method for the annual production planning was basically similar to that for the middle- and long-term production planning.

4. 3 Daily drawing instruction

In the block caving at Tongkuangyu mine, the stope drawing control was achieved finally by the daily drawing instruction, that is to say, the daily controlled drawing quantity for the slusher drifts was assigned by the drawing control centre every day, and the controlled drawing quantity on the day for every slusher drift was allocated to every drawcone and working shift.

The daily drawing instruction is a link through which the drawing control technique was combined directly with the mine production. The requirements for daily drawing instruction are that the monthly plan should be finished and the practical conditions of production must be satisfied; in addition, the optimal drawing result has to be obtained. As for the drawcones beneath both the caved face and the overlying rock, therefore, the different drawing control method was used respectively according to various drawing characteristics. The former followed the principle of even drawing and the later obtained the optimal drawing control beneath the overlying rock under the conditions of both satisfying the monthly output plan and the production status. Therefore, the dainly drawing instruction plan for Tongkuangyu mine was the optimal drawing plan that the optimized result of ore recovery can be obtained under the conditions of satisfying the monthly output plan and the practical site production conditions.

4.4 Optimization of ore drawing under the overlying rock

The optimal drawing under the overlying rock was obtained according to the optimal drawing control model Eqn. (4) and the basic Eqn. (7) of particles motion for the caved ore and rock, and by use of the digitalized method and the optimized method.

As for the optimal drawing control, the node number matrix for the contact surface subunit was automatically established by computer at first, and the constrained drawing quantity for r special drawcones was given, then the constraintless optimization solution for $R-r$ dimension was conducted by use of the coordinate cyclic method; finally, the check was made according to its production requirement and the equipment capacity.

The basic method of constraintless optimization solution for $R-r$ dimension is as follows:

Firstly, according to the principle that the remainder ore quantity based on the production planning is evenly drawn out this month, give the initial drawing quantity $\{Qf^{\circ}\}$, and determine the ore quantity error limit ε_1, ε_2 and the initial value E of optimized step length, then:

(1) Calculate the initial space state of contact surface nodes beneath the coordinate system according to Eqn. (9);

(2) Calculate the initial area S_0 of contact surfaces according to Eqn. (10);

(3) The drawing quantity is increased by one step length E of optimized ore quantity;

(4) The conversion of nodes coordinate of contact surfaces is carried out according to Eqn. (7);

(5) Calculate the converted area S_1 of contact surfaces according to Eqn. (10);

(6) If $S_1 < S_0$, taking $2E$ as the optimized step length, repeat from (3);

(7) If $\|E\| \geqslant \varepsilon_1$, taking $-E/4$ as the optimized step length, repeat from (3);

(8) If the optimized numbers of drawcones are less than $R-r$, repeat from (1) to optimize the drawing quantity for next drawcone;

(9) If $\left\|\sum_{i=1}^{R-r}(Qf_i^k - Qf_i^{k-1})\right\| > \varepsilon_2$, taking $\{Qf^k\}$ as the initial drawing quantity, repeat from (1) to go to the next cycle optimization.

5 CONCLUSION

The ore drawing control department has been set up at Tongkuangyu mine, and the computer-based drawing control center was also established. The processing of all drawing data, the production planning and the drawing instruction were finished by computer.

The computer software for the drawing control of the block caving at Tongkuangyu mine includes five executive files, one deposit model file, one geological grade model file and several data files. The software package with modular structure and multistage menu selection was characterized by simple operation, easy use and good user interface. At Tongkuangyu mine, using the computer software for the drawing control made the engineering technicians working at the drawing control thoroughly get rid of overelaborate data processing work and centre on the micro analysis and the optimized drawing control. In addition, a good drawing result was obtained through the medium of both the optimal drawing control under the overlying rock and timely rectifying unreasonable doing in the drawing.

REFERENCES

1 Laubscher D H. The Journal of the South African Institute of Mining and Metallurgy, 1994, 94(10): 279 – 293.

2 Zhou Aimin, Wang Daxun. Quarterly of The Changsha Institute of Mining Research, (in Chinese), 1989, 9(2): 20– 27.

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