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Research on parameters of the extraction unit based on the optimization

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ABSTRACT

Take the issue of optimizing paraments of the extraction unit as the background, according to the effect of the extraction unit on evaluation indexes of safety production, optimization model of which is established. First, two-parameter optimization model is established, accoding to evaluation indexes such as yield, efficiency and benefit, and for the joint distribution charateristics of the parameters. Second, according to ton-coal cost, the model has been established, by fractional and polynimial function. Third, for the two-parameter optimization model is nonlinear unconstrained optimization problem, the model has been solved by adopting the DFP method, according to the charateristic of which, and the optimization result matches pratical case. Finally, analyze and evaluate its result. And the quantitative prediction is carried out according to the parameter model of the extraction unit.

KEYWORDS

Extraction unit;
DFP method;
Optimization theory.

INTRODUCTION

In order to achieve the sustainable development of the mining industry, two pillars are necessarily established, including the macro control of the mining industry on the basis of scientific decisions and optimization of mining exploitation by means of modern technologies. The former is the commanding height for the sustainable development of the mining industry, while the latter is its concrete manifestation. Optimization is used to provide the scientific-decision support, optimal production schemes, and parameters for management and engineering personnel, so as to improve extraction rates, enhance the security, maximally reduce investment risks, and attain high yield and efficiency when the given information and technical conditions are limited. Therefore, the research on the optimization parameter of the extraction unit is not only an optimal selection method but also a new practical technology.

Coal mining is the core of the mine-shaft work. The size of the extraction unit (the minimal unit of coal beds in the course of extraction) is not only related to the rational exploitation of mine shafts, but also largely influence the extraction rates of coal resources, the safety of mine shaft production, output, efficiency, and benefits, etc. In regard to the extraction rate of coal resources, the quantity of various coal pillar will vary with changes in the extraction unit, leading to the difference in extraction rates. From the perspective of the mine shaft exploration, the size of extraction unit determines

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and affects the division mining in the mining area, thereby affecting the layout of the mine tunnel system, and then affecting the arrange of the coal transportation, auxiliary transport, ventilation, drainage, pedestrian, grouting, drainage, power supply, communication, auxiliary systems, and mine production. In terms of the mining technology, the change in extraction units affects the use of mining equipment, inputs and associated costs. What's more, it also influence the number of personnel involved in production, management difficulty and effect of the extraction unit. In short, the change in the size of the extraction unit will have both positive and negative impacts on the extraction rate, yield, efficiency, benefits, safety and other indexes of coal resources.

In recent years, with large mining equipment and the constant pursuit of efficiency of the yield per unit, the extraction unit is gradually large. Currently, the largest extraction unit is 350m × 6700m, with the trend of further development. The wide fluctuation of extraction unit parameters results in fluctuations of other parameters of mine shafts in the larger range, leading to the huge uncertainty in the design and evaluation of mine shafts, which, to some extent, has lost its standards. In view of a mine shaft with the specific coal bed conditions, there must be a size of the extraction unit able to achieve the maximal comprehensive benefits, namely a reasonable extraction unit. The division of the extraction unit of coal beds in the shaft aera is the premise of the layout of the production system, while the extraction unit is the basis for exploration unit division. Whether the parameter of the extraction unit is reasonable or not has an impact on the rationality of the mine production system, as well as efficiency, safety, yield, production and extraction rates of mine shafts. Optimization of recovery unit parameters is the basis and core to achieve the exporation optimization of mine shafts. Results of optimization supply engineering and technical personnel with scientific decision support and optimal production schemes, to attain high yield and efficiency and minimize investment risks when the given information and technical conditions are not enough.

THE ESTABLISHMENT OF THE MODEL

Following assumptions are made in the model:

(1) Ignore the impact of man-made and objective factors on the extraction unit, such as weather, in the optimization madel of the extraction unit;

(2) In the analysis of the extraction unit, efficiency, benefits, yields, extraction rates, etc. of the mine safety production are regared as the major influencing factors. The surrounding conditions are negelected due to their uncertainty.

As the minimal coal mining unit, the extraction unit is artificially divided. As to the longwall system, the extraction unit is a rectangule in terms of geometry, the length S of which is the summation of the length of the working face and the width of the pillar, the width L of which is the summation of length of the mining working face and the width of the coal pillar between the two crossheadings and the extraction unit. The formula is as follows:

$$L = l_m + l_y + l_h + l \qquad S = s_1 + s_2$$

In this fomular:

L - the width of the extraction unit, m;

l - the length of the working face, m

l_m - the coal pillar width between extraction units, m;

l_h - the width of the return way, m;

l_y - the width of the haulage gate, m;

S - the length of the extraction unit, m;

s_1 - the width of the coal pillar, m;

s_2 - The length of the advancing face, m

The two-parameter optimization model and algorithm design

Because the content of optimization includes the plan of the roadway layout and the main parameters of the mining area, the cost of the project involving in almost all the costs of the mining area, the expense of each ton of coal in the mining area is close to unit cost of coal mining. The expense per ton coal in the mining area related to the system of the roadway layout and the major parameters includes eight aspects: roadway excavation costs Z_1, roadway maintenance costs Z_2, transportation costs of coal Z_3, mine ventilation fee Z_4; fees of mining area parking lots and chamber excavation Z_5, auxiliary transport fees Z_6, moving charging Z_7, working face costs Z_8. Therefore, unit cost of coal mining is $\sum_{i=1}^{8} Z_i$.

Starting from a selected starting point $x_0 \in R_n$, make a point range $\{x_k\}$ in accordance with the rules of a particular iteration, so that when there is a finite sequence $\{x_k\}$, the last point is the optimal solution to the problem. When the point range $\{x_k\}$ is infinite, there is a limit point, which can be regarded as the optimal solution of the problem.

Provided $f: R_n \to R_1, x^* \in R_n, 0 \neq p \in R_n$, if $\delta > 0$, then $\forall t \in (0,\delta)$, so $f(x^* + tp) > f(x^*)$, the vector p is f in the descent direction of x^*. Provided $X \subset R_n, x^* \in X, 0 \neq p \in R_n$ $X \subset R_n$, if $\delta > 0$, then $\forall t \in (0,\delta)$, so $x^* + tp \in X$, the vector p is said that x^* is in the feasible direction of X. A vector p, if the function f is both in the descent direction of and in the feasible direction of X, it can be said that the direction is the function f in the feasible descending direction of x^*.

The principles of Algorithm design:

(1) Basic structure

① determine the search direction p_k, and make f in the descent direction of x_k according to certain rules;

② determining step factor a_k, so there is a descent direction in the value of the objective function;

③ Assume $x_{k+1} = x_k + a_k p_k$, if x_{k+1} meets certain termination condition, stop the iteration, approximate optimal solution x_{k+1} can be acquired. Otherwise, repeat the above steps.

(2) The basic idea

Expand the second-order Taylor $f(x)$ at the approximate point $x^{(k)}$ of the minimum point x^*, and regard the minimum point of the quadratic function as a new approximate point $x^{(k+1)}$ x^*, and so forth. With a series of the minimum point $\{x^{(k+1)}\}$ of the quadratic, the minimum point x^* of $f(x)$ can be obtained by approximation

Assume that $\min f(x), x = (x_1, x_2, \cdots, x_n)$ is continuously and at least bidifferentible in $f(x)$ at the area D, similar to the expansion of function of one variable. As to the multivariable function $f(x)$, it can be expanded at the point of x_0 as the second-order Taylor expansion:

$$f(x) = f(x_0) + \frac{1}{1!}\nabla f(x_0)^T (x - x_0) + \frac{1}{2!}(x - x_0)^T \nabla^2 f(x_0)(x - x_0) + o(\|x - x_0\|^2)$$

Provided

$$g(x) = f(x_0) + \frac{1}{1!}\nabla f(x_0)^T (x - x_0) + \frac{1}{2!}(x - x_0)^T \nabla^2 f(x_0)(x - x_0)$$

Then

$$f(x) \approx g(x) = f(x_0) + \frac{1}{1!}\nabla f(x_0)^T (x - x_0) + \frac{1}{2!}(x - x_0)^T \nabla^2 f(x_0)(x - x_0)$$

In accordance with $\nabla f(x_0) + \nabla^2 f(x_0)(x - x_0) = 0$, the result is: $x_{k+1} = x_k - [\nabla^2 f(x_k)]^{-1} * \nabla f(x_k)$.

Considering the large amount of calculation of second-order differentiable $f(x)$ and $[\nabla^2 f(x_k)]^{-1}$ as well as the severe requirements of starting points, the symmetric positive definite matrix B_k, which resorts toand is constructed by reciprocals to approximately replace $\nabla^2 f(x_k)$:

$$f(x) \approx g(x) = f(x_0) + \frac{1}{1!}\nabla f(x_0)^T (x - x_0) + \frac{1}{2!}(x - x_0)^T B_k (x - x_0)$$

Correspondingly, $x_{k+1} = x_k + a_k d_k = x_k + a_k \nabla^2 [B_k]^{-1} \nabla f(x_k)$. B_k shall meet following three conditions:

① B_k is a symmetric positive definite matrix, so $d^{(k)} = -B_k^{-1} \nabla f(x^{(k)})$ in the descent direction

② B_{k+1} is acquired by checking B_k, namely $B_{k+1} = B_k + \Delta B_k, \Delta B_k$ is correction matrix.

③ B_{k+1} must meet Quasi-Newton condition: $B_{k+1}\delta^{(k)} = y^{(k)}$, in it $\delta^{(k)} = x^{(k+1)} + x^{(k)}, y^{(k)} = \nabla f(x^{(k+1)}) - \nabla f(x^{(k)})$

The correction term ΔH_k is determined by the specific algorithm, with its construction related to specific algorithm. The symmetric rank structure1 (SR1) and the symmetrical rank structure2 (SR2) are very common. Quasi-Newton algorithm modified by SR2 is called DFP method.

The model solution

The iterative formula of the Quasi-Newton Method

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$$\begin{cases} x_{k+1} = x_k + \lambda_k p_k, \\ p_k = -H_k \nabla f(x_k), \\ \lambda_k : f(x_k + \lambda_k p_k) = \min_{\lambda \ge 0} f(x_k + \lambda p_k), \\ H_{k+1} = H_k + \Delta H_k, k = 0,1,\cdots. \end{cases}$$

B_k refers to Quasi-Newton direction, which is steepest descent direction of the metric matrix H_k. H_{k+1} represents the correction matrix, while ΔH_k stands for the correction term. ΔH_{k+1} is required to meet the following properties:

① Suited for Quasi Newton equation:

$H_{k+1} y_k = s_k (s_k = x_{k+1} - x_k, y_k = g_{k+1} - g_k = \nabla f(x_{k+1}) - \nabla f(x_k))$.

② Of Genetic symmetry and positive definition: if H_k is of positive definition, so is H_{k+1}.

The construction of the correction term ΔH_k is related to H_k, s_k, y_k. Suppose $H_0 = 1$, and set the error limit $\varepsilon_1, \varepsilon_2, \varepsilon_3$ of the termination in the objective function $f(x), x \in R_n, H$. The concrete steps are as follows:

(1) The initial point x_0 is given: calculate $f_0 = f(x_0), g_0 = \nabla f(x_0)$;

(2) Set $H_0 = I, P_0 = -g_0, k = 0$

(3) Calculate $\lambda_k : f(x_k + \lambda_k P_k) = \min_{\lambda \ge 0} f(x_k + \lambda P_k)$

(4) Calculate $x_{k+1} = x_k + \lambda_k P_k$, $f_{k+1} = f(x_{k+1})$

(5) Judge whether $f_{k+1} \ge f_k$ is valid. Turn to the step (6) if so, while turn to the step (7) if not.

(6) If $k = 0$, go to the step (13). If not, turn to (12);

(7) Calculate $g_{k+1} = \nabla f(x_{k+1})$;

(8) If the termination rule can work, turn to the step (13). If not, turn to the step (2).

(9) Calculate $y_k = g_{k+1} - g_k, s_k = x_{k+1} - x_k$

(10) If $k = n$, then set $x_0 = x_{k+1}, f_0 = f_{k+1}, g_0 = g_{k+1}$. Turn to the step (2), while turn to the step (11), if not.

(11) Calculate $H_{k+1} = H_k + \frac{s_k s_k^T}{s_k^T y_k} - \frac{(H_k y_k)(H_k y_k)^T}{y_k^T H_k y_k}, P_{k+1} = -H_{k+1} g_{k+1}$;

(12) Set $k = k+1, P_k = P_{k+1}, g_k = g_{k+1}, f_k = f_{k+1}, x_k = x_{k+1}$, and then turn to the step (3);

(13) Calculate f_{k+1}, x_{k+1}

(14) Stop.

Taking into account that the steepest descent method has no special requirement on the initial point, as well as the advantages of the reasonable calculation work and small storage, we first use the steepest descent method to obtain the initial search interval. However, it is easy to produce the obvious crenellated phenomena at the minimum point attachment by means of the steepest descent method, with the slow convergence. The speed of convergence is largely related to variable scales, unstable to small perturbations. Generally, small perturbations are inevitable in the calculation. Being steepest descent is only a partial nature. Therefore, having obtained the initial interval, we then obtain the solution by means of DFP method, with the condition (1) as a termination criterion. The iterative point range $\{x_k\}$ can be acquired:

The following result can be obtained through the steepest descent method

$x_0 = [80,100], x_1 = [291.785, 3989.237],$

$x_2 = [331.965, 6370.026], x_3 = [338.418, 6450.128]$

The following result can be acquired by DFP method:

$x_0 = [338.418, 6450.128], x_1 = [342.267, 6481.369],$

$x_2 = [347.149, 6504.806]$

Results and parameters of extraction unit match the reality of the objective situation, with good effect. Therefore, the DFP method is feasible and effective to be applied to two-parameter model.

CONCLUSION

We need to fully consider if the situation of coal seam, roof and floor lithology, way of Ida pioneering, ventilation and other conditions are appropriate and matching the equipment selection phase to the parameters of mining unit. When doing its technical and economic analysis, it is necessary to have effective decision-making scientific theories and methods. The above results for the research of optimizing recovery unit parameters shows that the economic model of cost per ton of coal e built by nonlinear optimization is an effective method of decision-making, it is consistent with the objective law of mine production process so that the decisions can be made on the basis of scientific quantitative analysis.

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