Parameter Optimization of Drilling Based on Biogeography-based Optimization

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Abstract. In this paper, the drilling machine is taken as the research object. Based on the model of drilling rate and model of bit life, a multi-objective optimization model for drilling parameters is established, which is based on two parameters, drilling speed V and bit life tf, with drilling pressure W and speed of revolution N as design variables. The change and its regulation of bit life are considered on the premise of ensuring the speed of drilling, and the relationship between the sub targets of the drilling parameters optimization is explored. Through the analysis of the optimization results, it is found that there is a mutual restriction between the mechanical drilling speed and the life of the drill bit. It is proven that the bio-geographic optimization algorithm proposed in this paper and the multi-objective optimization model of drilling parameters is correct and effective.

1. Introduction

Drilling parameters is important factors that affect and restrict drilling speed, cost and quality. With the continuous development and progress of drilling engineering technology, rapid upgrading of related equipment and test instruments, drilling parameter optimization technology has ushered in a new research topic. The research on drilling parameters optimization of drilling rig has already been carried out overseas. The hydraulic parameters optimizing model had established by Kendall and Goins, which established the basic theory for the optimal selection of hydraulic parameters [1]. Domestic researchers have also done some research. An improved adaptive genetic algorithm had proposed in document [2]. The adaptive quantum genetic algorithm based on the Fibonacci sequence, which had proposed in the literature. It effectively solved the problem of parameter optimization in real time [3]. The particle swarm optimization (PSO) algorithm had been used to design the target function in literature [4]. A multi-objective particle swarm optimization algorithm had been proposed in literature, which had been applied to solved multi-objective drilling parameters optimization model, which was based on penetration rate, bit life and bit specific energy [5]. Above research results and methods had been provided a solid theoretical basis for the parameters optimization of drilling. The author was based on the classical model of mechanical drilling speed and the model of drill wear model. Mechanical drilling speed and bit life has applied as the optimization target. Drilling pressure and the revolution speed of bit has applied as design variables. Multi-objective optimization model of drilling parameters was established by used biogeographic optimization algorithm. The simulation
experiment has completed by used Matlab simulation software. The optimization analysis and multi-objective optimization of drilling parameters was carried out according to the results of the simulation experiment. The change and its regulation of bit life was considered on the premise of ensuring the speed of drilling, and the relationship between the sub targets of the drilling parameters optimization is explored.

2. Drilling Model of Drilling Rig

2.1. Model of Mechanical Drilling Speed

In this paper, the model of mechanical drilling speed by YoungF.S has been modified. The modified model is integrated with the effects of bit tooth wear, drilling pressure, drilling speed, drilling fluid performance, water factors and other external reasons. In reference to the results of other researchers, the drilling speed model as shown in (1) is established.

\[ V = K_R C_r C_h (W - M) N^\lambda \frac{1}{1 + C_3 h} \]  

KR is the coefficient of drillability for stratum. CP is the coefficient of influence for pressure difference. CP is 1 indicating no pressure difference. CH is the coefficient of waterpower purification. CH is 1 indicating thorough purification. W is drilling pressure (KN). M is threshold drilling pressure (KN). N is rotating speed (r/min). λ is index of rotating speed. C2 is the coefficient of tooth wear for bit. Relative wear extent for teeth of bit is h.

2.2. Model of Life for Drill

As the main tool of drilling, the drill has a great friction with the rock, so the wear of drill is a problem that has to be taken into consideration. There are two main aspects of the wear for the drill, that is, the wear of the drill and the bearing. Because the severe wear of the drill and rock is worse than that of the bearing, the wear equation of the drill is considered first, and the life model of the drill is set up to (2).

\[ \frac{dF}{dt} = \frac{A_r (Q_1 N + Q_2 N^3)}{(Z_2 - Z_1 W) (1 + C_1 h)} \]  

A_r is the coefficient of abrasiveness for stratum. Z1 and Z2 is the coefficient of influence for drilling pressure. Q1 and Q2 is the coefficient of influence for rotating speed. C1 is the coefficient for slow down the tooth wear of a drill. The formula (2) can derive the function relation between the working time of the drill and the wear amount of the tooth of a drill and the total wear of the tooth of a drill (3).

\[ \frac{A_r (Q_1 N + Q_2 N^3)}{(Z_2 - Z_1 W)} (t_r - t) = (0.5 C_1 h^2 + h_f) - (0.5 C_1 h^2 + h) \]  

The h_f is the limit of wear amount. The h_f is 1. The “t_r” is life of drill when the “t” is 0. For example (4).

\[ t_r = \left[ (0.5 C_1 + 1) - (0.5 C_1 h^2 + h) \right] \frac{(Z_2 - Z_1 W)}{A_r (Q_1 N + Q_2 N^3)} \]  

The t_r is the theoretical life of a drill when the wear amount of the drill teeth is 0.
3. **Optimization of Drilling Parameters for Drilling Rig**

3.1. **Objective Function**

As an important index for evaluating the optimization scheme, the objective function must contain all the variables and reflect the small changes of the variable. In this paper, two parameters of drilling speed and wear of drill (life of drill) are selected as the optimization targets. The objective function for (5).

\[ F = \min(V, t) \]  

\( V \) is the model of mechanical drilling speed, \( t \) is the model of life for drill. The model of mechanical drilling speed is (1). The model of life for drill is (4). The design variables are drilling pressure \( W \) and rotational speed \( N \). The constraint range of the design variable is (6).

\[
\begin{align*}
W_{\text{min}} &< W < W_{\text{max}} \\
st. & N_{\text{min}} < N < N_{\text{max}} \\
0 &< h < 1
\end{align*}
\]  

In general conditions, \( W_{\text{min}} \) is equal to \( M \) and \( W_{\text{max}} \) is equal to \( Z_2/Z_1 \).

3.2. **Coefficient of Multiobjective Optimization Model for Drilling Parameters**

The coefficients in the multi objective optimization model of drilling parameters can be divided into two kinds: the drill coefficient and the correlation coefficient of the stratum. The coefficients of drill include \( Z_1, Z_2, Q_1, Q_2 \) and \( C_1 \). It is determined by the type of a drill, usually by a data table of drill. The correlation coefficient of the stratum include \( K_h, M, \lambda, C_2 \) and \( A_r \). It is usually determined by field test and actual analysis with drilling data. The 21 type drill is used in this well section. This type of drill is suitable for medium and hard strata, and the range of the speed of \( N \) is 0-250r/min. The specific coefficient of drill is \( C_1=5, Z_1=0.0146, Z_2=6.45, Q_1=1.5, Q_2=6.52\times10^{-5} \). The hydraulic purification coefficient (\( C_{1h} \)) is generally assumed to be 1 in the optimization of drilling parameters. In the optimization of drilling parameters, it is generally assumed that the influence coefficient of pressure difference (\( C_p \)) is 1. The correlation coefficient of the formation can be estimated using the data from the near well and the test data of the new bit, when the drill will be start. In the process of drilling, the correlation coefficient of the formation is determined in the way of the work record of the current drill and the way of inversion. Because of the many interference factors and strong randomness during the drilling process, many groups of data are generally used for linear regression. Multiple linear regression models, such as formula (7) and (8). Twenty sets of sampled data, such as Table 1, were obtained according to the document [6]. The application type (7) and formula (8) regression analysis on the ten sets of data in Table 1 to obtain a group of stratigraphic correlation coefficients. Correlation coefficient of the stratum include \( K_h=0.00228, M=10.2, \lambda=0.682, C_2=3.678 \) and \( A_r=0.0029 \).

\[
\ln V = \ln K_h + \ln(W - M) + \lambda \ln n - \ln(1 + C_2h) \]  

(7)

\[
\ln(t - t_0) = \ln(Z_2 - Z_1W) - \ln A_r - \ln(Q_1 + Q_2n^3) + \ln \left[ \left( h_0 + \frac{C_1}{2} h_0^2 \right) - \left( h_0 + \frac{C_1}{2} h_0^2 \right) \right] \]  

(8)
Table 1. Drilling Sampling Data

| Number | Drilling Pressure | Rotating Speed | Drilling Speed | Number | Drilling Pressure | Rotating Speed | Drilling Speed |
|--------|-------------------|----------------|----------------|--------|-------------------|----------------|----------------|
| 1      | 288               | 60             | 10.35          | 11     | 300               | 69             | 9.11           |
| 2      | 285               | 62             | 10.14          | 12     | 301               | 70             | 9.02           |
| 3      | 286               | 62             | 9.87           | 13     | 295               | 66             | 8.28           |
| 4      | 288               | 63             | 9.77           | 14     | 292               | 67             | 8.14           |
| 5      | 289               | 63             | 9.54           | 15     | 294               | 68             | 8.13           |
| 6      | 292               | 64             | 9.50           | 16     | 286               | 66             | 7.60           |
| 7      | 298               | 65             | 9.54           | 17     | 288               | 65             | 7.47           |
| 8      | 300               | 64             | 9.27           | 18     | 290               | 68             | 7.64           |
| 9      | 293               | 65             | 8.92           | 19     | 293               | 69             | 7.67           |
| 10     | 294               | 66             | 8.85           | 20     | 295               | 70             | 7.67           |

3.3. Biogeography-based Optimization

The Biogeography-based optimization (BBO) is an intelligent optimization algorithm proposed by Dan Simon in 2008 to solve the global optimization problem [7]. The mathematical model of biogeography mainly describes the process of species generation, extinction, and migration [8, 9, 10, 11]. The main theoretical basis is to simulate the mechanism of species migration between various habitats in order to find the global optimal solution. Habitat has a certain habitat suitability index (HSI). High HSI habitats correspond to high quality solutions, and low HSI habitats correspond to poor solutions.

BBO first randomly generates an initial group, and then calculates the fitness of the individual in the group. According to the order of fitness, the individual species count is obtained, and then the individual's migration rate and emigration rate are obtained. The individual migration operator based on the migration rate and the emigration rate and the mutation operator based on the individual counting probability are used to evolve the group. The HSI is improved by the evolution of the group, and then the optimal solution of the problem is obtained [12, 13, 14]. Repeat the process over and over until the termination condition is met. Because BBO adopts the individual immigration operator based on immigration rate and migration rate, it makes the variable information of excellent individuals be shared in the migration process, ensuring the convergence of the group. The mutation operator based on the counting probability can have a great possibility to change the worst or the best individual of the existing group, and then produce more excellent individuals. In this paper, the BBO algorithm is used to the multi-objective optimization [15, 16, 17]. The relationship between the BBO algorithm and the drilling rig parameters is like a Table 2.

Table 2. The corresponding relationship between the BBO and the optimization of drilling parameters

| BBO parameters                      | Drilling Parameters of Drill                        |
|-------------------------------------|-----------------------------------------------------|
| Population migration mutation process | Optimization of drilling Parameters                |
| Habitat H                           | F possible solutions                                |
| Suitability index vector SIV         | Drilling Parameters of Drill                        |
| Habitat index variable              | W, N                                               |
| Habitat suitability index HSI       | Optimize the objective function F                  |
| Highest HSI                         | Optimal solution of F                               |

BBO mainly through the above migration operator and mutation operator to improve the population, and its flow chart is shown in Figure 1.
4. Optimized Result and Analysis

4.1. Test Results of the Algorithm
In order to test the effectiveness of the algorithm, a more complex Ackley function is used to test the algorithm, and the convergence of the algorithm is obtained. For this function, the BBO algorithm is used for iterative calculation. The number of iterations of the set algorithm is 500 times, and the result is Figure 2. The algorithm will be converged when the algorithm has been 200 times, thus proving the effectiveness and availability of the algorithm.

4.2. Optimization Results of Drilling Parameters

The BBO optimization algorithm and the combination type (5) are used to optimize the drilling parameters. The number of habitat is $S=20$, the number of evolution $N=200$, the maximum number of species $n=2$, the maximum value of immigration rate $I=1$, the maximum value of the emigration rate $E=1$.

Figure 1. BBO algorithm flow chart

![Figure 1. BBO algorithm flow chart](image1)

Figure 2. BBO algorithm fitness curve

![Figure 2. BBO algorithm fitness curve](image2)

Figure 3. Optimization results

![Figure 3. Optimization results](image3)
E=1 , and the maximum variation rate $m_{\text{max}}=0.05$. Optimization results are shown in Figure 3. It can be seen that the curve is smooth and the distribution of the optimal solution is uniform.

### Table 3. Optimization of the Four Solutions

| Number | Design Variable | Objective Value of Function |
|--------|-----------------|-----------------------------|
|        | $W$/kN          | $N$/r·min⁻¹                 |
| 1      | 302.4           | 180                         |
| 2      | 269.7           | 70.7                        |
| 3      | 368.7           | 38.4                        |
| 4      | 363.7           | 118.6                       |
|        | $V$/m·h⁻¹       | $t$/h                       |
| 1      | 5.91            | 6.83                        |
| 2      | 2.88            | 18.41                       |
| 3      | 2.63            | 19.13                       |
| 4      | 6.82            | 4.31                        |

5. Conclusion

This paper proves the correctness and effectiveness of the proposed biogeographic optimization algorithm and multi-objective optimization model of drilling parameters. The performance improvement of a sub goal often results in the deterioration of the performance of another sub target.

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