Optimum Design of the Parameters of the Shearer Drum

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Abstract: To design high quality and efficiency cutting drum, taking the drum speed, traction speed, pick line distance and helix angle as design variables, reducing the cutting energy consumption and load fluctuation of the shearer drum as the objective function, this paper establishes optimization design model of working parameters of shearer drum, and takes the MG300/700-WDK shearer as an example, carries out the optimization analysis and obtains the best working parameters. The feasibility and superiority of the optimized drum is verified by LS-DYNA simulation and experiment, providing theoretical basis for the improvement and optimization of the cutting drum structure.

1. Introduction

The drum shearer is widely used in fully mechanized coal mining face due to its advantages such as large coal breaking capacity and strong adaptability. As the main working part of the drum type shearer, the structure and performance of the shearer drum have a decisive influence on the overall structure of the shearer, the performance of the machine and the conditions of adaptation. For a long time, from the angle of different optimization targets, a lot of scholars, have done a lot of research on the optimization of the working parameters such as the cutting distance [1] of the shearer drum, the roller speed and the traction speed [2], the diameter of the drum and the number of the head number of the blade[3], but the working parameters of the cutting teeth are not optimized in the process of cutting the cutting teeth in the process of cutting the roller. In this paper, based on the cutting mechanism of the shearer drum, the optimization design model of the working parameters of the shearer drum is set up by taking the cutting ratio of the cutting ratio of the shearer drum to the energy consumption and the load fluctuation coefficient as the objective function. The optimization design model of the working parameters of the shearer drum is set up, and the MG300/700-WDK shearer is taken as an example. Through optimization analysis, the best working parameters were obtained, and the feasibility and superiority of the optimized drum were verified by LS-DYNA simulation and experiment.
2. Optimization of Drum Structure Parameters

The performance index of the shearer drum are commonly used in cutting specific energy consumption, load fluctuation, and the rate of lump coal loading performance. Considering the comprehensive consideration, the weight of cut ratio is used as the objective function to optimize the ratio of energy consumption and load fluctuation coefficient.

2.1 Selection of design variables

The working parameters of the shearer, such as the speed of traction $\nu$, the rotational speed of the drum $n$, the spiral rise angle of the tooth tip of the blade $\beta$ and the intercept of the cutting tooth $t$, are the important factors that affect the productivity of the shearer, the fluctuation of the load and the energy consumption of the cutting ratio.

Therefore, the design variables are taken as Equation (1).

$$X = [X_1, X_2, X_3, X_4] = [\nu, n, \beta, t]^T.$$  

2.2 The determination of the objective function

The performance index of the shearer drum are commonly used in cutting specific energy consumption, load fluctuation, and the rate of lump coal loading performance. The vibration of the shearer can be caused by the fluctuation of the roller load, the cutting working condition is worsened and the wear and destruction of the cutting teeth and other parts will be accelerated, so the shearer can not work or even affect the life of the shearer. At the same time, cutting energy consumption is an important economic indicator of shearers, which directly reflects the cutting efficiency of shearers. Therefore, taking the weighted combination of specific energy consumption and load fluctuation as the objective function [4], the process is as follows.

2.2.1 Cutting ratio energy consumption model

The cutting ratio energy consumption is the energy consumed by the cutting unit volume coal rock. The lower cutting ratio energy consumption not only reflects the energy consumption of the cutting unit volume coal, but also reflects the large cutting lump coal rate to some extent. It improves the economic benefit from two aspects of reducing consumption and increasing output, and the calculation formula of cutting ratio energy consumption is Equation (2).

$$H_w = \frac{P_j}{60BH\nu} \times 10^6, KW \ h/m^3. \quad (2)$$

In the formula, $B$ - Cutting depth of shearer drum, mm; $H$ - Mining height of Shearer, mm; $\nu$ - Tow speed of Shearer, m/min; $P_j$ - Drum cutting power consumption, kW;

The calculation formula is Equation (3).

$$P_j = \frac{M \cdot n}{9550} \quad (3)$$

In the formula, $M$ — Cutting mean torque, N \cdot m; $n$ - Drum speed, r/min
2.2.2 Model of roller load fluctuation coefficient

The load fluctuation of the roller mainly comes from the inhomogeneity of the coal and rock, the irrational arrangement of the cutting teeth, and the change of the number of the cutting teeth involved in the cutting during the cutting process of the roller. The load fluctuation coefficient of the roller is the three direction force that the roller is subjected to, namely, the working drag resistance of the roller \( F_x \) at any time, the lateral resistance of the roller \( F_y \) and the vertical drag of the drum \( F_z \) and the torque around the three axis [5]. The torque is mainly derived from the action of three directions. Therefore, the load fluctuation of the three direction force of the roller is studied here. The load fluctuation coefficient of the three direction force can be expressed as Equation (4).

\[
\delta = \frac{1}{F} \sqrt{\int_0^{2\pi} (F - \bar{F})^2 \, d\varphi} 
\]  

(4)

And the wave coefficient of the equivalent load \( \delta_F \) is Equation (5).

\[
\delta_F = c_1 \delta_x + c_2 \delta_y + c_3 \delta_z
\]  

(5)

In the formula, \( c_1, c_2, c_3 \) the weighting factor of \( \delta_x, \delta_y, \delta_z \), respectively, and the addition is equal to 1, that is \( c_1 + c_2 + c_3 = 1 \). Because of the load fluctuation of the feed force and lateral force, the influence of the load fluctuates greatly, so take it here. \( c_1 = c_2 = 0.4, c_3 = 0.2 \).

2.2.3 The establishment of the objective function

According to the above cutting ratio energy consumption and load fluctuation model, we use the weighting method to transform the multiple models to the final optimization solution model, shown in Equation (6).

\[
\min H(X) = W_1 H_1' + W_2 H_2'
\]  

(6)

In the formula, \( H_1' \)-The objective function of the cutting ratio energy consumption; \( H_2' \)-The objective function of the load fluctuation of the drum; \( W_1', W_2' \)-Weighting factor of drum cutting ratio energy consumption and equivalent load fluctuation. Consider the factors that affect it and choose here \( W_1' = 0.6, W_2' = 0.4 \).

2.3 Solving target and constraint condition

1) Constraint of blade helix angle \( \beta \)

Experience shows that the fluctuation range of the helical angle of the drum blade is 8~30 degrees, so there are constraints.

\[
g_1 = \beta - 8 > 0 \quad g_2 = 30 - \beta < 0
\]

2) Constraint of roller speed \( n \)

Drum rotation speed is lower in large diameter drum, higher in small diameter drum, general roller speed range is, so there are constraints.
3) Constraint of drum traction speed $v_q$

The traction speed range of shearers is usually 1~7 m/min, the largest is also within 15 m/min, so there are constraints.

$$g_5 = 1 - v_q < 0 ; g_6 = v_q - 15 < 0$$

4) In order to prevent large coal from being stuck between two adjacent leaves, so there are constraints.

$$g_7 = 1 - \frac{2S}{N(D_y - D_g)} < 0 ; g_8 = \frac{2S}{N(D_y - D_g)} - 4.4 < 0$$

5) Constraint of Drum blade total package angle

The total angle of the spiral blade needs more than 420 degrees, that is,

$$\frac{360B_y N}{\pi D_y \tan \varphi} > 420$$

Therefore, there are the following constraints.

$$g_9 = 420 - \frac{360B_y N}{\pi D_y \tan \varphi} < 0$$

6) Prevention of two times breaking of coal

The high speed makes the coal flow throw along the radial direction of the drum, which makes it difficult to discharge and break for two times, so the speed should be less than a certain value, that is, there is inequality [6].

$$n \leq n_1'$$

Among them, $n_1'$ is the critical speed that does not break two times, and when there is $D_c = 500 \sim 600mm , n_1' = 80 \sim 120r/min ;$ when there is $D_c = 1800 \sim 2000mm , n_1' = 30 \sim 40r/min .$

$$g_{10} = n - n_1' \leq 0$$

7) Constraint of Cutting tooth strength

When the stress at the dangerous interface of the pick and the external force exceeds the maximum stress, the failure of the pick will happen. To prevent damage, the maximum stress at the dangerous section of pick is less than the allowable stress of pick, That is

$$\sigma < [\sigma]$$

In the formula, $[\sigma] \quad -$ Allowable stress of a cutting tooth, MPa, Material commonly used for cutting teeth, is $35\text{CrMnSiA}$, so there is $[\sigma] = 900 .

$$g_{11} = \sigma - 900 < 0$$

8) Speed constraint of tooth tip line
The oversize tooth tip speed is not only easy to produce sparks and large amounts of dust, but also shortens the service life of the teeth. In general, the line speed range of the tooth tip is 3 to 5 m/s, that is

$$3.0 \leq \frac{n}{60} \pi D_s 10^{-3} \leq 5.0$$

Collates constraints

$$g_{i2} = 3 - \frac{n}{60} \pi D_s 10^{-3} \leq 0 \quad ; \quad g_{i3} = \frac{n}{60} \pi D_s 10^{-3} - 5 \leq 0$$

9) Constraint of Shearer's traction power $t$ [7]

In order for the drum to work normally, the power of the shearer's resistance $P_n$ should be less than its traction power $P_q$, that is

$$P_q > P_n$$

10) Constraint of coal loading [8]

$$Q_z > Q_i$$

Among them, $Q_z$ - theoretical loading of a drum with an end plate, m$^3$/min; $Q_i$ - the amount of coal falling in the roller, that is

$$g_{i5} = Q_i - Q_z < 0$$

11) Constraint of Cutting power

In order to ensure the normal work of the drum, the maximum cutting resistance of the drum is less than the driving torque of the drum, that is to say, the cutting power of the single drum is greater than the maximum cutting resistance power, that is

$$P_j < P_i$$

In the formula, $P_i$ — Single drum cutting power, kW; $P_j$ — Single drum cutting resistance power, kW.

That is

$$g_{i6} = P_j - P_i < 0$$

The above constraints are summed up.

$$g_x \leq 0 (i = 1, 2, \cdots, 16)$$

2.4 Objective function calculation

From the characteristics of mathematical models, we can see that the optimization problem is multiple inequality constraints. It can be optimized by the optimization genetic algorithm.

2.5 Example optimization results

Taking MG300/700-WDK shearer as an example, this paper aims to reduce the cutting specific energy consumption and load fluctuation coefficient as the goal.

The mining height of this type shearer is 1800–3000 mm, Inclination angle of working face
\( \alpha \leq 35^\circ \), Neutral coal, Traction power \( P_q = 100 \) kW, Single drum cutting power \( P_l = 300 \) kW, roller diameter \( D_c = 1600 \) mm, Cutting depth of cylinder \( B = 630 \) mm, Numbers of head of leaf are 3. The type of cutting tooth arrangement is sequential arrangement, Pick \( l = 195 \) mm, \( l_l = 100 \) mm.

By optimizing the solution, we can get the relevant parameters of the optimized drum and the ordinary drum, shown in Table 1.

Table 1 The solution parameters.

<table>
<thead>
<tr>
<th></th>
<th>objective function</th>
<th>Specific energy consumption (kWh/m(^3))</th>
<th>Load fluctuation coefficient</th>
<th>Speed (r/min)</th>
<th>Feed speed (m/min)</th>
<th>Helix angle of tooth tip((^\circ))</th>
<th>Transversal distance(mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ordinary roller</td>
<td>2.398</td>
<td>3.965</td>
<td>0.0485</td>
<td>47.00</td>
<td>6.40</td>
<td>14.10</td>
<td>67.24</td>
</tr>
<tr>
<td>Optimization ratio</td>
<td>2.250</td>
<td>3.718</td>
<td>0.0473</td>
<td>47.46</td>
<td>7.47</td>
<td>13.63</td>
<td>64.60</td>
</tr>
<tr>
<td>ratio</td>
<td>0.9381</td>
<td>0.9378</td>
<td>0.9752</td>
<td>1.010</td>
<td>1.166</td>
<td>0.967</td>
<td>0.986</td>
</tr>
</tbody>
</table>

3. Result Verification and Analysis

Through the existing cylinder cutting experiment, the force parameters of the actual roller cutting coal rock are obtained, and then the simulation model of LS-DYNA is made through the roller model used in the experiment. The simulation is simulated and the force is compared with the actual cylinder to verify the correctness of the simulation. Finally, the cutting performance of the cylinder is optimized by simulation.

3.1 Experimental verification simulation

With the same structural parameters, a group of experimental parameters are obtained and a set of parameters are obtained through the HJC model, and the experimental parameters and simulation parameters are compared to verify the correctness of the simulation. The main parameters of drum simulation and experiment are: the diameter of the drum is 560 mm, the cutting depth is 400 mm, the speed is 80 r/min, and the feed speed is 1.135 m/min.

Experimental coal and rock parameters are shown in Table 2.

Table 2 Properties of coal and rock samples.

<table>
<thead>
<tr>
<th>Material</th>
<th>Density(kg/m(^3))</th>
<th>Modulus of elasticity(GPa)</th>
<th>Poisson ratio</th>
<th>compressive strength(MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>core sample</td>
<td>1511.60</td>
<td>0.570</td>
<td>0.36</td>
<td>2.49</td>
</tr>
</tbody>
</table>

The parameters of the simulation of coal and rock are shown in Table 3.

Table 3 HJC constitutive model parameters.

<table>
<thead>
<tr>
<th>( \rho ) (kg/m(^3))</th>
<th>( G ) (MPa)</th>
<th>( f_c ) (MPa)</th>
<th>( A )</th>
<th>( B )</th>
<th>( C )</th>
<th>( N )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1521</td>
<td>208.9</td>
<td>2.49</td>
<td>0.796</td>
<td>1.508</td>
<td>0.005</td>
<td>0.418</td>
</tr>
<tr>
<td>( S_{\text{max}} )</td>
<td>( D_1 )</td>
<td>( D_2 )</td>
<td>( \varepsilon_{\text{fmin}} )</td>
<td>( \sigma_c ) (MPa)</td>
<td>( P_{\text{crush}} ) (MPa)</td>
<td>( \mu_{\text{crush}} )</td>
</tr>
<tr>
<td>7.0</td>
<td>0.041</td>
<td>1.0</td>
<td>0.01</td>
<td>0.983</td>
<td>0.830</td>
<td>0.0012</td>
</tr>
<tr>
<td>( P_{\text{lock}} ) (MPa)</td>
<td>( \mu_{\text{lock}} )</td>
<td>( K_1 ) (MPa)</td>
<td>( K_2 ) (MPa)</td>
<td>( K_3 ) (MPa)</td>
<td>( \varepsilon_0 ) (s(^{-1}))</td>
<td>( FS )</td>
</tr>
<tr>
<td>81.3</td>
<td>0.099</td>
<td>85000</td>
<td>171500</td>
<td>208000</td>
<td>60</td>
<td>1</td>
</tr>
</tbody>
</table>
The comparison of the cutting torque between the experimental and simulation results is shown in Figure 1.

![Cutting torque comparison](image1)

(a) Cutting torque of experimental drum  
(b) Cutting torque of Simulation drum  

Figure 1 Torque Comparison of Drum Cutting.

Compared with the changing trend of the torque, the cutting torque in the experiment and simulation increases with the increase of the cutting depth, and tends to be stable after the half of the roller is cut into the coal and rock. In comparison experiment and Simulation of torque under steady state, we know that the average cutting resistance is 331Nm, and the cutting torque in the simulation is 312Nm. The gap between the two is smaller and is within the allowable range of error. Simulation is feasible.

The comparison of feed resistance between experiment and simulation is shown in Figure 2.

![Feed resistance comparison](image2)

(a) Feed resistance of experimental drum cutting  
(b) Feed resistance of Simulation drum cutting  

Figure 2 Feed Resistance Comparison of Drum Cutting

As shown in Figure 2, the experimental and simulation trends are the same, and the feed resistance experiment under dynamic equilibrium is 2380 N, and the simulation is 2210 N. The simulation is credible in the range of error allowed.

The comparison of coal and rock cutting state between experiment and simulation is shown in Figure 3.

From Figure 3, it is known that the coal rock fragmentation of the experimental roller cutting coal rock is similar to the coal rock fracture in simulation: there are intercepting grooves between adjacent intercepting lines, and there are more regular cut teeth scratches on the approximate plane.
of the coal wall of the end disc cutting teeth. Above all, the HJC model of coal and rock is feasible for drum simulation to verify the performance of drum.

(a) The effect diagram of the stable cutting  (b) The effect diagram of the stable cutting of the experimental drum of the simulation drum

Figure 3 Picture comparison of drum steady cutting.

3.2 Optimization of drum performance verification

In order to verify the optimization of the cutting ratio of the cutting ratio and the load fluctuation coefficient of the cylinder, the HJC coal rock simulation model, which is verified by the ordinary roller and the optimized roller cutting, is respectively used to obtain the force curve of the cutting torque and the feed resistance, and the comparison is made between the two simulated cutting ratio and the two groups of simulation. The cutting torque of cutting torque experiment and simulation is multiplied by the speed of the drum, and the cutting specific energy consumption is compared with that of the shearer, shown in Figure 4.

Figure 4 Specific energy consumption of drum stability cutting.

According to Figure 4, we can see that the energy consumption of the optimized roller cutting is smaller than that of the ordinary roller, and the ratio of the cutting energy consumption of the optimized roller to the ordinary roller is 0.874.

The load fluctuation part is mainly taken to optimize the load fluctuation of the cylinder and the ordinary roller in the direction of the three axis, and turn it into the weighted load fluctuation coefficient to view the load of the two cylinder in the steady state of the three axis direction and
download the wave shown in Figure 5.

(a) Comparison of axial load fluctuation in X

(b) Comparison of axial load fluctuation in Y

(c) Comparison of axial load fluctuation in Z

Figure 5 Load fluctuation coefficient of drum cutting
According to Figure 5, it is known that the load fluctuation of the optimized roller in the direction of three axes is similar to that of the ordinary roller. It is a quantitative view of the load fluctuation of the two kinds of rollers, and the load fluctuation coefficients obtained from the simulation of the two kinds of cylinder cutting simulation are shown in Table 4.

Table 4 Drum load fluctuation coefficient table.

<table>
<thead>
<tr>
<th></th>
<th>X axis</th>
<th>Y axis</th>
<th>Z axis</th>
<th>Weighted value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ordinary roller</td>
<td>4.355</td>
<td>0.309</td>
<td>0.209</td>
<td>1.907</td>
</tr>
<tr>
<td>Optimization roller</td>
<td>4.116</td>
<td>0.291</td>
<td>0.157</td>
<td>1.825</td>
</tr>
<tr>
<td>ratio</td>
<td>0.945</td>
<td>0.941</td>
<td>0.751</td>
<td>0.957</td>
</tr>
</tbody>
</table>

According to the above simulation research, the optimized drum has a lower cutting ratio energy consumption and a certain improvement in performance compared with the ordinary drum in the case of similar load fluctuation with the ordinary drum.

4. Conclusion

By analyzing the single tooth cutting model of the shearer drum, using the existing cutting force formula and combining the optimal formula of the single tooth cutting angle, the force and angle relation of the cutting teeth in the single tooth cutting are calculated, and the basis is laid for the calculation of the target function.

This paper optimizes the feed speed, roller speed, spiral rise angle and optimal intercept of the shearer drum cutting process, and optimizes the shearer drum under the given work and mine by the optimization code, taking the target function of the cutting of the shearer drum than the energy consumption and the load fluctuation. Through the experiment and simulation, the correctness of the simulation is verified first, and then the feasibility and superiority of the optimized drum are verified through the comparison of the simulation force between the ordinary roller and the optimized drum, which provides the theoretical basis for the improvement and optimization of the cutting drum structure.

References