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The Optimization of Jaw Crusher with Complex Motion Aimed at Reducing Stroke Feature Value of Its Outlet

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***Abstract*— The stroke feature value of jaw crusher outlet is an important performance parameter. Usually, the smaller the stroke feature value is, the milder the wear of the jaw liner is, and the higher the efficiency of crusher is. Firstly, the seal vector equation of jaw crusher is built to get mathematical expression of the stroke feature value. Taking the PEF600x900 jaw crusher as an example and choosing the stroke feature value of outlet as an objective function, the optimization model is built. Then based on the model the component sizes are obtained by random direction search method with MATLAB software. Finally the correctness of theoretical calculation is validated by the simulation with ADAMS. The result show that the stroke feature value of outlet decrease by 30.02%. Meanwhile the component sizes reduce greatly, the minimum locking angle diminish a little and the strokes of the swing jaw outlet in both horizon and vertical direction go down. Therefore, the wear of jaw crusher liner declines greatly, the jaw crusher efficiency is improved, and the granularity of product becomes more uniform.**

***Index Terms*— ADAMS, Jaw Crusher, MATLAB, Optimization, Stroke Feature Value.**

I. Introduction

The complex motion jaw crusher are widely used in department of mine, metallurgy, chemical, building, power, ceramic and cement for its advantages that are simple structure, reliability and easy maintenance etc. At present, the research on crusher is focused on the performance optimization of the crusher. Rusiń ski E, Moczko et al. studied on the failure of the crusher crank, when the crank subjected to heavy dynamic load, by adopting numerical method and experimental method[1]. Legendre D simulate the process of the single particle by EDEM software and optimize the efficiency of energy by genetic algorithm[2]. Inha R S optimize the parameter of crusher to reduce the failure rate by neural network algorithm[3]. BP Numbi et al. optimize the energy efficiency by optimizing the control model[4].

The stroke feature value of outlet is the ratio of vertical displacement to horizontal displacement of swing jaw. The stroke feature value of outlet has a great influence on the wear of the crusher. When the stroke feature value is large, the wear of liner is heavy. The horizontal displacement of swing jaw crush the aggregates and the vertical displacement push the crushed the aggregates out of the crusher chamber from the outlet. The consumption of crusher is high and the wear of liner is heavy when the vertical displacement is long. Therefore, the stroke feature value is an important factor for the performance of crusher.

At present, wear of liner is the main problem for jaw crusher, which is more obvious for crushing tungsten ore. Reducing the vertical stroke not only reduce the steel consumption, but also decrease the proportion of over-crush product and diminish the nonproductive consumption that, when the horizon displacement is fixed. In this paper, the mathematical model of PEF600x900 jaw crusher is built by seal vector method. The optimal design scheme is worked out by the program in which the stroke feature value of outlet is selected as objective function, 6 components size are chosen as independent variable, the constraint equations are built that based on the crank existence, locking angle, transmission angle, swing angle, outlet stroke and components size. After optimization, the production costs is reduced for the component sizes deducing, the liner wear of the jaw crusher reduce because the stroke feature value of the outlet deduce .

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II. Methodology

A. Kinematic Analysis

The working principle of complex motion jaw crusher can be simplified as crank-rocker mechanism. As shown in Figure1, The size of each parts is shown in Table1.

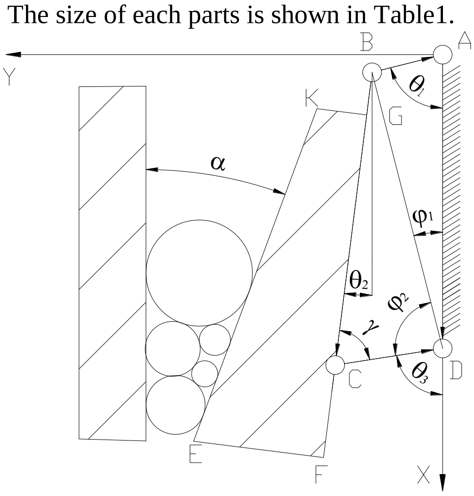


Figure1 The sketch of Complex Motion Jaw Crusher.

Table1 The size of parts.

Parts	AB	BC	CD	AD	BF	BG	KG	EF
Size	l_1	l_2	l_3	l_4	l_5	l_6	l_7	l_8

Rectangular coordinate system whose the origin base on the center of the crank rotation is built. The left direction in horizon is defined as increasing direction of Y axis and the down direction in vertical is defined as increasing direction of X axis. The complex motion jaw crusher is four-bar mechanism consisted of close loop kinematic chain. Therefore, the seal vector equation is obtained, as follow

$$\vec{l_1}+\vec{l_4}=\vec{l_2}+\vec{l_3} \tag{1}$$

The equation(2) is given by projecting the vector of equation(1).

$$\begin{cases} l_1\cos\theta_1+l_4=l_2\cos\theta_2+l_3\cos\theta_3 \\ l_1\sin\theta_1+l_4=l_2\sin\theta_2+l_3\sin\theta_3 \end{cases} \tag{2}$$

However, it's difficult to solve the equation(2) for its nonlinearity. Therefore, the geometric method is applied to solve the equation(2). Because l_1, l_2, l_3, l_4 is given, the equation(3) based on the geometric relationship can be obtained.

$$\begin{cases} l_{BD}=\sqrt{l_1^2+l_4^2-2l_1l_4\cos\theta_1} \\ \varphi_1=\arccos(\dfrac{l_4^2+l_{BD}^2-l_1^2}{2l_4l_{BD}}) \\ \varphi_2=\arccos(\dfrac{l_3^2+l_{BD}^2-l_2^2}{2l_3l_{BD}}) \\ \gamma=\arccos(\dfrac{l_2^2+l_3^2-l_{BD}^2}{2l_2l_3}) \\ \theta_2=\arcsin(\dfrac{l_3\sin\theta_3-l_1\sin\theta_1}{l_2}) \\ \theta_3=\pi-\varphi_1-\varphi_1 \end{cases} \tag{3}$$

The coordinate of point E and point K can be obtained based on vector method. As follow:

$$\begin{cases} X_E=l_1\cos\theta_1+l_2\cos\theta_2+l_8\sin\theta_2 \\ Y_E=l_1\sin\theta_1+l_2\sin\theta_2+l_8\cos\theta_2 \\ X_K=l_1\cos\theta_1+l_6\cos\theta_6+l_7\sin\theta_2 \\ Y_K=l_1\sin\theta_1+l_6\sin\theta_6+l_7\cos\theta_2 \end{cases} \tag{4}$$

When θ_1 is given, l_{BD}, φ_1, φ_2, γ, θ_2, θ_3, X_E, Y_E can be obtained by the equation(3). If the stroke of point E is S_x in horizon and in vertical is S_y, then

$$\begin{cases} S_x=X_{E\max}-X_{E\min} \\ S_y=Y_{E\max}-Y_{E\min} \end{cases} \tag{5}$$

The stroke feature value of outlet is point E.

$$M_E=\frac{S_x}{S_y} \tag{6}$$

B. Establishment of Optimized Mathematical Model

The stoke value of outlet is an important parameter for jaw crusher, because it affect the performance of crusher. If the stroke value become smaller, the wear of crusher liner reduce a lot, the life of liner become longer, the product granularity become more stable and the consumption of energy decrease greatly. So the stroke value is chosen as the objective function, that is

$$f(x)=\frac{S_x}{S_y} \tag{7}$$

The variables (l_1, l_2, l_3, l_4, l_5, l_8) in Table1 are chosen as independent variables because they influence the stroke feature value of outlet directly. Then the variable set is

$$X=[l_1,l_2,l_3,l_4,l_5,l_8]^T=[x_1,x_2,x_3,x_4,x_5,x_6]^T \tag{8}$$

The value of independent variable should be got in a suitable interval. If the range is too long, the parameter calculated is not so well. If the range is too short, it's difficult to look for feasible initial point and the time of calculating is long. Therefore, the constraint condition based on the theory and engineering experience is listed as follow.

- Boundary constraints condition of independent variable

Each independent variable should be set constraint boundary to ensure that the optimization run smoothly. The boundary of independent variables can be obtained, according to the component sizes of similar series jaw crusher.

- The existence condition of a crank

There are two conditions to need to satisfy, if the crank exist in four-bar mechanism. One is that either frame link or frame is shortest in the four-bar mechanism, the other is that the sum of the shortest link and the longest link is not more than the sum of the others.

- The locking angle constraint condition

The locking angle is the angle between fixed jaw and swing jaw, it has a great influence on the performance of crusher. The locking angle should be chosen from the suitable interval to make the aggregates no-sliding with the liner in the crusher chamber. At present, the range of the locking angle is obtained by solving the balance equation based on the balance of friction and extrusion force. When the locking angle is less than the critical value, the aggregates won't be pushed out of the crush chamber from feeding inlet, during the jaw crusher working. If the locking angle more than critical value, the aggregates is easily pushed out of the chamber from the feeding inlet, that lead to the wear of the crusher liner is heavy, meanwhile the efficiency of jaw crusher become lower. So the locking angle should be constrained in a suitable interval.

- The transmission angle constraint condition

The complex motion jaw crusher is a concrete application of four-bar mechanism, so the transmission angle decide the efficiency of the jaw crusher. If the transmission angle is small, the efficiency of jaw crusher will be poor. So the transmission angle should be constrained to ensure the efficiency of crusher.

- The swing angle constraint condition of toggle plate

The toggle plate and frame, swing jaw is connected by high pair and there is heavily wear in high pair for the sliding friction. The life of the crusher will be shorten greatly for wear, meanwhile the swing angle is larger and the wear is heavier. Therefore, the swing angle of toggle plate should be constrained to reduce the friction.

- The stroke constraint of outlet in horizon

The horizon stroke increasing not only affect the production capacity, but also influence the stability of the production granularity, even more, the life of jaw crusher will be shorten for the over compressing. So the horizon stroke of outlet should be constrained to meet the need of the performance.

The equation(9) based on the constraint conditions is obtained.

$$\begin{cases} x_{\min} \le x_i \le x_{\max}, \quad (i=1,2\cdots 6) \\ x_1 \le x_2 \\ x_1 \le x_3 \\ x_1 \le x_4 \\ x_1 + x_2 \le x_3 + x_4 \\ x_1 + x_3 \le x_2 + x_4 \\ x_1 + x_4 \le x_2 + x_3 \\ 18^\circ \le \alpha \le 35^\circ \\ 45^\circ \le \gamma \le 55^\circ \\ \Delta\theta_3 \le 10^\circ \\ 17 \le S_x \le 30 \end{cases} \quad (9)$$

Among them,

$$x_{\min} = [5,800,250,800,1300,250]^{\mathrm{T}},$$

$$x_{\max} = [25,1400,550,1300,1800,750]^{\mathrm{T}},$$

$$\alpha = \arctan\left(\frac{Y_E - Y_K}{X_E - X_K}\right), \gamma = \arccos\left(\frac{l_2^2 + l_3^2 - l_{BD}^2}{2 l_2 l_3}\right),$$

$$\Delta\theta_3 = \Delta\theta_{3\max} - \Delta\theta_{3\min}, S_x = x_{E\max} - x_{E\min}$$

The equation(7) is chosen as design independent variable, the equation(8) is regarded as objective function, the equation(9) is constraint equation to optimize the jaw crusher.

C. Optimal Design

The random direction search method, the complex method and the internal penalty function method is the most common method in the engineering. In this paper, the random direction search method is adopted to optimize the jaw crusher, because it's reliability and convenient for the complex calculation of nonlinear equation consisted of the objective function and constraint equation. The convergence precision of algorithm is set to be $\xi = 0.1$ to reduce the computer-time and meet the engineer demands.

The random direction search method is a simple method to get optimal solution. Its basic principle is as follow: a feasible initial point is got in feasible region. The random directions generated by the property of uniform distribution of random numbers are obtained. The direction is chosen as feasible search direction, along which the value of objective function decrease fast, denoted by d . The iteration start from the initial point x^0 and search along the direction d by a step size. If the new point x satisfy the constraint condition and $f(x) < f(x^0)$, an iteration is completed. The initial point x^0 is replaced by the point x, namely, $x^0 \leftarrow x$. The optimal solution is obtained after several iterations by repeating the upon process. The program flow chart is shown in Figure2.

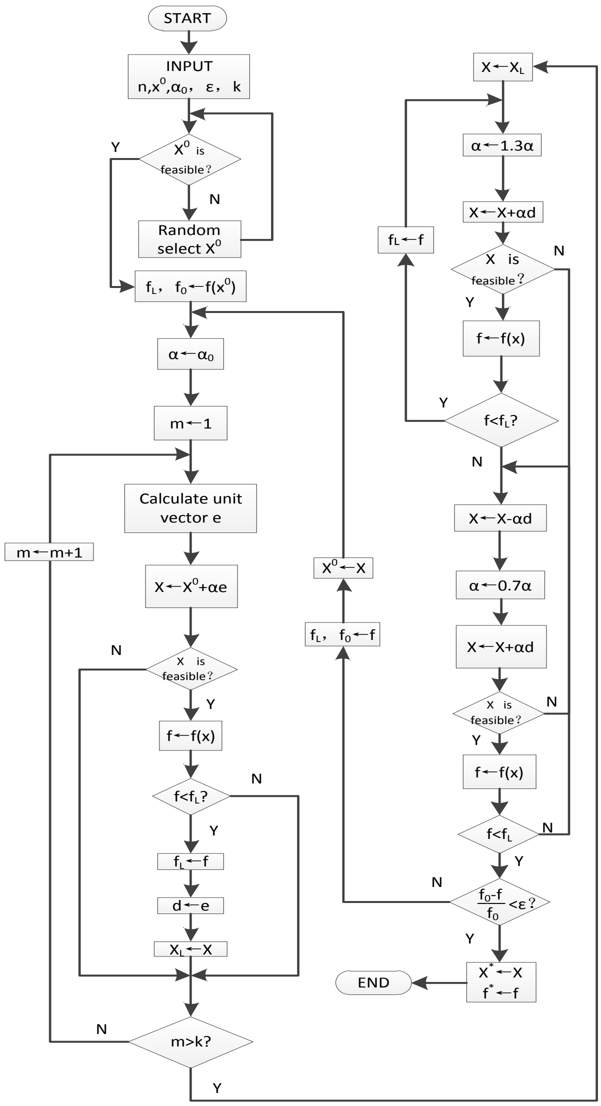


Figure2 Flow process diagram of the random direction exploring method.

III. Result and Discussion

A. The Analysis Result of MATLAB

The parameter of PEF600x900 jaw crusher is optimized by adopting the random direction search method to program with MATLAB software. The optimized result is shown in Table2. The motion trajectory of point E is shown in Figure3(a) before optimization and the after is shown in Figure3(b). The minimum locking angle decrease by 0.64°, and the locking angle law is shown in Figure5(a). The minimum transmission angle is 45°that meet the design demands, the transmission angle law is shown in Figure6(a). The change of the locking angle and the minimum transmission angle not only reduce the possibility of aggregates being pushed out of the crush chamber from the feeding inlet, but also improve the efficiency of jaw crusher. The stroke of point E decrease by 8.8473 in vertical direction, which can reduce the wear of liner greatly. The stroke of point E reduce by 32.1364 in horizon direction, which can improve the stability of the product granularity.

The component size of complex motion jaw crusher is optimized by adopting the random direction search method to program with MATLAB software. The stroke feature value of outlet decrease to 1.6449 from 2.3505, which reduce by 30.02%. The vertical stroke of swing jaw reduce by 35.50% and the horizon stroke deduce by 54.86%, which reduce the wear of liner, improve the efficiency and ensure the stability of the particle size of the product. Meanwhile, the transmission angle of jaw crusher increase a little, which raise the efficiency of crusher. The locking angle decrease, which reduce the possibility of sliding friction between aggregates and crusher liner during the crushing and prolong the life of crusher liner.

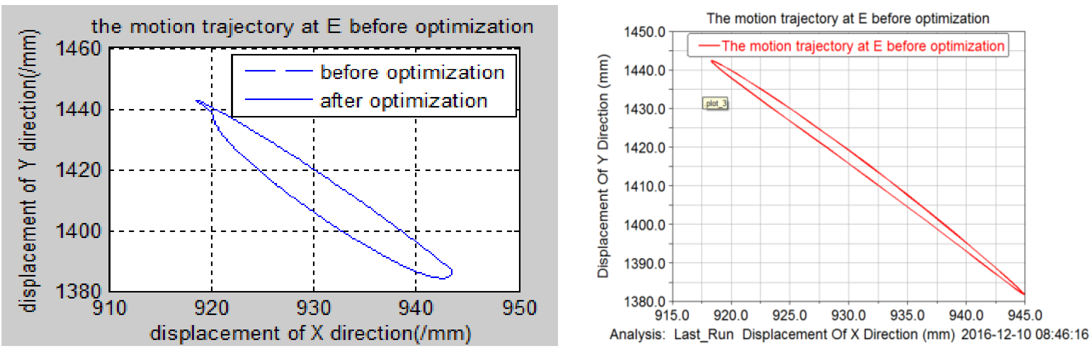
B. The Simulation Result of ADAMS

The virtual prototype model of the crusher is set up in ADAMS with the structural parameters before and after the optimization, and the kinematics simulation is carried out with the model. The virtual prototyping model based on the optimized parameter is established. And the simulation experiment is conducted with ADAMS. It's obtained that the law of the motion trajectory of point E, the locking angle and the transmission angle, before optimization and after. As is shown in Figure3(b), Figure4(b), Figure5(b), Figure6(b). The result of the simulation with ADAMS is consistent with the result of theory analysis with MATLAB, which verify that the optimal result.

The method used for optimizing the PEF600x900 jaw crusher also could be applied to optimize other machines. It is significant to improve the quality of product and shorten the cycle time of product design.

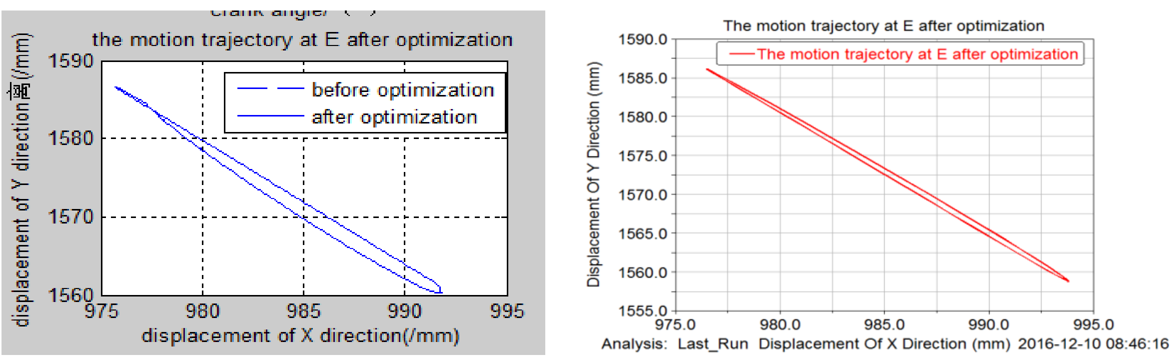
Table2 Comparison of original mechanism and optimized one in parameter.

Optimization variable	x_1 (mm)	x_2 (mm)	x_3 (mm)	x_4 (mm)	x_5 (mm)	x_6 (mm)	M_E	S_x (mm)	S_y (mm)
Before optimization	18	1264	400	1040	1620	490	2.3505	58.5755	24.9203
After optimization	7.1	1087.5	275.4	920.9	1748.8	619.4	1.6530	26.7762	16.1962
After rounding	7	1088	275	921	1749	620	1.6449	26.4391	16.0730



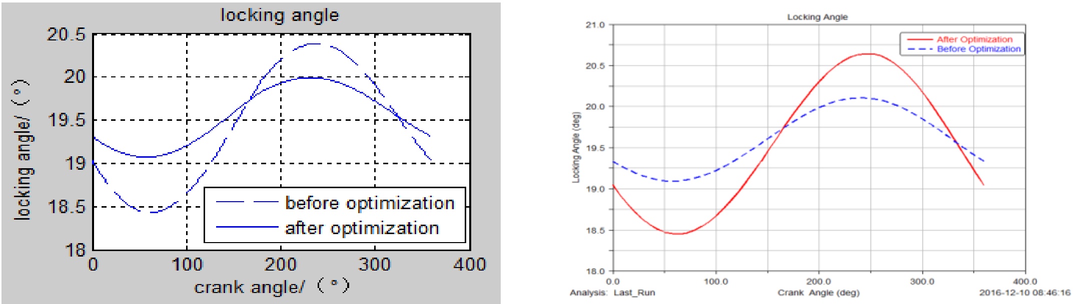
（a）MATLAB analysis results. （b）ADAMS simulation results.

Figure3 The motion trajectory of point E before optimization.



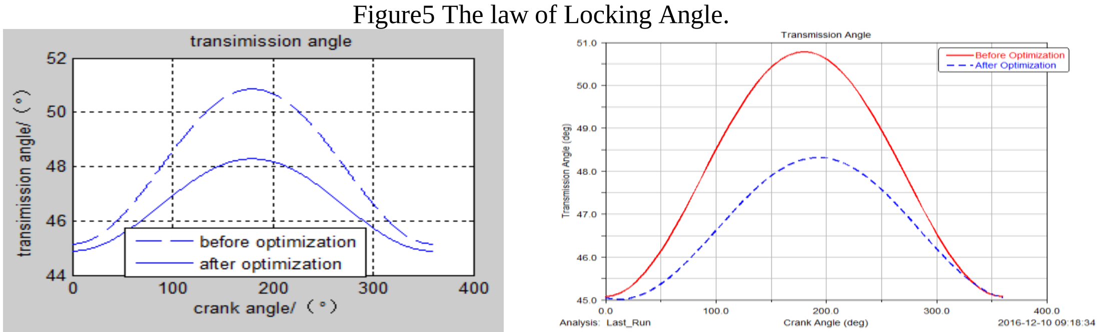
（a）MATLAB analysis results. （b）ADAMS simulation results.

Figure4 The motion trajectory of point E after optimization.



（a）MATLAB analysis results.　　　（b）ADAMS simulation results.

Figure5 The law of Locking Angle.



（a）MATLAB analysis results.　　　（b）ADAMS simulation results.

Figure6 The law of Transmission Angle.

IV. Conclusion

To summarize, this paper choose seal vector method to analyse crusher and build the kinematic equation and the mathematical model for the optimization of stroke feature value of outlet. The component sizes are chosen as independent variable and the stroke feature value is chosen as objective function to write program to optimize the component sizes by random direction exploring method. The result of theory analysis with MATLAB is tested by the simulation with ADAMS.

After optimization, the stroke feature value reduce by 30.2%. The locking angle, the displacement of horizon and vertical displacement reduce a little. The performance of optimized crusher is improved obviously. The components size are shorten, which save the costs and the material. The wear of liner is weaken and the consumption of crusher deduce, meanwhile the granularity of product become stable and prolong the life of crusher.

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