OPTIMIZED DESIGN OF TEA SIEVING MACHINE BASED ON ABC ALGORITHM

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ABSTRACT: *According to the requirements of tea refining and sorting, a tea sieving machine driven by crank slider mechanism is designed. In order to improve the dynamic performance of tea screening machine, considering the requirements of tea screening process, the minimum transmission angle of crank slider mechanism is selected as the design objective function. According to the mechanism dynamics and the tea making process requirements, the mathematical model of multi-dimensional nonlinear constrained optimization problem is established. The program based on ABC algorithm is compiled by MATLAB. The optimization results show that when the crank length is 20mm, the length of connecting rod is 995mm, the crank offset distance is 300mm, the screen face inclination is 1.5 ° and the vibration direction angle is 21.8 °, the machine motion smoothness is improved, the minimum transmission angle increases from 62.7 ° to 71.2 ° and the noise decreases from 76dB to 66dB.*

KEYWORDS: *ABC algorithm, tea sieving machine, optimized design*

1 INTRODUCTION

China is a large tea producing country, with an area of 2.93 million hectares of tea gardens and an annual output of 2.6 million tons of tea, accounting for 60% and 45% of the world respectively, ranking first in the world. More than 10% of the tea is exported every year, with an annual export value of about US $1.6 billion (Deng et al., 2021). China's tea processing has realized continuous and clean production(Liu et al., 2021), and is committed to the optimization design of key tea processing equipment, in order to improve the level of tea processing automation and intelligence, and improve the quality of tea processing(Wang et al., 2020; Xiao, 1999). In order to improve the cleanliness and shape uniformity of tea, tea screening is an important process in the process of tea production (Yang, 1994). Broken tea and tea powder are removed by screening. The reciprocating motion of the screen bed is realized by crank connecting rod mechanism. In the actual production process, the minimum transmission angle of the mechanism affects the smoothness and noise of the motion. When the minimum transmission angle is small, the motion of the sieve bed will be stuck, and the tea is easy to block the sieve hole and improve the tea screening quality (Lou, 2011).

In traditional design, it is difficult to get the ideal minimum transmission angle only through experience. With the application of modern mechanical optimization design and related algorithms, the above optimization problems can be solved by establishing relevant mathematical model and optimization algorithm to get the optimal solution. When applied to the tea screening machine, it can make the screen bed move more smoothly, effectively reduce the phenomenon of tea blocking the screen hole, and improve the screening quality. Artificial bee colony algorithm is an optimization method which imitates the behavior of bees. It is a concrete application of the idea of cluster intelligence. Its main characteristic is that it does not need to know the special information of the problem.

2 ABC ALGORITHM

In order to solve the problem of multivariable function optimization, Karaboga and Akay (2007) proposed artificial bee colony algorithm (ABC). ABC algorithm has been applied to optimization problems in mechanical and civil engineering or electrical engineering (Rao et al., 2009). ABC algorithm is a kind of bionic intelligent method to simulate the behavior of bee colony. Compared with genetic algorithm, particle swarm optimization and other bionic intelligent computing methods, the outstanding advantage of ABC algorithm is to carry out global and local search in each iteration, and can effectively avoid falling into local optimum (Rao et al., 2011).

Unlike genetic algorithm and other swarm intelligence algorithms, role conversion is a unique mechanism of ABC algorithm. Bee colonies work together to find high-quality honey sources by changing the roles of employed bees, scouts and onlookers. In the search and optimization of ABC algorithm, the functions of the 3 kinds of bees are different: employed bees are used to maintain a good solution, scouts are used to increase convergence speed, onlookers are used to enhance the ability to get rid of local optimum(Ozturk et al., 2010).The location of the nectar source is abstracted as a point in the solution space, representing the potential solution of the problem. The nectar source i (i=1,2,…,SN), SN is the number of nectar sources.The quality of the honey source corresponds to the fitness value of the solution fit_i. The initial location of the nectar source is randomly generated in search space according to formula (1).

$$x_{ij} = l_j + \delta * (u_j - l_j) \qquad (1)$$

where j ∈{1, 2,…, D}, D is dimension of the problem, l j and u j are the lower and upper bound of the parameter xi j and δ is a random number inthe range [0, 1), i = 1 . . . , SP/2.

Each employed bee produce a new solution according to formula (2).

$$v_{ij} = x_{ij} + \varphi_i * (x_{ij} - x_{kj}) \qquad (2)$$

where φ_i is random number in range [1,1),k∈{1, 2,…,SP/2}, k≠i is randomly chosen index, φ_i is randomly chosen real number in range [0,1) andj = 1, 2,…,D.

When new nectar source vi=[v1,v2,…,vd], The fitness is better than that of Xi.

Greedy election is adopted. The alternative method is vi instead of xi, Otherwise, keep xi. All employed bees complete operation (2), fly to the information exchange area to share the nectar source information. An onlooker bee chooses a nectar source depending on the probability value associated, pi, calculated by formula (3), and the employed bees exchange their information with the onlookers in this way.

$$p_i = fit_i / \sum_{n=1}^{SN} fit_n \qquad (3)$$

Where fit_i is the fitness value of the solution i evaluated by its employed bee, which is

Proportional to the nectar amount of the food source in the position i and SN is the number of food sources which is equal to the number of employed bees. The scout bee chooses to employed bee by roulette, that is, to produce a uniformly distributed random number r at (0,1). If the pi is greater than r, the scout bee produces a new honey source around the honey source I, and identifies the reserved nectar source by the same greedy selection method as the employed bee.

During search, if the nectar source xi is searched by trial iterations,The threshold limitis met, and no better nectar source is found. The nectar source is xi will beabandoned, and the corresponding employed bee role will be transformed into a scout bee, and it will randomly generate a new nectar source in search space in stead of xi .The process mentioned is executed according to formula (4).

$$x_{ij} = \begin{cases} x_{ij} = l_j + \delta * (\mu_j - l_j) & trial \ge \lim it \\ x_{ij} & otherwise \end{cases} \qquad (4)$$

For minimizing the optimization problem, the fitness of the solution fit_{ij} is calculated by formula (5).

$$fit_{ij} = \begin{cases} 1/(1+f_i) & f_i \ge 0 \\ 1+|f_i| & otherwise \end{cases} \qquad (5)$$

ABC algorithm program flow chart is shown in the figure 1.

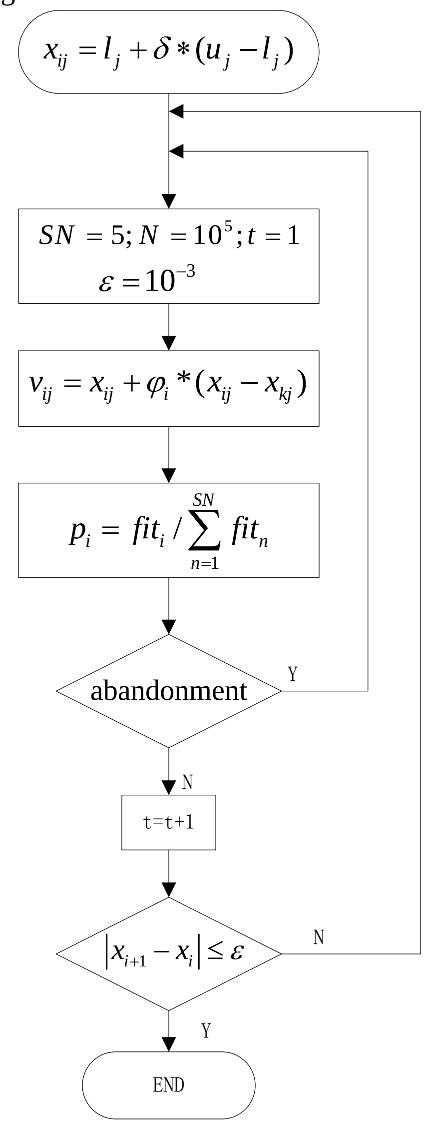

Fig. 1 ABC algorithm program flow chart

3 OPTIMIZATION DESIGN AND EXPERIMENT

3.1 Structural design

As shown in the figure 2, the tea sieve shaker consists of upper sieve, sieve surface, leaf spring, gear motor, crank, connecting rod, tea outlet, tea dust outlet, framework and sieve box. The crank is installed on the motor output shaft, the vibrating screen is connected with the ground frame through the spring steel plate, and the middle part is connected with the connecting rod through the hinge.

The motor drives the vibrating screen through the crank slider mechanism to realize reciprocating vibration. Under the reciprocating vibration of the screen surface, the tea leaves are thrown up and slide down along the screen surface. In this process, the tea dust and the broken tea will automatically sink down due to its small volume. The tea on the screen slides down the screen surface and flows out of the outlet, while the tea powder and the broken tea exit through the sieve. The tea on the screen slides down along the screen surface at the same time and flows out from the tea outlet, while the broken tea and tea powder pass through the screen hole and flow out from the tea dust outlet. The movement of the screen body is driven by the crank connecting rod. The inclination angle of the screen surface affects the screening time of tea. When the inclination angle is too large, the screening time shortens and affects the screening rate. When the inclination angle is too small, the screening time increases. Although the screening rate increases, the productivity decreases. The geometry parameters of crank slider mechanism also affect the screening process. The above parameters will affect the minimum transmission angle of the mechanism (Chen et al., 2015). When the minimum transmission angle of the mechanism is too small, the transmission performance of the mechanism will decrease, the reciprocating motion of the sieve surface will be stuck, and the tea on the mechanism will accumulate and the sieve hole plug will be blocked, which will affect the sieving effect.

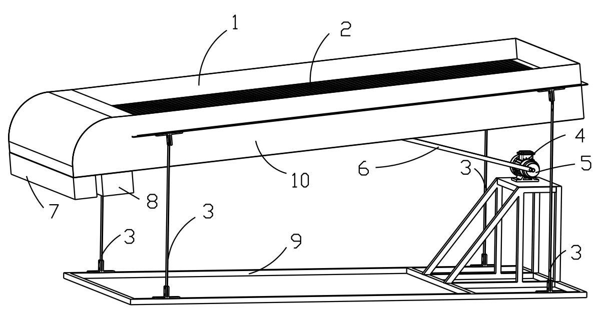

Fig. 2 Diagram of tea sieving machine

Note: 1.uppersieve 2.sieve surface 3.leaf spring 4.gearmotor 5.crank 6.connecting rod 7.tea outlet 8.tea dust outlet 9.framework 10.sieve box

The technical parameters of the tea sieving machine are shown in the table 1.

Table 1. Parameters of the tea sieving machine

item	Performance index
L*W*H/(mm)	2800*1800*1480
motor power/(kW)	1.5
speed regulation mode	frequency control
driving mechanism	crank-slider mechanism
screening rate/(%)	>86
productivity/(kg/h)	450
working noise /(dB)	<82

3.2 Optimization mathematical mode

3.2.1 Optimize design parameters

The force diagram of tea on the screen surface is shown in Figure 3. The tea leaves are subjected to gravity G, screen surface supporting force N, friction N and inertia force μ. The kinematic equation is shown in equation (1)-(3).inertia force μ can be represented by equation (4).

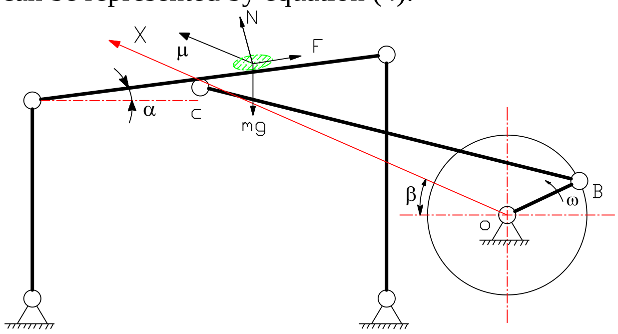

Fig. 3 Force diagram of tea on sieving machine

$$x = -a\cos\omega t \qquad (1)$$

$$V_x = a\omega\sin\omega t \qquad (2)$$

$$a_x = a\omega^2\cos\omega t \qquad (3)$$

$$\mu = ma\omega^2\cos\omega t \qquad (4)$$

In order to make the tea slide in front of the screen, the acceleration ratio of the screen motion must satisfy equation (5).

$$\frac{r\omega^2}{g} \geq \frac{\sin(\varphi-\alpha)}{\cos(\beta+\alpha+\varphi)} \qquad (5)$$

Where a is the length of crank, ω is the angular velocity of crank, α is the Angle between screen surface and horizontal direction, β is the Vibration direction angle, φ is friction angle between tea and stainless steel sieve surface, which is 15-25º(Li et al., 2009).

The angle θ of the extreme position refers to the acute angle between the two positions of the corresponding crank when the follower is in two limit positions, and its size reflects the quick return characteristics of the mechanism. The experimental results show that: when the stroke speed ratio coefficient K of the tea sieve shaker is 1.02-1.30, it is conducive to the replacement of the upper and lower layers of tea on the screen surface; if K value is too small, the position of the upper and lower layers of tea remains unchanged, the lower layer will produce scorched leaves; if K value is too large, the tea will be thrown out from the screen surface. The transmission angle is the remainder of the acute angle between the driven force of the follower and its velocity direction. In the crank slider mechanism, the transmission angle is the angle between the connecting rod and the vertical line of the slider guide. When the crank is perpendicular to the guide direction, the transmission angle is the minimum.

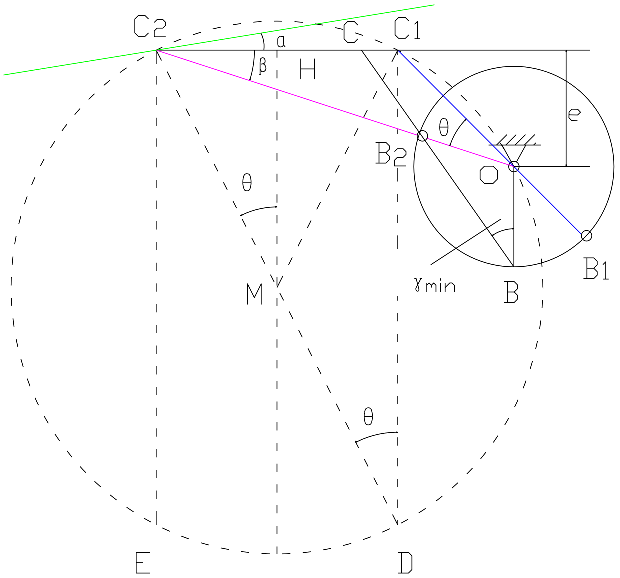

Fig.4 Schematic diagram of minimum pressure angle

As shown in Figure 4, C_1 and C_2 are the left and right limit positions of the slider respectively, which are also the direction lines of sieve. Let line C_1C_2 = H, make the middle vertical line of C_1C_2, make line C_2D throughC_2, make the angle C_1C_2D=90°-θ, the intersection of the above two lines is the auxiliary circle center m, take line MC_2 as the radius, take any point O on the circumference as the rotation center of the crank, then the extreme angle of the mechanism is θ, make the crank length a, the connecting rod length b, offset distance of crankis e. When straightening collinear, line OC_2= a+b, when folding collinear, line OC_1 = b-a. Take O as the center of the circle, a as the radius, make a circle, make a vertical line C_1C_2 from O and the intersection point B with the circle, and make line BC =b, then the angle OBC is γ_{min}. Let the auxiliary angle OC_2C_1 = β, in triangle OC_2C_1, it can be easily obtained from the sine theorem.

The key parameters of the transmission mechanism of the tea Slitter are: crank length a; connecting rod length b; offset distance of crank e; slider stroke h; auxiliary angle β; polar angle θ. Take a, b, e, β , θ,α,ω as design variables. Namely

$$X = [x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8]^T$$
$$= [a, b, e, h, \beta, \theta, \alpha, \omega]^T \qquad (6)$$

3.2.2 Objective function

The transmission angle of the crank and connecting rod mechanism is highly related to the motion performance of the mechanism. When the mechanism has a small transmission angle, the movement is more stable, the force condition of the mechanism is improved, it is not easy to get stuck, and the machine has less vibration and noise. Therefore, the minimum transmission angle of the mechanism is selected as the objective function, that is to seek the maximum of the minimum transmission angle. The following formula can be easily obtained from the geometric relationship of the mechanism.

$$\min F(X) = -\gamma_{nin} \qquad (7)$$

$$a = H\frac{\sin(\beta+\theta)-\sin\beta}{2\sin\theta} \qquad (8)$$

$$b = H\frac{\sin(\beta+\theta)+\sin\beta}{2\sin\theta} \qquad (9)$$

$$e = H\frac{\sin\beta\sin(\beta+\theta)}{\sin\theta} \qquad (10)$$

$$\gamma_{\min} = \cos^{-1}\frac{\sin(\beta+\theta)\sin\beta+\cos(\beta+\theta/2)\sin\theta}{\sin(\beta+\theta/2)\cos(\theta/2)} \qquad (11)$$

Where H is the distance between left and right limit positions of sieve,that is, the amplitude; e is the offset distance of crank; γ_{min} is the minimum transmission angle.

3.2.3 Constraint condition

According to the motion continuity principle of mechanism, point a can only be on arc C_1D and arc C_2E, that is, 0≤β ≤ 90- θ.

$$g_1(X) = x_5 > 0 \qquad (12)$$

$$g_2(X) = 90 - x_5 \geq 0 \quad (13)$$

The experiment shows that the stroke of vibrating screen is 400 ≤H ≤530. At the same time, all design variables have non negative requirements.

$$g_3(X) = x_1 > 0 \quad (14)$$

$$g_4(X) = x_2 > 0 \quad (15)$$

$$g_5(X) = x_3 > 0 \quad (16)$$

$$g_6(X) = x_5 > 0 \quad (17)$$

$$g_7(X) = x_4 - 400 > 0 \quad (18)$$

$$g_8(X) = 530 - x_4 > 0 \quad (19)$$

From the geometric relationship between design variables, the following constraints can be easily obtained.

$$g_9(X) = x_1 - x_4 \frac{\sin(x_5 + x_6) - \sin x_5}{2\sin x_6} \geq 0 \quad (20)$$

$$g_{10}(X) = x_4 \frac{\sin(x_5 + x_6) - \sin x_5}{2\sin x_6} - x_1 \geq 0 \quad (21)$$

$$g_{11}(X) = x_2 - x_4 \frac{\sin(x_5 + x_6) + \sin x_5}{2\sin x_6} \geq 0 \quad (22)$$

$$g_{12}(X) = x_4 \frac{\sin(x_5 + x_6) + \sin x_5}{2\sin x_6} - x_2 \geq 0 \quad (23)$$

$$g_{13}(x) = x_3 - x_4 \frac{\sin x_5 \sin(x_5 + x_6)}{\sin x_6} \geq 0 \quad (24)$$

$$g_{14}(x) = x_4 \frac{\sin x_5 \sin(x_5 + x_6)}{\sin x_6} - x_3 \geq 0 \quad (25)$$

In order to ensure the normal replacement of the upper and lower layers of tea on the sieve surface.

$$g_{15}(x) = \frac{180° + \theta}{180° - \theta} - 1.02 \geq 0 \quad (26)$$

$$g_{16}(x) = 1.3 - \frac{180° + \theta}{180° - \theta} \geq 0 \quad (27)$$

In order to ensure good transmission, it is required that γ min > 40 ° and

$$g_{16}(x) = \gamma_{\min} - 40 > 0 \quad (28)$$

3.3 Simulation experiment

The optimum design program of crank-rocker mechanism of tea sieve shaker based on ABC algorithm is compiled by using MATLAB language. It runs on PC with Intel Pentium Dual E5200 and RAM of 4G. The parameter optimization results of the program are shown in table. 1

Table 1. Parameter optimization results

item	Before optimization	After optimization
a/(mm)	21	20
b/(mm)	875	995
e/(mm)	380	300
H/(mm)	453	437
β/(°)	23	21.8
θ/(°)	2	2.6
α/(°)	1.8	1.5
ω/(rad/s)	26.2	25
$-\gamma_{min}$/(°)	-62.7	-71.2
noise/dB	76	66

4 CONCLUDING REMARKS

The mathematical model of mechanical optimization design is generally a multi-dimensional nonlinear constrained problem. ABC algorithm has fast convergence speed in solving such problems, and can effectively avoid falling into the local optimal solution. Therefore, ABC algorithm is more suitable for solving the mechanical design problems. This paper establishes the optimal design model of the driving mechanism of tea shaker screen machine, and uses ABC algorithm to solve it, which improves the kinematic performance of the driving mechanism, and can provide reference for the design of similar machine. This paper not only considers the constraints of mechanical principle, but also considers the requirements of tea screening process. However, due to the variety of Chinese tea, the influence of different physical properties of tea particles on the simulation results is not considered. In order to obtain more accurate results, the above factors should be fully considered in the future research.

5 ACKNOWLEDGEMENTS

This work was supported by Chinese National Key Research and Development Program (No. 2018YFD0700504).

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7 NOTATION

The following symbols are used in this paper:
a= crank length;
b= connecting rod length;
e= offset distance of crank;
H= the amplitude of the sieve;
β=vibration direction angle;
θ= angle of extreme position;
ω=angular velocity of crank;
γ_{min} = the minimum transmission angle.