Hindawi
Journal of Mathematics
Volume 2020, Article ID 4863653, 12 pages
https://doi.org/10.1155/2020/4863653

Research Article

Design of Bacteria Bottle Clamping Elements Based on Regression Models

Wenshuo Gao, Weidong Song, Tianhang Ding, and Jiaoling Wang

Nanjing Institute of Agricultural Mechanization, Ministry of Agriculture and Rural Affairs, Nanjing 210014, China

Correspondence should be addressed to Weidong Song; niamsong@163.com

Received 13 July 2020; Revised 11 August 2020; Accepted 21 August 2020; Published 1 October 2020

Academic Editor: Niansheng Tang

The fixture design of the bacteria bottle plays a vital role in designing a bottled fungus picking robot to save labor cost in the picking process of bottled fungus. This paper proposed a kind of clamping element design method based on regression models. Several sets of clamping elements were designed according to the appearance data of bacteria bottle. A single-factor test was conducted by using these clamping elements, and three levels of every factor were selected to obtain the desired values of clamping elements. Then, a Box–Behnken test was performed by selected levels. The established regression models described a numeric relationship between the variation of vital measurement points and all variation sources under a precise clamping element layout. To solve the problems in obtaining the direct parameters, a response surface method was presented based on the regression models. Finally, a test was used to demonstrate the effect of the optimized clamping elements when clamping a bacteria bottle. Through the related analysis and optimization, it was demonstrated that the holding effect of the clamping elements was the best under these conditions: the inner arc area was 4948 mm^2; the downward displacement was 1.48 mm; and the rubber thickness was 3.69 mm. It showed that the proposed method was feasible, and the assembly quality after optimizing had been greatly improved. It can provide a reference for designing the bottle fixture of a picking machine.

1. Introduction

It is a fact that some mushrooms are cultivated by bacteria bottles in most edible fungus factories. Besides, *Flammulina velutipes* (*F. velutipes)* is one of the six most cultivated mushroom species in the world, and over 300,000 t are produced per year [1]. As for the production process of bottled *F. velutipes*, it is still picked by manual drawing. As China's population aging progresses, labor cost also increases significantly. The contribution of labor to overall production costs for growers is generally at least 40%. Automation has the potential of improving the quality of fresh produce, lowering production costs and reducing the requirement of labor [2]. As a result, designing a kind of picking robot, such as *F. velutipes* harvester, contributes to increasing factories' profits. During the process of production, amounts of bacteria bottles are applied. Therefore, it is necessary to pay more attention to designing clamping elements that can be used in picking robots.

A fixture is a work-holding device that locates and supports the workpiece [3]. Moreover, clamping elements are essential parts of a fixture. Fixtures should have appropriate structures and supply reasonable force to hold objects. Some methods were proposed to avoid the workpiece deformations, which can be caused by the clamping system itself. Gonzalo et al. [4] presented an analysis to identify the causes of the static deformations during clamping and a method to correct the geometrical distortion and deformation of a clamped workpiece by the evaluation of the reaction forces in the selected relevant clamping points. Vukelic et al. [5] proposed a method that was based on preprocessing of contact interfaces and indenting the clamping elements into the workpiece. It realized to use lower clamping forces to achieve deeper indenting and higher tangential load capacity. Sun et al. [6] introduced a measurement prototype for the real-time dynamic clamping force monitoring, which can be employed to realize the real-time vibration monitoring in thin-walled components milling, as well as to preliminarily identify the machining quality of the thin-walled components. Huamin et al. [7] suggested a linear programming technology to verify the force existence and the force feasibility at the corresponding clamping point. Because the proposed method transforms the continuous design problem of clamping forces into the discrete analysis problem of workpiece stability, it can apply to the complex workpiece and benefit the development of automated fixture design. Wu and Xi [8] designed a synchronous plane of the clamping mechanism and proposed a design criterion for the locking mechanism's clamping force. Through those, they obtained the relevant motion curves, which could be served as a new idea for designing clamping elements of the robot. Li et al. [9] designed a new type of clamping end-effector's structure for the robot to realize the pickup of the box goods. The finite element analysis of key components improved the feasibility of structural design, which verified the feasibility of the structure design and provided references for subsequent optimization. Din et al. [10] designed a new type of Arcan fixture by a mechanical test to obtain applicable design standards. Papastathis et al. [11] presented an adaptive fixture able to reconfigure the clamping elements; it also uses position and clamping force feedback. Besides, modeling of the workpiece-fixture system allows the implementation of optimization strategies for attaining a suitable fixture structure. Wu et al. [12] proposed a computerized framework for computer-aided fixture design and evaluation for near-net shaped jet engine blades based on the mechanical model and mathematical model. It evaluated and optimized the fixture of the same type blade to obtain the positioning and mechanical behavior of the fixture and can realize high-precision manufacturing of near-net-shaped jet engine blades. Yu [13] designed a more applicable robust fixture by using a response surface method to establish the vector regression mode, which had improved the assembly quality. Liu et al. [14] improved the fixture quality by optimizing the clamping force plan and the fixture layout design in a finite element model. Nategh and Parvaz [15] developed a mathematical foundation of clamping system design and an algorithm by using the concept of screw theory and the minimum norm principle. It relegalized the minimum number of clamps, maximum contrariety of clamping force components with respect to the twists tending to break contact between the workpiece and the locators, and maintenance of workpiece's static stability under different wrenches. Zhang et al. [16] proposed a design method to improve the clamping apparatus for replacement of insulator strings in the ultrahigh-voltage (UHV) transmission line. The mechanical properties of the clamping apparatus are analyzed to determine the structure with the fixtures of carbon fiber composites by the finite element method. It could improve the working efficiency and reduced the labor intensity. Zhu [17] designed the pneumatic clamping device and arc-shaped parts and optimized them by orthogonal test and regression analysis. Wang et al. [18] designed and optimized holding devices of the banana picking manipulator by using Pro/E and ANSYS software. The results having a dedicated application value met the stiffness and strength requirement for harvesting bunches of bananas. Medellín et al. [19] presented a biaxial tensile testing fixture using finite element analysis, which can be used along with a universal testing machine for the characterization of sheet metals. Calabrese et al. [20] optimized the performance of the fixtures used in thin-walled workpiece machining depending on the local rigidity characteristics of the component to be machined by designing topology optimized.

At present, objects clamped are relatively dense in agriculture or industry. However, there is no research on the fixture for holding bacteria bottles with fresh materials used to design clamping elements for the mushroom harvester. Therefore, we combined experimental research with mathematics analysis, which was first applied to design fixtures of bacteria bottles with culture. And we ensured the minimum size of clamps to keep contact between the bottle and locators. It contributed to the recyclable lifetime of the bottles.

Pull-out is a universal method when labors pick up the bottled *F. velutipes.* In designing a bottled mushroom picking robot, it is necessary to ensure that the bacteria bottles are clamped appropriately by the holding parts during the pull-out process of picking *F. velutipes*. And the proper holding capacity can increase the recyclable lifetime of the bottles. Therefore, studying the mechanical properties of bacteria bottles has become necessary. Several scholars [21–23] have conducted many mechanical tests using plastic bottles to obtain related data. Therefore, we presented a set of clamping elements and conducted a compression test, aiming to design a fixture used in exploiting a robot that can harvest the bottled *F. velutipes* by pull-out. The levels of Box–Behnken test were selected by the single-factor test. According to the obtained data, the variation models were established to describe accurately the relationship between the clamping quality and variation sources under specific clamping elements. And the response surface modeling method was employed to obtain the interaction between factors that significantly influence clamping quality. Finally, optimized parameters were corroborated by a confirmation test, which supplied a foundation for the bacteria bottle fixture design.

2. Materials and Methods

2.1. Design of the Clamping Elements. The bacteria bottle is a kind of plastic bottle. It has three types, including small, medium, and large. Medium bottles have the most commonly used in the process of cultivating *F. velutipes* in a factory. Figure 1 shows the medium bacteria bottle with external dimensions. The fixture should hold a plastic bottle tightly. And the rubber is attached to the interior to reduce the impact of the metal fixture. The main body of the bottle, length of 140 mm, is an excellent position to hold.

Thus, the clamping elements were devised based on the parameters of the central bottle part. A V-block has broad applications for clamping in terms of holding plastic bottles. It does not have large contact areas with the bacteria bottle, which could decrease the lifetime of the bottle due to high load. Therefore, circular surface contact is more conductive

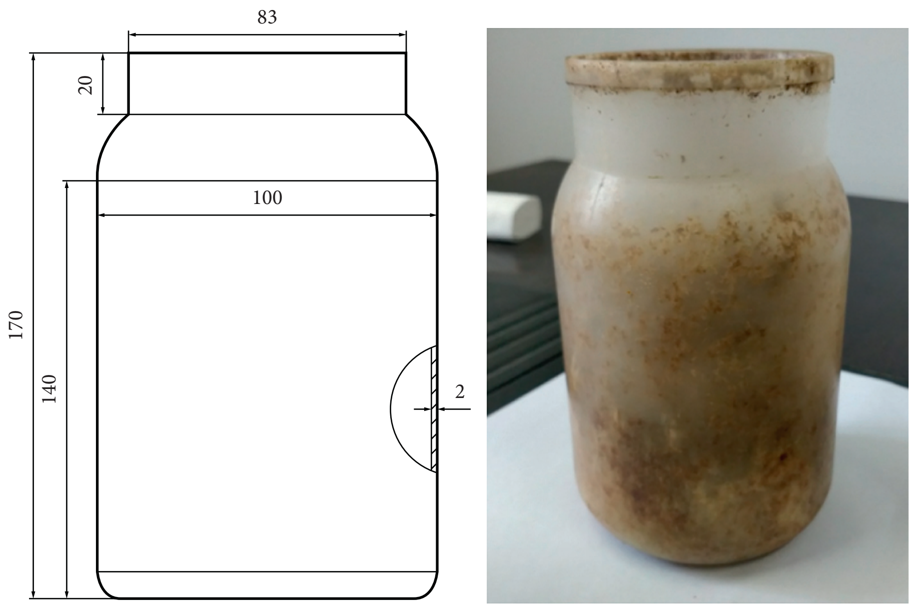

Figure 1: Medium bacteria bottle (mm).

to protecting the bottle. It has smaller contact pressure that exists between the bottle and the clamping elements. Besides, clamping the whole bottle is not a scientific method. It should have an appropriate area, including the central angle and thickness of it. The thickness of the rubber is ignored because it cannot significantly influence the area of the clamping elements. To make errors under 5.6%, the radius value "54 mm" is applied. As a result, the structure of the clamping elements is shown in Figure 2(a). Then,

$$B = 54 \times \beta' * h, \tag{1}$$

where B is the internal arc area of the clamping elements and β' (rad) is the central angle corresponding to the clamping arc of the clamping elements. The value of it can be$\{\pi/2, 2\pi/3, 5\pi/6\}$. h (mm) is the thickness of the clamping elements. The value of it can be{25, 35, 45}. According to the combination, the areas can be 2121 mm^2 ($\pi/2 \times 25$), 2969 mm^2 ($\pi/2 \times 35$), 3817 mm^2 ($\pi/2 \times 45$), 2827 mm^2 ($2\pi/3 \times 25$), 3958 mm^2 ($2\pi/3 \times 35$), 5089 mm^2 ($2\pi/3 \times 45$), 3534 mm^2 ($5\pi/6 \times 25$), 4948 mm^2 ($5\pi/6 \times 35$), and 6362 mm^2 ($5\pi/6 \times 45$). Areas selected should have an appropriate range and interval. Besides, we considered errors. The areas of the clamping elements, 2121 mm^2, 2969 mm^2, 3958 mm^2, 4948 mm^2, and 6362 mm^2, were used to make the corresponding parts, as shown in Figure 2(b).

2.2. Experimental Procedure. Several bacteria bottles with fresh culture were applied rather than empty bottles due to the great differences in mechanical properties between them. To obtain the desired values of the clamping elements by the compression test, the single-factor and Box–Behnken tests were designed. First, the clamping elements attached rubber were fixed to the testing machine with pins. The position between the bottle and the upper one until they contacted tightly with each other without any interaction. According to the two designed tests, the compression test was conducted using the electronic universal testing machine (UTM6503) under a sliding speed of 5 mm/min. When the testing machine stopped, the long axis and short axis of the bottle mouth were measured by an electronic vernier caliper (SR44). After that, a pointer push-pull force meter (NK-50) was used to measure the friction coefficient between the bottle and the rubber. The data obtained were recorded for further analysis.

Furthermore, the stress analysis of the bottle in the test is shown in Figure 3. It was not analyzed and drawn in Figure 3 because the gravity of the bottle is equal to the support produced by the inferior clamping element [24]. Then,

$$\begin{aligned} F &= F_{f1} + F_{f2}, \\ F_f &= \mu F_N, \end{aligned} \tag{2}$$

where F is the pull force measured by the dynamometer, N; F_{f1} and F_{f2} are the sliding friction force generated by the positive pressure in the pull direction of the push-pull dynamometer, N; F_{N1} and F_{N2} are the positive pressure of the clamping element on the bottle, N; and μ is the equivalent friction coefficient between the clamping element and the bottle.

2.3. Design of Experiments. According to the designed bacteria bottle clamping elements, the main factors affecting the holding quality are the inner arc surface area, the downward displacement, and the rubber thickness of the clamping elements. And consequences are the pressure on the bacteria bottle, the ratio of the long and short axis, and the pull on the bacteria bottle.

2.3.1. Single-Factor Test. Factors and levels of the single-factor test were selected by the designed clamping elements and the final effect, as shown in Table 1. Some details were as follows.

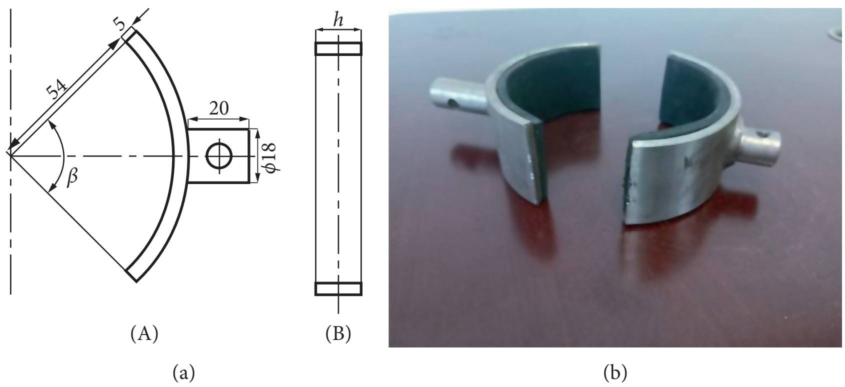

FIGURE 2: Clamping parts. (a) Structure of clamping elements. (A) Front view. (B) Side view. (b) A set of clamping elements.

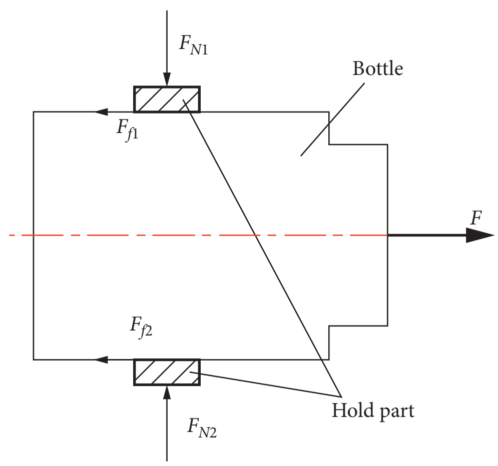

FIGURE 3: Force analysis.

TABLE 1: Factors and levels of single-factor test.

Levels	Inner arc surface area A (mm^2)	Displacement B (mm)	Thickness C (mm)
1	2121	1.4	1
2	2969	1.5	2
3	3958	1.6	3
4	4948	1.7	4
5	6362	1.8	5

Areas selected should have an appropriate range and interval. Based on the self-made clamping elements, the inner arc surface area's levels are "2121 mm^2, 2969 mm^2, 3958 mm^2, 4948 mm^2, and 6362 mm^2." It can include different angles (β') and thickness (h) of the clamping elements. The thickness of the rubber, "1 mm, 2 mm, 3 mm, 4 mm, and 5 mm," is chosen as the single-factor test levels according to the existing ones in the market. The compression test of the whole bottle was conducted with the area 2121 mm^{2}and 6362 mm^2, as shown in Figure 4. And the curves were obtained, as shown in Figure 5. It illustrated that the curves' trends were increasing quickly when the displacement was beyond 2 mm. Through the pull-out test of the bottled *F. velutipes*, the average pull-out force required for picking is 30 N. When the safety factor is 1.1, the maximum safe pull-out load is about 32.94 N [25]. According to the model of pull-out (Figure 3), it is calculated that the pressure was at least 35 N to ensure to pick bottled *F. velutipes* under the coefficient of friction of 0.47. Therefore, the force above 35 N is necessary, and the displacement is 1.4 mm at this time according to Figure 5. If the downward displacement were too large, the pressure on the bottle would be too tremendous. It would affect the subsequent cycle usage and lifetime of bottles. Therefore, we took 0.1 mm as a value interval. And the single-factor test levels of downward displacements were 1.4 mm, 1.5 mm, 1.6 mm, 1.7 mm, and 1.8 mm.

2.3.2. Box–Behnken Test. The Box–Behnken technique is a technique that makes an efficient design space, and it requires only the fraction of full factorial points to estimate the

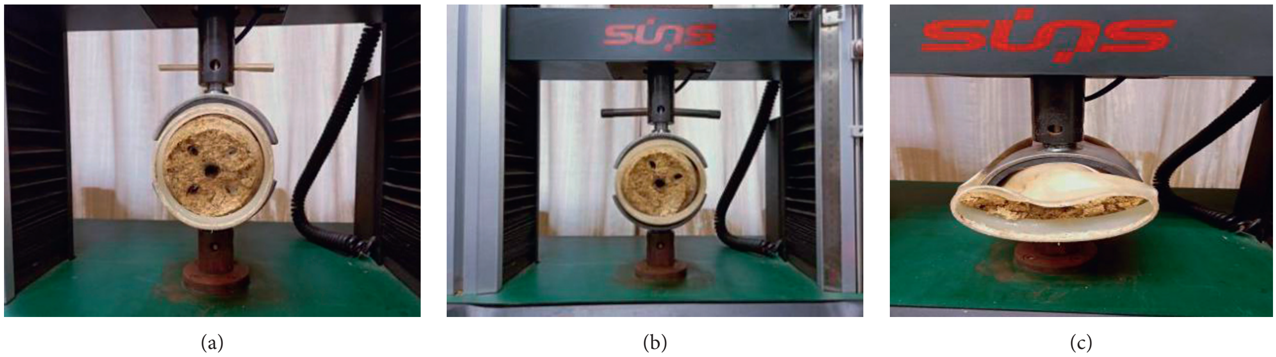

FIGURE 4: Squeeze deformation. (a) Before extrusion. (b) Extrusion displacement of 2 mm. (c) Complete extrusion.

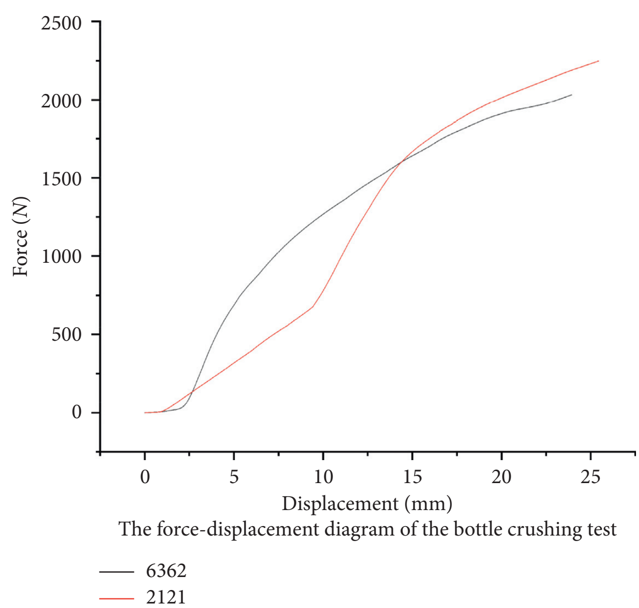

FIGURE 5: Bacterial bottle entirely squeezed.

TABLE 2: Factors and levels of the Box–Behnken test.

Factors	Code	Levels of codes		
		−1	0	1
Inner arc surface area	A (mm^2)	2121	3958	4948
Displacement	B (mm)	1.4	1.5	1.6
Thickness	C (mm)	2	3	4

second-order effects of the response surface [26]. Based on the single-factor test results, the Box–Behnken test was performed with a combination of A, B, and C factors each at three levels (high, +1, medium, 0, and low, −1). The results are shown in Table 2.

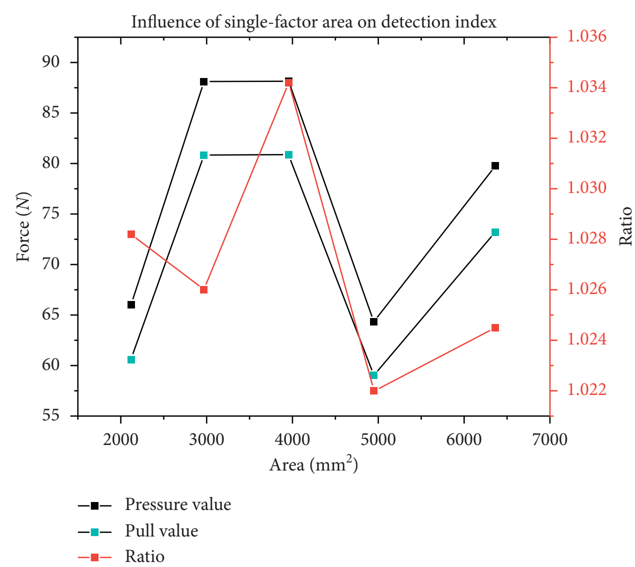

FIGURE 6: Impact of different areas on the detection indexes.

3. Results

3.1. The Results of the Single-Factor Test

3.1.1. The Influence of the Internal Arc Surface Areas on the Detection Indicator. Three physical quantities were used as detection indicators to evaluate the clamping effect. They are pressure value, long and short axis ratio of bottle mouth, and pull value. They can reflect the clamping elements' holding effect and the degree of deformation of the bacteria bottle.

When the downward displacement of the clamping was 1.6 mm and the rubber thickness was 3 mm, the bacteria bottle pressure test was carried out by using different clamping elements which had different arc surface areas. Figure 6 shows the results of the pressure, pull, and the ratio with different areas changing.

The range of tensile force measured by push-pull dynamometer is from 0 to 50 N. When the value exceeded the range, it was calculated according to the equivalent friction coefficient between the bacteria bottle and rubber obtained from the test. Then, the corresponding value was obtained. The average of the equivalent friction coefficient between the bottle and the rubber was 0.458. As shown in Figure 6, it demonstrated that the pressure of the bacteria bottle and the tensile force produced by the dynamometer had similar trends, and the ratio fluctuated with the increase of the inner arc surface area of the clamping elements. The clamping elements need to meet the requirements for picking bottled *F. velutipes*, and it will not exert a significant force on the bacteria bottle, so as not to affect subsequent use. Therefore, it is necessary to have a small deformation of the bacteria bottle. It should have more appropriate pressure and tension. Besides, the selected inner arc surface areas should conclude three kinds of central angles. Based on the results, the three levels of the arc surface area were selected. They were 2121 mm^2, 3958 mm^2, and 4948 mm^2.

3.1.2. The Influence of Downward Displacement on Detection Indicator. The bacteria bottle pressure test was carried out while the arc surface area was 3958 mm^2 and the rubber thickness was 3 mm. Figure 7 shows the pressure, pull, and the ratio with different downward displacements.

All three detection indexes have increased with downward displacement increasing. To meet the requirements, it should cause small damage and deformation to the bacteria bottle. Three downward displacements were selected. They were 1.4 mm, 1.5 mm, and 1.6 mm.

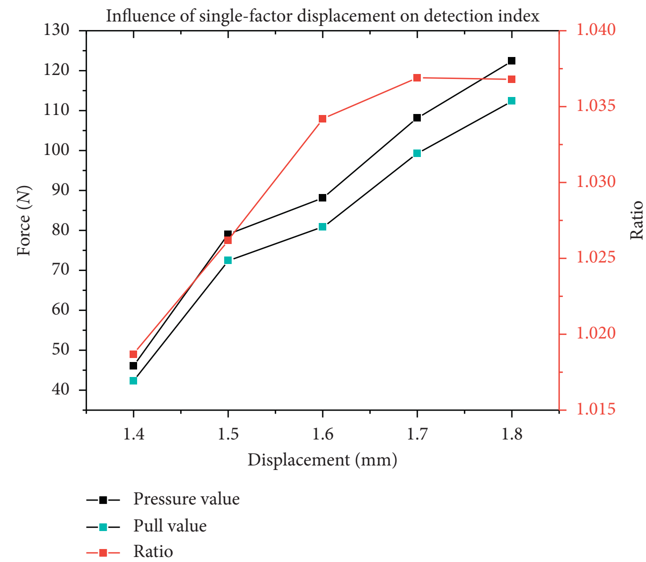

Figure 7: Impact of different displacements on detection indexes.

3.1.3. The Influence of Rubber Thickness on Detection Indicator. When the arc surface area was 3958 $mm^2$and the rubber thickness was 3 mm, the bacteria bottle pressure test was carried out using different clamping elements with different thicknesses of rubber. Figure 8 presents the pressure, pull, and the ratio with the different thickness of rubber changing.

The three detection index values showed a downward trend when the thickness of the rubber was more exceptional than 3 mm. To meet the picking requirements, the tensile force was not less than 35 N. When the rubber thickness was 5 mm, it was not sufficient for the test. As for the “1 mm” thick rubber, the pressure of the bacteria bottle was immense, and the thickness of 1 mm was relatively thinner than 3 mm. It was not conducive to reducing the buffer of the force from the clamping component. Therefore, the thicknesses, “2 mm, 3 mm, and 4 mm,” were chosen as the comprehensive consideration factors.

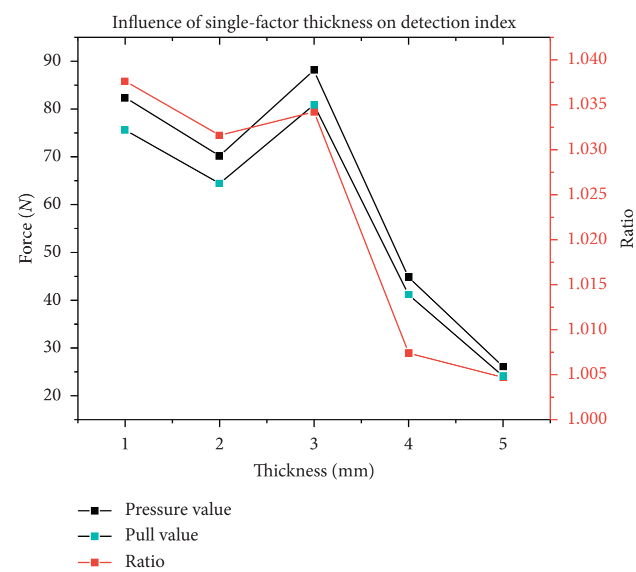

Figure 8: Impact of rubber thickness on detection indexes.

3.2. The Results of Box–Behnken Test. To explore the optimal value of the clamping elements’ relevant parameters, the three values, the pressure on the bacteria bottle, the length-to-short axis ratio of the bottle mouth, and the value of the tensile force, were used as the response values. The experimental design scheme and results are shown in Table 3.

A mathematical model was exploited. And the relevant summary results of quadratic and linear models were specified in ANOVA, as shown in Table 4 [27].

The response surface is constructed as a surrogate model based on the most important effects. To find the relationship between the objective function and factor values, the following second-order polynomial model is used, in which $\{x1, ..., xk\}$ are the factors and βi s are the coefficients and e is the approximation error [26]. Then,

$$y = \beta_0 + + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i<j} \sum \beta_{ij} x_i x_j + e. \quad (3)$$

Comparing the values between the predicted at the design point and the average prediction error, the value of adequate precision (AP) in this model showed that it was well above (4). The models can be used to navigate the design space. Moreover, according to equation (3), the regression equations of the three indicators are obtained. Then,

$$\begin{aligned} Y_1 = {} & 95.42 + 9.46A + 1.58B - 0.33C - 8.92\,\mathrm{AB} - 17.47\,\mathrm{AC} \\ & - 5.91\,\mathrm{BC} - 7.22A^2 - 18.34B^2 - 27.45C^2, \end{aligned} \quad (4)$$

$$\begin{aligned} Y_2 = {} & (10300 - 4.25A + 9.085B - 61.14C - 28.1\,\mathrm{AB} \\ & - 83.36\,\mathrm{AC} - 24.5\,\mathrm{BC} - 12.93A^2 - 49.75B^2 \\ & - 85.75C^2\big) \times 10^{-4}, \end{aligned} \quad (5)$$

Table 3: Design and results of Box–Behnken test.

Number	Area A (mm^2)	Displacement B (mm)	Thickness C (mm)	Pressure value Y_1 (N)	Ratio Y_2	Pull value Y_3 (N)
1	1	−1	0	95.3677	1.0294	87.5080
2	0	1	1	44.8350	1.0074	41.1401
3	−1	0	1	69.8008	1.0259	64.0492
4	0	0	0	97.6077	1.0316	89.5642
5	−1	0	−1	33.8430	1.0200	31.0548
6	0	1	−1	70.1823	1.0316	64.4002
7	1	0	−1	85.9326	1.0341	78.8523
8	0	0	0	97.6077	1.0316	89.5642
9	0	−1	1	45.2780	1.0094	41.5477
10	0	0	0	97.6077	1.0316	89.5642
11	0	−1	−1	46.9875	1.0238	43.1147
12	−1	1	0	66.0295	1.0282	60.5865
13	−1	−1	0	53.6762	1.0227	49.2530
14	1	1	0	64.3165	1.0220	59.0159
15	1	0	1	53.4558	1.0079	49.0513

Table 4: ANOVA table for the fitted models.

Source	Sum of squares	Df	Mean square	F value	P value	
For Y_1 model	6434.64	9	714.96	9.70	0.0111	Significant
Residual	368.38	5	73.68			
Total	6803.02	14				
Std. Dev.	8.58				R^2	0.9459
Mean	68.17				Adjusted R^2	0.8484
C.V. %	12.59				Predicted R^2	0.1532
					Adeq precision R^2	9.053
For Y_2 model	1125.0	9	125.0	22.78	0.0015	Significant
Residual	27.44	5	5.488			
Total	1153.	14				
Std. Dev.	0.0023				R^2	0.9762
Mean	1.02				Adjusted R^2	0.9333
C.V. %	0.23				Predicted R^2	0.6201
					Adeq precision R^2	15.133
For Y_3 model	5417.44	9	9.69	9.69	0.0112	Significant
Residual	310.73	5	62.15			
Total	5728.17	14				
Std. Dev.	7.88				R^2	0.9458
Mean	62.55				Adjusted R^2	0.8481
C.V. %	12.60				Predicted R^2	0.1516
					Adeq precision R^2	9.046

$$
\begin{aligned}
Y_3 = {} & 87.56 + 8.69A + 1.69B - 0.30C - 8.17\,\mathrm{AB} - 16.03\,\mathrm{AC} \\
& - 5.42\,\mathrm{BC} - 6.63A^2 - 16.84B^2 - 25.18C^2,
\end{aligned}
\tag{6}
$$

where Y_1 is the code value of the pressure value; Y_2 is the code value of the ratio; Y_3 is the code value of pull value; A represents the code values of the inner surface area, B represents the code values of the down pressure displacement, and C represents the code values of the rubber thickness. The parameters whose p value is less than 0.05 are statistically significant. It can be seen in Table 4. It has been found that the models are fairly well fitted with the experimental values [28].

3.3. Effect of Experimental Parameters on Detection Indicators. The response surface method [29–32] is a common way to analyze the effect of factors on the detection indicators. Therefore, according to the established regression equation, we obtained the relationships between the factors and indicators by establishing the response surfaces.

Figure 9 shows the effect of experimental parameters on pressure value. The range of pressure value was from 33.843 N to 97.608 N. With the value of displacement increasing, the pressure value increased first and decreased later. The same trend was demonstrated in the relationship between the rubber thickness and the pressure value. However, the pressure value was increased with the areas increasing. Several designed points are out of the predicted value. Moreover, according to the contours of the response surface, it showed that the ellipse's curvature in Figure 9(b) was large. Therefore, there was an interaction between the arc surface area of the clamping elements and the rubber thickness, and the interaction had a significant effect on the pressure of the bacteria bottle.

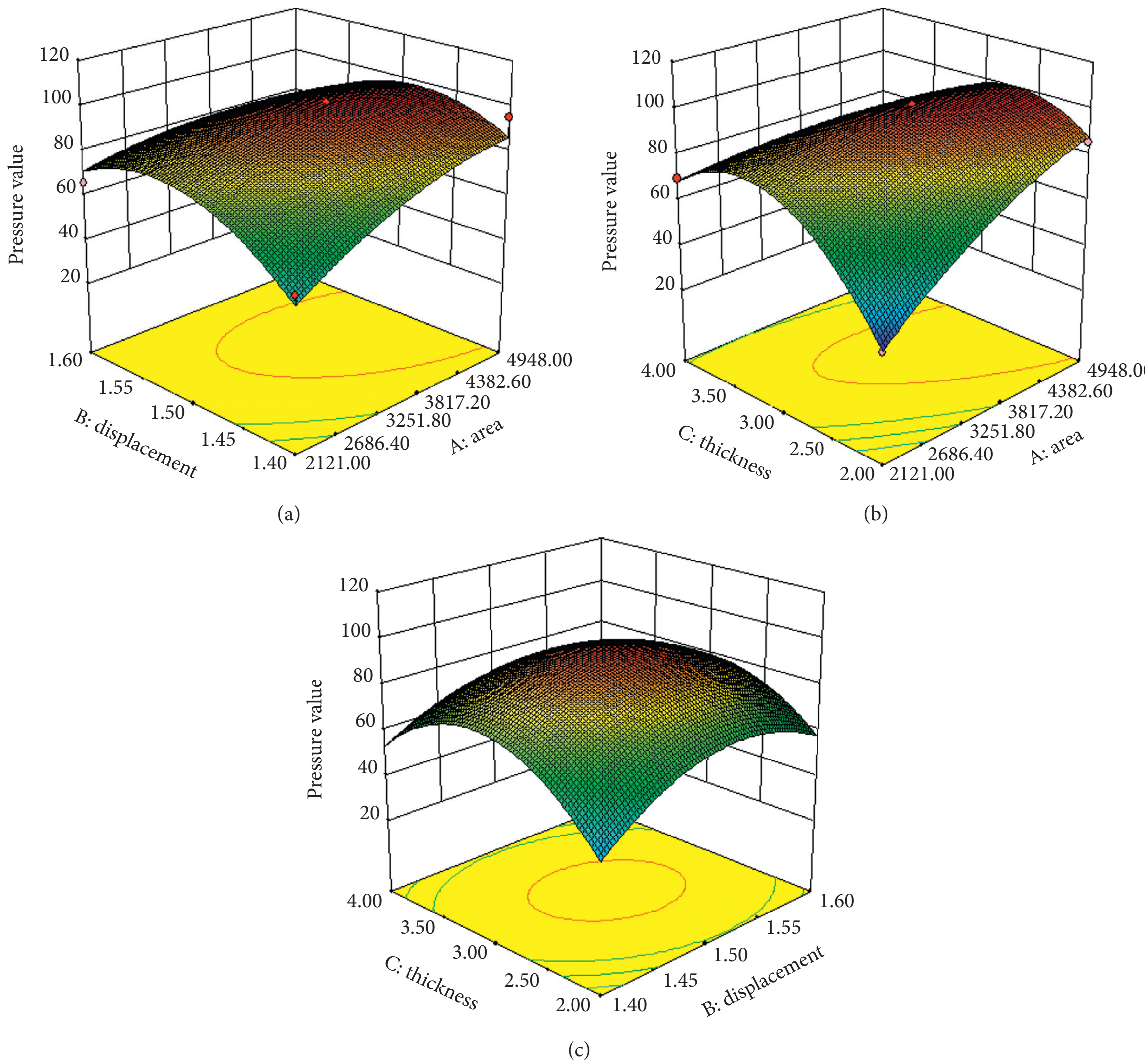

Figure 9: Effect of experimental parameters on the pressure value. (a) Effect of area and displacement. (b) Effect of area and thickness. (c) Effect of thickness and displacement.

The effect of experimental parameters on the long and short axis ratio is shown in Figure 10. The range of the ratio was from 1.0074 to 1.0341. Three factors have different effects on the ratio. When the displacement increased, the ratio increased first and decreased later. The same phenomenon of change can be found in the effect of thickness. The ratio decreased with the area decreasing, respectively. It also has several designed points beyond the predicted value. The contours of the response surface showed that the elliptic curvature in Figure 10(b) was the largest. There was an interaction between the arc surface area of the clamping element and the rubber thickness.

Figure 11 shows the influence of the three factors on the pull value of the bacteria bottle. The pull value was in the range of 31.055 N to 89.54 N. The more significant the area is, the higher the pull value is. Moreover, the pull value increased first and decreased later due to the increase of the displacement or the thickness. It can be found that some designed points are out of range. The contour of the response surface showed that the elliptic curvature in Figure 10(b) was the largest. It had an interaction between the arc surface area of the clamping elements and the rubber thickness.

3.4. Experimental Verification. According to the Design-Expert software, the multiobjective and nonlinear optimization method was used to solve the regression model under the target, and the optimal parameter combination was finally obtained. The optimization constraints were min Y_1 (A, B, C), min $Y_2(A, B, C)$, and Y_3 $(A, B, C) > 32$. The variable range is $-1 \leq A \leq 1$, $-1 \leq B \leq 1$, $-1 \leq C \leq 1$.

Finally, the optimized parameters were obtained. The inner arc area of the clamping element was 4948 mm^2. The downward pressure displacement was 1.48 mm. The rubber thickness was 3.69 mm. The pressure of the bacteria bottle was 73.84 N. The long and short axis ratio of the bacteria bottle mouth was 1.02, and the tensile force of the bacteria bottle was 67.75 N.

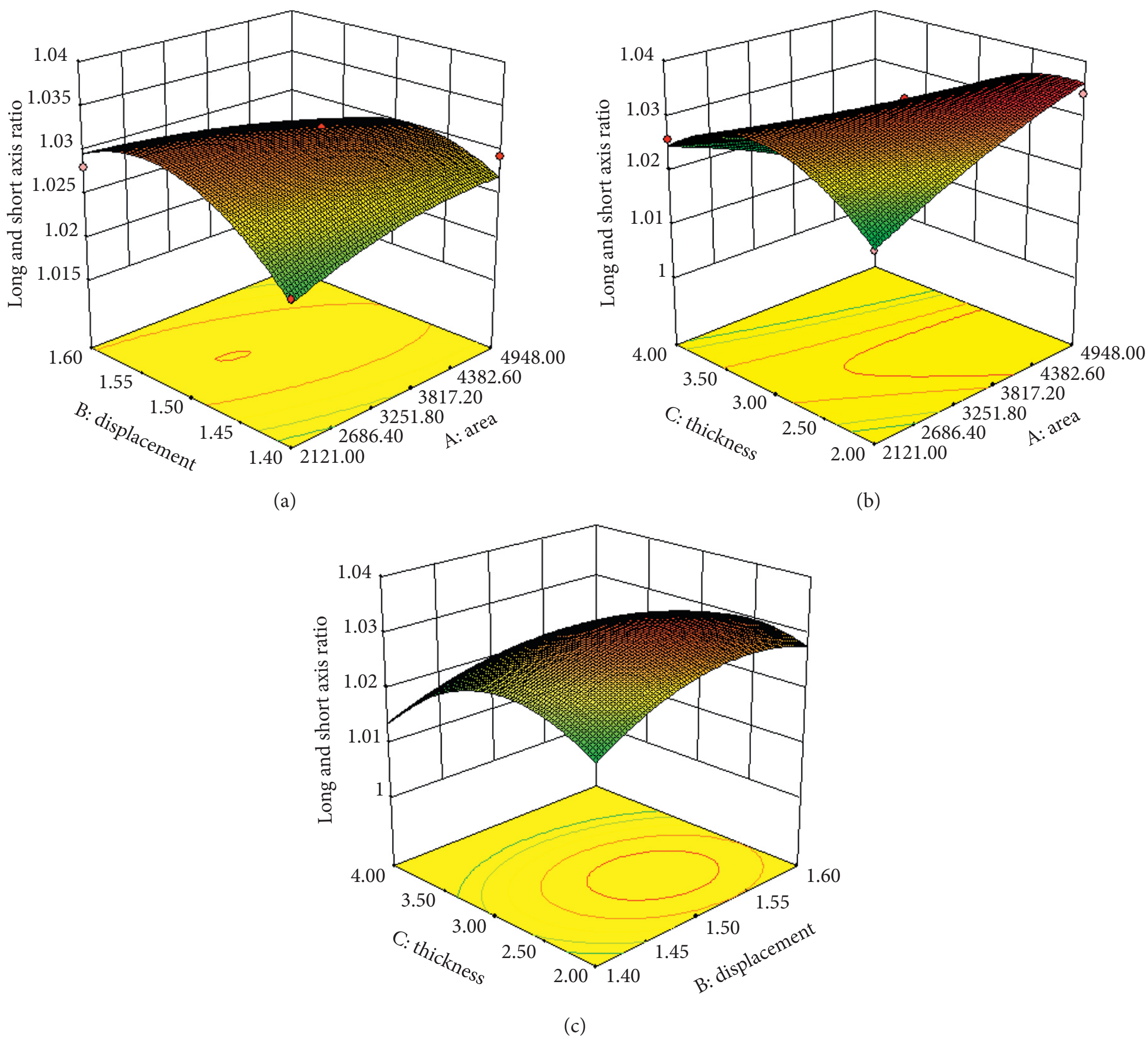

Figure 10: Effect of experimental parameters on long and short axis ratio. (a) Effect of area and displacement. (b) Effect of area and thickness. (c) Effect of thickness and displacement.

To verify the feasibility of the optimization results, experimental verification of the optimization parameters was performed. The inner arc surface area of the clamping element was 4948 mm^2, the downward displacement was 1.48 mm, and the rubber thickness was 3.7 mm. Under these conditions, the bacteria bottle pressure test was repeated three times, and an average was obtained. As shown in Table 5, the results were obtained and were close to the predicted values. Therefore, it appears that the relevant test research meets the clamping component's performance and technical requirements.

4. Discussion

The clamping elements' design is similar to banana fixtures [17, 18] in terms of research methods, though they have different mechanical tests subjects. Besides, some models and methods using the design of Wu and Xi [8] are also evaluated in our study. It can improve the property of the clamping elements due to using these reasonable methods.

The pressure test of a whole bacteria bottle was conducted for selecting levels of the single-factor test. The results are shown in Table 1. Compared with other studies [23], the test machine is used to produce a uniform force on the bottle's surface instead of using different weights. It is more direct, accurate, and convenient.

A Box–Behnken test was designed and used to obtain related data. The results are shown in Tables 2 and 3. Moreover, the mathematical models were established by referring the analysis of variance and response surface methods [27, 30]. The relationships among three factors were obtained after analyzing formulas (4) to (6). Figures 9 to 11 show the response surface exhibiting the effects of three factors on the detection indicators. The response surfaces reflect that they have a good agreement of the variance with mathematics analysis, and results are observed. In detail, the estimated value and measured value are presented in Table 5. They have a good fit in an acceptable range of errors. Finally, the optimized parameters are validated by its great agreement with well-established analytical models and verification experiments.

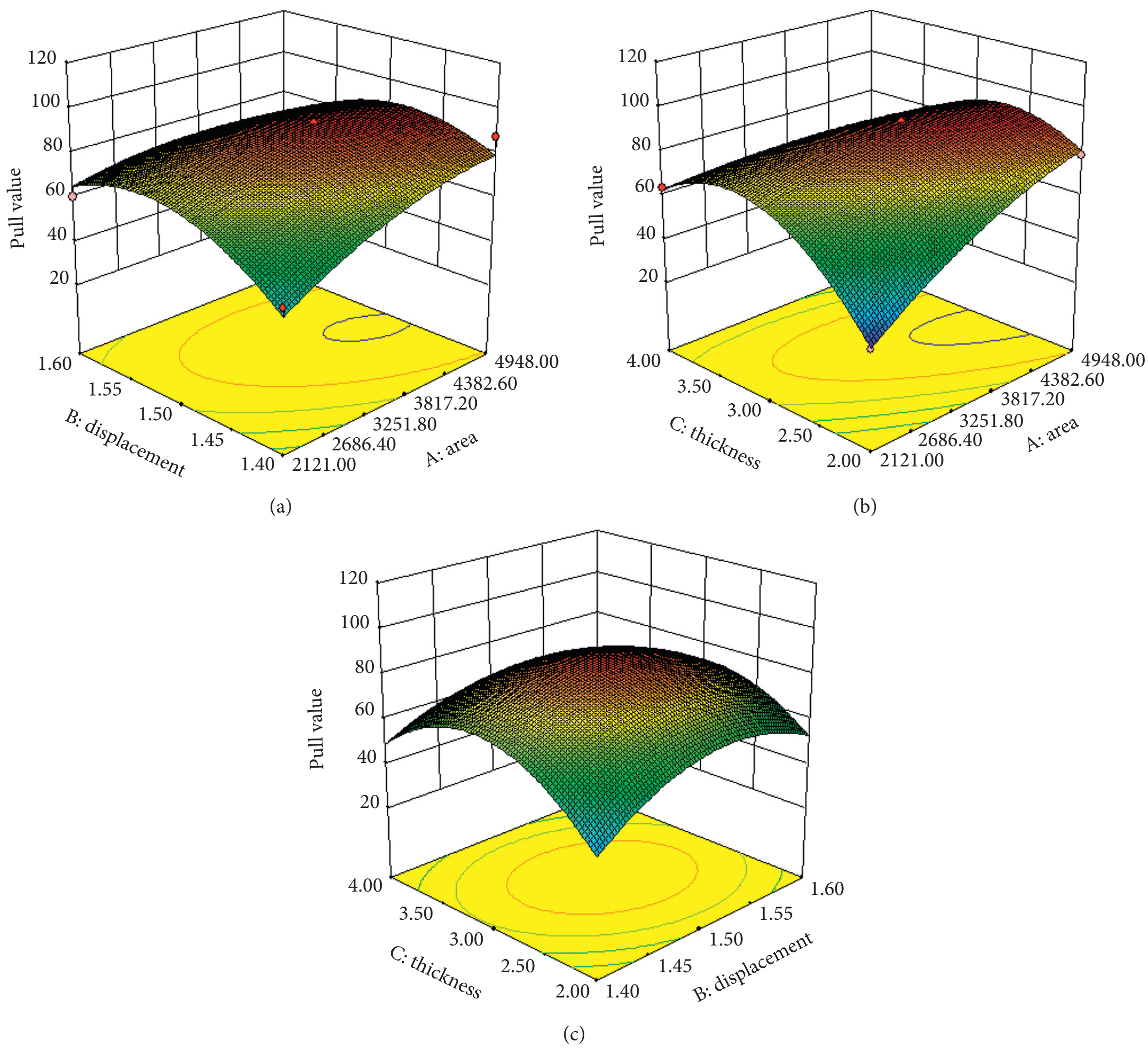

Figure 11: Effect of experimental parameters on the pull. (a) Effect of area and displacement. (b) Effect of area and thickness. (c) Effect of thickness and displacement.

Table 5: Optimal performance and corresponding parameters.

Experimental factors			Test index			Actual results		
A	b	c	y1	y2	y3	y1	y2	y3
4948 mm^2	1.48 mm	3.69 mm	73.8377 N	1.0166	67.7549 N	75.6856 N	1.0261	69.4506 N

In the present study, we investigated the fact that labors picked the bottled mushroom due to lack of the harvester. And a set of clamping elements was devised to effectively hold the bacteria bottles, which was an essential part of designing a picking robot. We conducted the Box–Behnken test to obtain data that were used to establish the regression models. The response surface method was applied to obtain the relationship between the variation and variation resources. The results demonstrated that the mathematical models had a good fit to the designed experiment. The verification test confirmed that the optimized clamping elements had a good clamping effect. This finding is significant because it provides the possibility of using a robot to pick the bottled mushroom, especially the bottled *F. velutipes*. To our knowledge, this was the first time a mechanical test was conducted using the bacteria bottles with fresh culture material, aiming to design and optimize a fixture for bottled mushroom picking robots. However, the bacteria bottle's mechanical properties have a few differences from that of the plastic bottle because of the different contents in bottles. And the effect of the response surface method is verified again. Compared to other studies, we connected the mechanical test with the response surface method to design a fixture. It is more direct and concise in optimizing parameters of clamping elements.

To improve the clamping elements' holding effect, the method of mechanical test needs to be investigated systematically. The range of the pointer push-pull force meter is limited. A further study should be performed to verify whether using a force transducer can make a difference in this study or not. Besides, the method of choosing the area of the clamping elements should be improved further. Finding a more accurate project becomes necessary in the future. In this study, we demonstrated that the clamping elements were designed and optimized by the mechanical test and response surface method. The desired values have a good agreement with the experiment. This suggests the feasibility of designing a fixture of a thin-walled pipe by using the method of our study process. The optimized clamping elements would be a valuable part of the application in designing a bacteria bottle fixture of the picking robot.

5. Conclusion

In this paper, we proposed a kind of clamping element for designing a fixture of the bottled *F. velutipes* picking machine. After the experimental research, the influences of process parameters on pressure, long and short axis ratio, and rubber thickness were investigated. To obtain the desired values of the clamping elements' parameters, the adequacy of the proposed model was examined and the confirmation test was carried out to study the accuracy of the optimized parameters. The differences between the actual value and the predicted value were seen as within the acceptable limit. For these experimental investigations, the following conclusion has been drawn:

(a) The clamping elements were designed according to the medium bacteria bottles that were used universally in the industrial production of edible fungi. The pressure test of the bacteria bottle was carried out using the clamping elements. The significant levels were obtained by conducting a single-factor test.

(b) A Box–Behnken test was used to establish a mathematical regression model between the performance indicators of the bacteria bottle pressure test and three test factors (including the inner arc surface area, the displacement of the pressure, and the rubber thickness). The influence and interaction of each factor on the test index were obtained by establishing variance models. Among these experimental factors, the inner arc surface areas significantly influence the pressure and pull value of the bacteria bottle. The ratio of the long and short axis can be influenced dramatically by changing the rubber thickness.

(c) Mathematical models were established for analyzing the test data, and the response surface method was used to optimize the regression equation. The optimal parameters were as follows: the area of the clamping element's internal arc surface was 4948 mm^2, the downward displacement was 1.48 mm, and the rubber thickness was 3.69 mm. Meanwhile, the bacteria bottle's pressure value was 73.84 N, the long and short axis ratio of the bacteria bottle was 1.02, and the strain value of the bacteria bottle was 67.75 N. The same test method was used to verify the optimization results. The actual values were as follows: the pressure value of the bacteria bottle was 75.69 N. The ratio of the long and short axis of the bacteria bottle mouth was 1.03, and the strain value of the bacteria bottle was 69.45 N.

(d) The method of the mechanical test needs to be investigated systematically to improve the clamping elements' holding effect. The designed clamping elements are used to hold the bottled *F. velutipes*. It is important to study whether different cultures in bottles have different effects on the results or not. It is also necessary to develop a kind of fixture that can hold several bacteria bottles to improve the efficiency of harvesting in the future.

Data Availability

The data used to support the findings of the study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This study was supported by grants from the China Agricultural Research System Fund (CARS-20), P. R. of China. The authors would like to thank NIAM for equipment support, Jiangnan Biotechnology Limited for material and technical support, and Professor Weidong Song for critically reviewing the manuscript.

References

[1] M. Rugolo, L. Levin, and B. E. Lechner, "Flammulina velutipes: an option for "alperujo" use," *Revista Iberoamericana de Micología*, vol. 33, no. 4, pp. 242–247, 2016.

[2] G. Sun, X. Wang, H. L. Luo, T. Z. Zhang, and H. Liu, "A low cost 3D acquiring system for mushroom robot based on webcam and line laser," *Sensors & Transducers*, vol. 26, pp. 35–39, 2014.

[3] V. D. Kamble and A. Tom Mathew, "Brief review of methodologies for creation of cohesive fixture design," *Materials Today: Proceedings*, vol. 22, pp. 3353–3363, 2020.

[4] O. Gonzalo, J. M. Seara, E. Guruceta et al., "A method to minimize the workpiece deformation using a concept of intelligent fixture," *Robotics and Computer-Integrated Manufacturing*, vol. 48, pp. 209–218, 2017.

[5] D. Vukelic, B. Tadic, B. Bogdanovic, and P. Todorovic, "Using pre-processing and indenting of contact interface to improve fixture clamping efficiency," *International Journal of Advanced Manufacturing Technology*, vol. 104, no. 1-4, pp. 179–194, 2019.

[6] W. Sun, M. Luo, and D. Zhang, "Machining vibration monitoring based on dynamic clamping force measuring in thin-walled components milling," *International Journal of*

Advanced Manufacturing Technology, vol. 107, no. 5-6, pp. 2211–2226, 2020.

[7] W. Huamin, Q. Guohua, W. Zhuxi, and Z. Dunwen, "A workpiece stability-based iterative planning of clamping forces for fixturing layout specification of a complex workpiece," *International Journal of Advanced Manufacturing Technology*, vol. 103, no. 5-8, pp. 2017–2035, 2019.

[8] B. H Wu and J. J Xi, "Design and research of synchronous-style clamping mechanism for cable-detecting robot," *Advanced Materials Research*, vol. 1028, pp. 127–133, (2014).

[9] Z. Li, B. Xu, M. Huang et al., "Structure design and finite element analysis of box type cargo picking robot clamp type end effector," *The Journal of Engineering*, vol. 23, pp. 8812–8815, 2019.

[10] U Din, P Hao, P. Panier et al., "Design of a new Arcan fixture for in-plane pure shear and combined normal/shear stress characterization of fiber reinforced polymer composites," *Experimental Techniques*, vol. 44, no. 2, pp. 231–240, 2019.

[11] T. Papastathis, M. Ryll, and S. Ratchev, "Rapid reconfiguration and part repositioning with an intelligent fixturing system," in *Proceedings of the 2007 International Manufacturing Science and Engineering Conference*, ASME, pp. 705–713, Atlanta, GA, USA, October 2007.

[12] D. Wu, B. Zhao, H. Wang, K. Zhang, and J. Yu, "Investigate on computer-aided fixture design and evaluation algorithm for near-net-shaped jet engine blade," *Journal of Manufacturing Processes*, vol. 54, pp. 393–412, 2020.

[13] K. G Yu, "Robust fixture design of compliant assembly process based on a support vector regression model," *The International Journal of Advanced Manufacturing Technology*, vol. 103, no. 1-4, pp. 111–126, 2019.

[14] Z. Liu, Y. W. Michael, K. Wang et al., "Fixture performance improvement by an accelerated integral method of fixture layout and clamping force plan," *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, vol. 227, no. 12, pp. 1819–1829, 2013.

[15] M. J. Nategh and H. Parvaz, "Development of computer aided clamping system design for workpieces with freeform surfaces," *Computer Aided Design*, vol. 95, pp. 52–61, 2018.

[16] B. Zhang, R. Dai, W. Ma et al., "Analysis and design of carbon fibre clamping apparatus for replacement of insulator strings in ultra-high voltage transmission line," *The Journal of Engineering*, vol. 16, pp. 2212–2215, 2019.

[17] Z. B Zhu, Z Yang, J. F Sun et al., "Parameter optimization and experiment of pneumatic holding part for banana crown cutting," *Transactions of the CSAE*, vol. 32, no. 4, pp. 33–39, 2016.

[18] H. J Wang, Z. F Tang, R. M Zhao et al., "Simulation and optimization design of holding device for banana picking manipulator," *Machine Design and Manufacture*, vol. 6, pp. 161–164, 2015.

[19] L. F. P. Medellín, V. A. R. Elías, A. de J. B. García et al., "On the implementation of FEA for the design and development of a new biaxial tensile test fxture for uniaxial testing machine: a validation for cruciform test specimens," *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, vol. 41, p. 367, 2019.

[20] M. Calabrese, T. Primo, and A. Del Prete, "Optimization of machining fixture for aeronautical thin-walled components," *Procedia CIRP*, vol. 60, pp. 32–37, 2017.

[21] R Dijk, J. C Sterk, D Sgorbani et al., "Lateral deformation of plastic bottles: experiments, simulations and prevention," *Packing Technology and Science*, vol. 11, pp. 91–117, 1998.

[22] D Tsiourvas, J Pagidas, and A Stassinopoulos, "Development of plastic bottles resistant to lateral deformation," *Packing Technology and Science*, vol. 6, pp. 23–29, 1993.

[23] A Winkler, A. Santo, M. A Ortenzi et al., "Does mechanical stress cause microplastic release from plastic water bottles," *Water Research*, vol. 166, pp. 1–13, 2019.

[24] Y. Fang, *Engineering Mechanics*, Tsinghua University press, Beijing, China, 2nd edition, 2012.

[25] W. Gao, W. Song, M. Wang, J. Wang et al., "Design and analysis of bottled Flammulina velutipes pull-out testing," *International Agricultural Engineering Journal*, vol. 29, no. 2, 2020.

[26] M. Mohammad and K. R. Pullen, "Optimization of a centrifugal compressor using the design of experiment technique," *Applied Sciences*, vol. 9, no. 2, p. 291, 2019.

[27] A Pandiyan, G Arun Kumar, S Ranganthan et al., "Optimization of wear performance on aluminium die cast A360-M1 master alloy using response surface method," *Materials Today: Porceedings*, vol. 22, pp. 551–557, 2019.

[28] C. Bikash, S. Ruma, K. G. Subrata et al., "Modelling and multi-reponse optimization of wire electric discharge machining parameters using response surface methodology and grey-fuzzy algorithm," *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, vol. 231, no. 10, pp. 1760–1774, 2017.

[29] Q Wang, K He, C. Q Jin et al., "Mechanical analysis and experiment optimization on parameters of maize exciting and picking," *Transactions of the Chinese Society for Agricultural Machinery*, vol. 49, pp. 249–257, 2018.

[30] J. M Kang, X. G Chen, H. J Wen et al., "Opitization of comb-type cotton picker device based on response surface methodology," *Transactions of the Chinese Society for Agricultural Machinery*, vol. 44, pp. 57–61, 2013.

[31] Y. F Liu, J Lin, B. F Li et al., "Design and experiment of horizontal disc seed metering device for maize seeder," *Transactions of the CSAE*, vol. 33, no. 8, pp. 37–46, 2017.

[32] I. Ahmad Yusuf, N. Gangta, and B. Koo, "Topology and response surface optimization of a bicycle crank arm with multiple load cases," *Applied Sciences*, vol. 10, no. 6, p. 2201, 2020.