ANALYSIS AND OPTIMIZATION ON THE PROCESS OF ADJUSTABLE DOUBLE DRUM CASTOR SHELLING BASED ON DISCRETE ELEMENT METHOD

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ABSTRACT
The shelling stress of the castor capsule is difficult to obtain by experiments, which is vital for the design of the key components for the shelling machine. The stress analysis of the shelling process of the castor capsule is carried out. In this study, the typical variety castor Tongbi 11 is taken as the research object, and the model of castor shelling is established. The stress and rate of shelling removal of the inner drum are analysed. The effects of size optimization on the shelling results were analysed. The shelling machine was designed for the experiment. In the condition of the highest rate of shelling, the size of the outer drum is maintained, and the inner drum angle is 4.5°. The length of the drum is 605mm. At this time, the shelling rate is 96.42 %, which is 0.39 % different from the fitting value. This study provides theoretical support for the design and parameter optimization of the castor shelling machine and its key components.

INTRODUCTION
Castor is one of the ten oil crops in the world. Its oil is a crucial lubricating oil for aerospace, railway, and high-speed machine tools (Li Jinqin et al., 2004; Hou J.M., et al., 2020; Huang Zhihui et al., 2013; Liu Rukuan et al., 2015). Shelling is the first step of castor oil processing, which directly affects the quality of subsequent products. The existing shelling machine is low efficiency and high shelling damage rate, which reduces the quality of castor oil. (Sebastian Romuli et al., 2015; Bo Yuan Lim et al., 2014; Boyuan L. et al., 2015). The principles of the force properties among particles in the process of shelling are not clear, which leads to the unclear mechanism of shelling damage. The discrete element method can be applied to study the principles of group force in the process of shelling, which enrich the design theory of castor oil shelling equipment.

Some scholars (Wang Zhibing et al., 2015; Ali Nejat Lorestani et al., 2013; Hou Junming et al., 2015) explored the mechanical properties of agricultural material and analysed its rupture principle. Mehrdad et al., (2016), took corn as the research object, constructed two different models, explained the movement and mixing of corn in the machine, and compared with the experiment results. Coetsee et al., (2016), calibrated a gravel particle model, which established the gravel particle composed of 2, 4, and 8 particles, and compared the results with the resting angle calibration. Some scholars (Jia Honglei et al., 2018; Zhao Shuhong et al., 2016; Shi Song et al., 2015; Dun Guoqiang et al., 2016) used discrete element method to analyse the movement of particles in the seeder and compared the seeding rate, seeding leakage rate and reseeding rate were obtained by simulation analysis with the experiment.

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The EDEM software was applied to study the stress on the lining board of a ball mill and analysed the interaction between pulp and coarse particles (Sun Shanshan et al., 2018; Hao Wanjun et al., 2010; Bian Xiaolei et al., 2017; Li Kunyuan et al., 2017; Cleary P W et al., 2015; and Sinnott M D et al., 2017). The key discrete element parameters of soil were calculated and the stress condition of the rotary blade under different working conditions were studied (Wang et al., 2017; Wu Tao et al., 2017; Xiong Pingyuan et al., 2017; and Xiong Pingyuan et al., 2018). That provides a reference for studies on rotary tillage, energy consumption, and blade wear. In conclusion, the research on the mechanical properties of agricultural material has made specific progress, but there are a few studies on the force analysis of the group moved blade wear.

**MATERIALS AND METHODS**

**Hertz-Mindlin bonding contact model**

In this study, a castor bond model is established. In the model, the relationship between the force and displacement of particles in each contact is described by six parameters, including the stiffness and tangential stiffness, and the friction coefficient between two contact particles. The particle to particle contact, the centre of the contact area, the line between the centre point of two particles, and the centre point are established.

**Establishment of a castor capsule fragmentation model**

We established the castor discrete model, and the contact model is by Hertz-Mindlin model. The whole particle is composed of three particles, which are combined by bonding to form a single castor capsule. Fig 1 is the model replacement model. Table 1 is the primary setting of parameters for the castor discrete element, and Table 2 is the setting of bonding parameters.

![Fig. 1 - Replacement effect of castor discrete element model](image)

| Parameters setting of castor discrete element model | Table 1 |
|-----------------------------------------------|--------|
| **Category** | **Value** | **Category** | **Value** | **Category** | **Value** |
| Castor Poisson’s ratio | 0.3 | Q235 steel Poisson’s ratio | 0.3 | Rubber Poisson’s ratio | 0.45 |
| Castor shear modulus [10^6 MPa] | 17 | Q235 steel shear modulus [10^6 MPa] | 79 | Rubber shear modulus [10^6 MPa] | 1 |
| Castor density [kg/m^3] | 1000 | Steel density Q235 [kg/m^3] | 7800 | Rubber density [kg/m^3] | 9100 |
| Castor - castor collision recovery coefficient | 0.15 | Collision recovery coefficient of castor-Q235 steel | 0.44 | Castor-rubber collision recovery coefficient | 0.37 |
| Castor - castor static friction coefficient | 0.6 | Static friction coefficient of castor-Q235 steel | 0.4 | Castor-rubber static friction coefficient | 0.7 |
| Castor oil - castor oil dynamic friction coefficient | 0.05 | Dynamic friction coefficient of castor-Q235 steel | 0.01 | Castor-rubber coefficient of kinetic friction | 0.05 |

| Setting of bonding parameters | |
|-------------------------------|--------|
| **Bonding parameters** | **Value** |
| Unit area normal stiffness | [N/m^2] | 2.1×10^9 |
| Tangential stiffness per unit area | [N/m^2] | 1.4×10^9 |
| Maximum normal force | [Pa] | 2.1×10^6 |
| Maximum tangential force | [Pa] | 1.5×10^6 |
| Bond plate radius | [mm] | 1.6 |
Establishment of castor capsule shelling model

It is known from the mechanical properties of the castor capsule (Fang Huimin et al., 2017) that when castor capsule is ruptured and unshelled, three-compartment separation is carried out firstly, and then single-compartment capsule is unshelled. When the three-compartment structure is destroyed, then it moves to the rubbing and pressing area for shelling. The six pressing pieces are welded at the shelling drum, which is distributed evenly on the inner drum. The pressing pieces are coated with 3.0mm thick mesh rubber. Fig.2 shows the model and the inner drum model, and Table 3 shows the parameters of the shelling machine model.

![Shelling model and inner drum model](image)

**Fig. 2 - Shelling model and inner drum model**

| Setting of shelling machine parameters | Name                        | Value | Name                        | Value |
|---------------------------------------|------------------------------|-------|------------------------------|-------|
| Minimum radius of the inner drum      | [mm]                        | 137   | The roller cone angle        | [°]   |
| Minimum radius of the outer drum      | [mm]                        | 158   | Outside of the roller cone   | [°]   |
| Inner drum length                     | [mm]                        | 600   | Inlet length                 | [mm]  |
| Length of outer drum                  | [mm]                        | 700   | Inlet width                  | [mm]  |
| Drum angle                            | [°]                         | 25    | Pressure height              | [mm]  |
| The end arc length of the pressing    | [mm]                        | 79    | Big end arc length           | [mm]  |

Setting and results of the simulation

The response values of pressure and decanting rate of the inner drum were taken as the response values. Response surface analysis was carried out according to the results. Table 4 is the factor level for simulation.

| Test factor level of Box-Behnken       | Level  | A Speed [r/min] | B Shelling gap [mm] | C Filling amount [%] |
|----------------------------------------|--------|----------------|--------------------|---------------------|
|                                       | -1     | 250            | 5.0                | 30                  |
|                                       | 0      | 300            | 6.0                | 40                  |
|                                       | 1      | 350            | 7.0                | 50                  |

RESULTS

Analysis of inner drum stress

In the process of shelling, the stress of the inner drum is analysed. Table 5 shows the analysis of the variance of the maximum pressure of particles.

| ANOVA of the model of Box-Behnken design experiment | Error sources | Square sum | Error freedom | Mean square | F value | P value |
|---------------------------------------------------|---------------|------------|---------------|-------------|---------|---------|
| Model                                             | 3.74×10⁵      | 9          | 41497.71      | 18.93       | 4×10⁴   |
| A                                                 | 5658.36       | 1          | 5658.36       | 2.58        | 0.1522  |
| B                                                 | 1.23×10⁵      | 1          | 1.23×10⁵      | 56.23       | <10⁻⁴   |
| C                                                 | 1.40×10⁵      | 1          | 1.40×10⁵      | 63.96       | <10⁻⁴   |
| AB                                                | 2126.59       | 1          | 2126.59       | 0.97        | 0.36    |
| AC                                                | 4449.56       | 1          | 4449.56       | 2.03        | 0.20    |
| BC                                                | 22422.07      | 1          | 22422.07      | 10.23       | <10⁻²   |
| A²                                                | 7124.41       | 1          | 7124.41       | 3.25        | 0.1     |
| B²                                                | 43885.37      | 1          | 43885.37      | 20.02       | 2.9×10⁻³|
| C²                                                | 17615.84      | 1          | 17615.84      | 8.04        | 0.03    |

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The coefficient of variation of C.V. is 9.19%, which shows that the test has high reliability. The Adep Precision value of 14.29 indicates that the test has high reliability and accuracy. The $P$ value of the missing fitting term is higher than 0.05, indicating that the quadratic polynomial equation has a high degree of fitting. Equation (1) is the quadratic polynomial equation of the shell breaking rate with all factors.

$$Y = -11455.99 + 11.24A + 1486.73B + 337.45C + 0.46AB - 0.13AC - 14.97BC - 0.02A^2 - 102.09B^2 - 2.59C^2 \quad (1)$$

Fig. 3 shows the response of the shelling clearance amount. When the shelling clearance amount is fixed, the pressure of the inner drum increases with the increase of the filling amount. When the filling amount is constant, the pressure of the inner drum decreases with the increase of the clearance. When the clearance gap is between 5.0 mm and 6.0 mm, the pressure of the inner drum decreases slowly with the growth of the filling amount. When the shelling gap is between 6.0 mm and 7.0 mm, the pressure of the inner drum decreases faster with the rise of the filling amount.

| Error sources | Square sum | Error freedom | Mean square | $F$ value | $P$ value |
|---------------|------------|---------------|-------------|-----------|-----------|
| Residual item | 1534.86    | 7             | 2191.98     |           |           |
| Missing items | 9782.56    | 3             | 3260.85     | 2.35      | 0.21      |
| Pure error    | 5561.30    | 4             | 1390.32     |           |           |
| Summation     | 3.89×10^5  | 16            |             |           |           |

Note: $R^2=0.9605$; $R^2=0.9098$; $C.V.=0.89$%; Adep Precision=14.29

Shelling removal rate results

According to Table 6, the variance analysis of the shelling pellet rate was performed. It can be seen that the coefficient of variation of C.V. is 0.89%, which proves that the experiment has a high degree of credibility. The determination coefficient $R^2$ and the adjusted determination coefficient $R^2$ are both close to 1, indicating that the fitting equation is highly reliable.

Equation (2) is the quadratic polynomial equation of the shell breaking rate with all factors.

$$Y = -60.97 + 0.46A + 7.07B + 3.59C - 0.02AB - 2.9 \times 10^{-3}AC - 0.18BC - 3.25 \times 10^{-4}A^2 - 0.27B^2 - 0.02C^2 \quad (2)$$

### ANOVA of the model of Box-Behnken designs experiment

| Error sources | Square sum | Freedom | Mean square | $F$ value | $P$ value |
|---------------|------------|---------|-------------|-----------|-----------|
| Model         | 133.39     | 9       | 14.82       | 22.73     | 2×10^{-4} |
| $A$           | 11.62      | 1       | 11.62       | 17.82     | 3.9×10^{-3} |
| $B$           | 67.57      | 1       | 67.57       | 103.83    | <10^{-4}   |
| $C$           | 5.46       | 1       | 5.46        | 8.38      | 2.32×10^{-2} |
| $AB$          | 4.20       | 1       | 4.20        | 6.45      | 3.87×10^{-2} |
| $AC$          | 8.41       | 1       | 8.41        | 12.90     | 8.80×10^{-3} |
| $BC$          | 12.57      | 1       | 12.57       | 19.27     | 3.2×10^{-3} |
| $A^2$         | 2.77       | 1       | 2.77        | 4.25      | 7.82×10^{-2} |
| $B^2$         | 0.31       | 1       | 0.31        | 0.48      | 0.51       |
| $C^2$         | 19.90      | 1       | 19.90       | 30.51     | 9×10^{-4}  |
| Residual item | 4.56       | 7       | 0.65        |           |           |
| Missing items | 1.94       | 3       | 0.65        | 0.98      | 0.48       |
| Pure error    | 2.63       | 4       | 0.66        |           |           |
| Summation     | 137.95     | 16      |             |           |           |

$R^2=0.9669$; $R^2=0.9244$; C.V.=0.89%; Adep Precision=19.38
The model’s \( P \) value is less than 0.01, so all factors of the design test have a significant impact on the rate of shelling removal. The rotational speed, shelling clearance, and filling amount have a significant impact on the shelling rate. Among them, the shelling clearance has the most significant impact, followed by the rotational speed, and the filling amount is the smallest.

The interaction between rotational speed×filling amount and shelling gap×filling amount has a significant impact on the shelling removal rate. Among them, the influence of rotational speed×filling amount is greater than the rotational speed×shelling rate.

The shelling removal rate was set as the maximum value, and the optimal parameters were obtained. When the rotational speed was 350r/min, the shelling gap was 5.0 mm, and the filling amount was 40%.

Take the shelling clearance gap as 5.0 mm and analyse the interaction between the remaining two factors. Fig. 4 (a) shows the effect analysis diagram of rotational speed×filling quantity. When the rotational speed was fixed, with the increase of the filling amount, the unshelled particles first increase and then decreased. As the filling amount was 40%, the castors shell broken. If the filling amount was fixed, the shell removal rate increased with the increase of rotational speed. When the filling amount was between 30% and 40%, the shelling rate rose rapidly with the rising of rotational speed. Furthermore, if the filling amount was between 40% and 50%, the shell removal rate increased slowly with the increase of rotational speed.

As the drum rotational speed was 350 r/min, the interaction between the remaining two factors was analysed. Fig. 4 (b) shows the effect analysis diagram of the shelling clearance×filling amount. When the shelling clearance was fixed, with the increase of the filling amount, the unshelled particle firstly increased and then decreased. The peak value reached when the filling amount was 40%. When the filling amount was fixed, the rate of shell removal decreased with the increase of shelling gap.

![Fig. 4 - Response surface of interaction](image)

Single factor analysis of castor capsule shelling

Table 7 shows the effect of rotational speed on each result. With the increase of rotational speed, the force on the inner drum first increased from 509.34N to 533.14N, and then decreased to 456.15N. The shelling rate first increased from 91.23% to 91.28% and then decreased to 88.89%.

| Speed [r/min] | Internal drum stress [N] | Shelling rate [%] |
|---------------|--------------------------|-------------------|
| 250           | 509.34                   | 91.23             |
| 300           | 533.14                   | 91.28             |
| 350           | 456.15                   | 88.89             |

Table 8 shows the influence of the shelling clearance on each result. With the increase of the shelling clearance, the force of the inner drum decreased from 576.39N to 528.14N. The shelling rate decreased from 92.50% to 83.41%.

| Shelling gap [mm] | Internal drum stress [N] | Shelling rate [%] |
|-------------------|--------------------------|-------------------|
| 5                 | 576.39                   | 92.50             |
| 6                 | 560.23                   | 89.59             |
| 7                 | 528.14                   | 83.41             |
Table 9 shows the influence of the filling amount on each result. With the increase of the filling amount, the force on the inner roller first increased from 338.58N to 603.364N. The rate of shelling decreased from 91.00% to 90.05%.

Table 9  

| Filling capacity [%] | Maximum pressure [N] | Maximum speed [m/s] | Inner drum force [N] | Shelling rate [%] |
|----------------------|-----------------------|---------------------|----------------------|------------------|
| 30                   | 55.86                 | 12.99               | 338.58               | 91.00            |
| 40                   | 68.67                 | 12.14               | 543.61               | 90.86            |
| 50                   | 76.93                 | 10.86               | 603.36               | 90.05            |

Size optimization of shelling parts

When the parameters of the inner and outer drum change, the volume of the unshelled drum will change. Fig. 5 shows the dimensions of the shelling parts.

In Fig.5, $l$ and $L$ are the length of the inner and outer drum; $r_1$ and $r_2$ are the radius of the small end of the inner and outer drum respectively. $R_1$ and $R_2$ are respectively the large end radius of the inner and outer drum; $x$ is the shelling clearance; $\alpha$ and $\beta$ are inside and outside the shelling drum cone angle respectively.

The volume change is shown in equation (3):

$$
\begin{align*}
\Delta V &= V_2 - V_1 \\
V_1 &= \frac{1}{3} \pi l (r_1^2 + r_2 R_1 + R_1^2) \\
V_2 &= \frac{1}{3} \pi l (r_2^2 + r_2 R_2 + R_2^2) \\
R_1 &= r_1 + l \tan \alpha \\
r_2 &= r_1 + x \\
R_2 &= r_2 + l \tan \beta \\
\alpha &< \beta
\end{align*}
$$

Where: $\Delta V$ for hulling chamber volume, mm$^3$.
$V_1$ and $V_2$ are respectively the volumes of the inner and outer drum, mm$^3$; $l$ and $L$ is the length of the inner and outer drum, mm; $r_1$ and $r_2$ are respectively the radius of the small end of the inner and outer drum, mm; $R_1$ and $R_2$ are respectively the radius of the large end of the inner and outer drum, mm; $x$ is the shelling clearance, mm; $\alpha$ and $\beta$, inside and outside the drum cone angle, respectively, °.

Fig. 6 - Relationship of shelling room volume changes and shelling rate
When the shelling rate was the highest, the rotational speed was 350r/min, the shelling gap was 5.0 mm, the volume of the outer drum platform was 8.06×10^{-2} m^3, and the volume of the shell removal chamber was 2.40×10^{-2} m^3. Fig. 6 shows the relationship between the volume change of the shelling chamber and the rate of shelling.

The fitting equation can be obtained as equation (4).

\[
y = 0.03x^2 + 6.35x + 227.20
\]  

(4)

As can be seen from Fig.6, with the increase of the volume of the shelling chamber, the shelling rate increased first and then decreased. From equation (3), it can be seen that the volume change of the shell removal drum is 105.83% to that of the original shelling inner drum. That is, when the volume of the original shell removal drum is increased by 5.83%, the maximum value of the shelling clearance rate is 96.03%. As the inner drum is the main shelling part, its size parameters are optimized, while the outer drum parameters are fixed. The shelling gap is 5.0 mm, so the small end radius of the inner drum is set. By changing the cone angle and length of the inner drum, the volume of the shell removal drum increases by 5.83%. By calculation, the volume of the internal drum is 5.61×10^{-2} m^3.

Shelling machine design

Based on the parameter setting of the simulation shelling model, the shelling machine was designed. We take shelling clearance and filling amount as the factors in the experiment. The experiment working conditions was compared with the simulation results. Shelling interval and filling quantity are factors, furthermore the damage rate and productivity are as an index. The experiment results were compared with the simulation results. Fig.7 is the schematic diagram of the whole machine, Fig.8 is the schematic diagram of the inner drum. Table.10 shows the adjustment parameters of the shelling machine.

![Schematic diagram of shelling machine](image1)

**Fig. 7 - Schematic diagram of shelling machine**

1. Motor; 2. Base frame; 3. Adjustment hole; 4. Adjustment arm; 5. Outer drum; 6. Feed hopper; 7. Inner drum

![Schematic diagram of the inner drum](image2)

**Fig. 8 - Schematic diagram of the inner drum**

| Adjustment parameters of test bench | Rotational speed | Shell clearance | Fill the quantity |
|------------------------------------|-----------------|-----------------|------------------|
| Adjustment mode                    | Frequency converter control | The drum moves forward and backwards on its axis | Input material quality |

**Table 10**

Test methods and instruments

The rotational speed of the inner drum, the clearance clearance, and the filling amount are the test factors, while the shelling rate, damage rate, and productivity are the test indicators. The rotational speed of the inner drum is changed through the frequency converter, the position of the outer drum is adjusted to change the shelling clearance, and the amount of feed is adapted to fit the filling amount.
The camera aims at the observation window and records the status of materials in the drum. Table 11 shows the test factor level setting.

Before each group of experiments, the total amount of feed was weighed. After the experiment, the castor capsules were selected and weighed, then the rate of shelling and damage is:

\[
C_1 = \frac{W_a + W_b}{W_a + W_b + W_c}
\]

(5)

\[
C_2 = \frac{W_c}{W_a + W_b + W_c}
\]

(6)

\[
C_3 = \frac{T}{W_a + W_b + W_c}
\]

(7)

Where, \(C_1\) is the shelling rate, \%; \(C_2\) is the damage rate, \%; \(C_3\) is the productivity, kg/h;

\(W_a\) is castor bean seed weight, kg;

\(W_b\) is the seed weight of damaged castor bean, kg;

\(W_c\) refers to the unpurified castor bean seed weight, kg;

\(T\) is the working time, h.

Table 11

| Level | A Rotational speed [r/min] | B Shelling gap [mm] | C Filling amount [%] |
|-------|--------------------------|--------------------|---------------------|
| -1    | 250                      | 5                  | 30                  |
| 0     | 300                      | 6                  | 40                  |
| 1     | 350                      | 7                  | 50                  |

The experimental material was castor Tongbi 11. When the moisture content of the material is 14.2%, the shelling experiment is carried out. Fig. 9 shows the testbed for castor shelling.

![Fig. 9 - Castor Shelling Test Bed](image)

1. Host; 2. Motor; 3. Light source; 4. Adjustment hole; 5. Frequency converter; 6. Adjustment arm; 7. Shelling drum; 8. Feeding hopper; 9. Observation window; 10. Frame; 11. High speed Camera

Analysis of test results

Table 12 shows the experiment results. It can be seen that for the shelling rate, the rotational speed is 350r/min, the shelling gap is 5.0mm, and the filling amount is 30% at the optimal level. For the damage rate, the optimal level is 250r/min, the optimal level is 7.0mm, and the optimal level is 50% of the filling amount. For productivity, the optimal speed is 350r/min, the shelling gap is 7.0mm, and the filling amount is 50%.

| Test number | A | B | C | Shelling rate [%] | Damage rate [%] | Productivity [kg/h] |
|-------------|---|---|---|-------------------|-----------------|---------------------|
| 1           | -1| -1| -1| 90.56            | 3.06            | 336.73              |
| 2           | -1| 0 | 0 | 86.72            | 2.82            | 362.49              |
| 3           | -1| 1 | 1 | 85.69            | 2.64            | 386.24              |
| 4           | 0 | -1| 0 | 90.51            | 2.93            | 375.26              |
| 5           | 0 | 0 | 1 | 90.86            | 3.16            | 382.46              |
| 6           | 0 | 1 | -1| 88.21            | 2.71            | 428.72              |
| 7           | 1 | -1| 1 | 91.82            | 3.22            | 456.75              |
| 8           | 1 | 0 | -1| 94.25            | 3.49            | 395.89              |
| 9           | 1 | 1 | 0 | 87.28            | 2.67            | 483.21              |
Comparison of shelling rate

It can be seen that the influences of rotational speed and shelling clearance on the shelling rate are both higher than the filling amount. Table 13 shows the comparison of simulation and test results of the shelling removal rate. It can be seen that the differences between simulation results and the measured results are small, with the difference ratio within 9%. The significance order of each factor obtained by simulation is the shelling gap, rotational speed, and filling amount. The significance order of each factor obtained by the experiment is the shelling gap, rotational speed, and filling amount. They are in the same order. The optimal combination obtained by the simulation is 350r/min, the shelling gap is 5.0mm, and the filling amount is 40%. The optimal combination obtained by the experiment is 350r/min, shelling gap is 5.0mm, and the filling amount is 30%. Among them, the speed and the shelling gap are incredibly significant factors, and the filling amount is substantial factor.

Table 13

Comparison between simulation and experiment results on shelling rate

| No. | Simulation results [%] | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  |
|-----|------------------------|----|----|----|----|----|----|----|----|----|
| 1   | 93.29                  |    |    |    |    |    |    |    |    |    |
| 2   | 91.36                  |    |    |    |    |    |    |    |    |    |
| 3   | 93.17                  |    |    |    |    |    |    |    |    |    |
| 4   | 96.24                  |    |    |    |    |    |    |    |    |    |
| 5   | 94.23                  |    |    |    |    |    |    |    |    |    |
| 6   | 89.47                  |    |    |    |    |    |    |    |    |    |
| 7   | 87.96                  |    |    |    |    |    |    |    |    |    |
| 8   | 88.32                  |    |    |    |    |    |    |    |    |    |
| 9   | 93.17                  |    |    |    |    |    |    |    |    |    |

CONCLUSIONS

(1) The shelling gap and the filling amount have a significant impact on the pressure of the inner drum, while the rotational speed has no significant impact on the pressure of the inner drum. With the increase of rotational speed, the force on the inner drum first increased from 509.34N to 533.14N, and then decreased to 456.15N. With the increase of the shelling clearance, the force of the inner roller first increased from 338.58N to 603.36N and the rate of shelling increased from 91% to 90.05%.

(2) The size of the shelling drum parameters was optimized. In the conditions of highest shelling rate, the size parameter was obtained. The optimized shelling drum cone angle was 4.5° and the drum length was 605.0 mm. Using this group of size parameters for simulation analysis, the shelling rate was 96.42%. There was a difference of 0.39% from the fitting value.

(3) The accuracy of the simulation model is verified on the shelling machine. The shelling clearance was significantly affected by the rotational speed, shelling rate, and filling amount. The damage rate was significantly affected by the rotational speed and shelling gap. By comparing the shelling rate, it can be seen that the difference ratio between the simulation result and the test result is 8.73% at the maximum and 1.43% at the minimum. The optimal parameter combination obtained by simulation was the rotational speed of 350r/min, the shelling gap of 5.0mm, and the filling amount of 40%. The optimal parameter combination obtained by experiment was the rotational speed of 350.0r/min, the shelling gap of 5.0mm, and the filling amount of 30%.

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