Structure design of camellia oleifera fruit sheller by EBD method

Jie Meng*, Ang Li and Xi Liang
College of Mechanical and Power Engineering, Chongqing University of Science and Technology, Chongqing, 401331, China
*Corresponding author’s e-mail: mj8101@163.com

Abstract. In this paper, through the analysis of the characteristics of camellia oleifera fruit (COF), a sheller with low damage rate of tea seeds, easy to manufacture and integrating shelling and screening functions is designed based on environment based design (EBD) method. The main structure of the COF sheller is designed and calculated. This design can provide a reference for the research of related machinery in camellia oleifera industry.

1. Introduction
Camellia oleifera is a kind of unique pure natural high-grade oil plant in China. COF which is composed of shell, tea seed and diaphragm, grows on the camellia oleifera tree. Most of the COF is irregular spherical, with a significant difference in size. Its shell is green with uneven thickness. Its tea seed is mostly prismatic or polygonal circular, which is more round and plump. According to statistics, the diameter of COF is mainly distributed in the range of 20-50mm, and the vertical and horizontal diameter distribution is the most between 25-45mm, reaching 91% and 97% respectively. 80% of COF with grain size more than 30mm, and the median diameter of COF is about 35mm. The distribution range of tea seed diameter is wide. The maximum size is more in the range of 16-28mm (99%), the minimum size is more between 8-15mm (92%)[1]. The total oil content of camellia oleifera seed is 26%-39%, while that of camellia seed is as high as 40%-50%. The oleic acid content of camellia oleifera seed oil is up to 80% and the fatty acid composition of camellia oleifera seed is very similar to that of olive oil, so it is known as "oriental olive oil" and has high economic value[2].

Because the shell of COF does not contain oil, the oil yield of COF is influenced by pressing with shell. It needs to be shelled. The traditional shelling method has the feature of long time, low efficiency, high labor cost, and is affected by the weather, which restricts the development of camellia oleifera Industry[3]. The existing COF sheller has the problems of low shelling rate, low efficiency and high damage rate of tea seeds[4]. On the basis of understanding the physical characteristics of COF, a practical modern COF sheller is designed in this paper, so as to improve the efficiency of shelling and screening of COF, reduce labor intensity and improve economic benefits.

2. EBD method
EBD is a relatively new design method which developed over the last two decades. Apart from traditional design methodologies, the EBD theory is logically derived from the axiomatic theory of design modeling, which is found on the recursive logic of design. The basic idea is that a design problem is implied in a product system and is composed of three parts: the environment in which the designed product is expected to work, the requirements on product structure, and the requirements on...
performance of the designed product. EBD method includes three main activities: environment analysis, conflict identification, and solution generation. These three activities work together progressively and simultaneously to generate and refine the design specifications and design solutions[5-6]. Recursive object model (ROM) is a key method for EBD, along with which implicit requirements can be revealed by recursive process.

Now, EBD is widely used in many design fields abroad. In this paper, this method is used to design the COF sheller.

3. Structure design of COF sheller

3.1. Overall design of COF sheller

Taking the Yangtze River valley and its south area as the background, combined with the analysis of the characteristics of COF and the existing sheller in previous part, a sheller is designed in this paper, which can remove the shell, has less damage to the COF and is easy to manufacture.

According to the design background and objective, a ROM diagram is drawn using EBD method, as Figure 1 shown. Then, generate questions using ROM-based question-asking method, as shown in Table 1 and Table 2. The solution is obtained by answering these questions.

Table 1. Questions based on design objective

| Questions                           | Answers                                      |
|------------------------------------|----------------------------------------------|
| What is shelling?                  | Separate the flesh from the shell            |
| What kind of shell to remove?      | The shell of COF                            |
| Why remove the shell?              | Obtain the tea seed of COF                   |
| What damage will be caused?        | The tea seeds are cracked or broken          |
| What does the lower damage mean?   | The number of damaged tea seeds is small     |
| What does it mean of easy to manufacture? | The structure is simple                   |

Table 2. Questions need to be solved by the solution

| Questions                          | Answers                                      |
|------------------------------------|----------------------------------------------|
| Where does the COF fed into the equipment? | By the hopper                               |
| How to remove the shell of COF?    | Through squeezing                            |
| What is used to remove the shell of COF? | Cylinder and grating concave plate           |
| What is the power source?          | Motor                                        |
| Where to remove the shell of COF?  | At the gap between cylinder and grating concave plate |
| How to make COF shell quickly?     | Remove many shells of COF at a time          |
| What’s the next step after shelling? | Filter the tea seed of COF with screen mesh  |
Through the above steps, the structure design scheme of COF shelling machine is gained, which is composed of feeding hopper, shelling mechanism, screening mechanism, frame, connecting rod, motor, belt pulley and so on, as Figure 2 shown. The power of the whole mechanism is provided by the motor and transmitted to the shelling mechanism and screening mechanism through belt transmission. There are two small belt pulleys, which form the transmission mechanism with a large and a medium pulleys respectively. The shelling mechanism squeezes the camellia fruit to shell, and then the separated COF shell and tea seed fall into the screen. The screening mechanism has three layers. The shell of larger volume remains in the first layer of screen, and falls out from the discharge outlet with the reciprocating vibration of the screen. The rest shell and tea seeds enter the second layer through the first layer screen. The shell of medium volume is left in the second layer screen until it falls out of the discharge outlet, and the remaining shell and tea seeds fall into the third layer. The frame plays the role of supporting and connecting. The rod connects the screening mechanism and the frame, and drives the screen to carry out reciprocating vibration and separate the shell and the tea seed of COF.

3.2. Design and calculation of shelling mechanism

The shelling mechanism is mainly composed of cylinder and grating concave plate, as shown in Figure 3.

3.2.1 Design and calculation of cylinder

1) Structure design of cylinder

The cylinder is designed as hollow, and its outer ring is designed with evenly distributed rods whose diameter is 9mm, as Figure 4 shown. Grooves are formed between the rods to drive COF into the shelling gap between the rod and the grid bar, where the COF is squeezed and the shell is broken. According to the statistical results of the characteristics of COF, the maximum diameter of COF is 50 mm. Therefore, the gap between the outer ring rods of the cylinder is designed to be 45mm, which can avoid bringing too many COFs into each groove, so as to increase the extrusion efficiency and reduce the damage rate of tea seeds. In addition, the gap can be adjusted on the basis of the variety of COF.

2) Determination the rotating speed of cylinder

The diameter and the length of designed cylinder are 290mm and 350mm respectively. Assuming the shelling efficiency is no less than 200kg/h, the actual power of shelling device is set to 4kW. Based on the mechanical design manual,[7], the model of motor is selected as Y2-112M-4 whose efficiency is 82%. So, the input power of cylinder is 3.28kW. Based on the reference [7], the maximum static pressure of COF is 800N. Take the above value into the equation $P=\frac{nT}{955000}$, where, $P$ is the input power of the cylinder, $T$ is torque, $n$ is the rotating speed of cylinder can be calculated, $n=270.23\text{r/min}$. Considering the selected motor model, the maximum speed is designed as 288r/min.

3) Shaft design

The shaft is designed as a rotating shaft, which is driven by a large belt pulley and plays a supporting role. The diameter of the shaft is calculated according to equation (1).
Figure 2. Structure design scheme of COF sheller
1-Feeding hopper 2-Shelling mechanism 3- Small belt pulley 4-Motor 5-Frame 6- Middle belt pulley 7- Conveyor belt 8-Screening mechanism 9- Connecting rod 10-Large belt pulley

Figure 3. Shelling mechanism diagram

Figure 4. Shelling gap

\[ d \geq \sqrt[3]{\frac{9.55 \times 10^6 P}{0.2 \tau n}} = A_0 \sqrt[3]{\frac{P}{n}} \]  

Take \( A_0 \) as 103, so \( d \geq 103 \sqrt[3]{\frac{3.28}{288}} = 23.17 \text{mm} \).

Because the shaft needs to be designed with shoulder and keyway, the shaft diameter need to be increased by 10%-15% and taken as 40mm.

Check the strength of the shaft according to equation (2).

\[ \sigma_{ca} \geq \frac{M}{W} + 4 \left( \frac{\alpha T}{2W} \right)^2 = \frac{M^2 + (\alpha T)^2}{W} \leq [\sigma_{-1}] \]  

Where, \( \alpha \) is discount coefficient, set as 0.6, \( W \) is bending section coefficient, \( M \) is combined bending moment of the shaft which is calculated to be 35N·m. So, the stress \( \sigma_{ca}=12.17 \text{MPa} \) is less than allowable bending stress \([\sigma_{-1}]=60 \text{Mpa}\), the shaft is safe.

3.2.2 Design of grating concave plate.
The grating concave plate is under the cylinder and used together with the cylinder. The size of the gap affects the composition of falling materials and their falling speed. Generally, the size of the gap is larger than that of the tea seed and smaller than that of the COF, so that only the tea seeds can enter the screen. In this design, the length of the grating concave plate is 392mm, the width is 446mm and the height is 165mm. The grid bars with a diameter of 6 mm are evenly distributed between two semicircular baffles, and the length of the bars is 360 mm. According to the statistical results of the properties of COF, the gap between the bars is designed to 25mm. The maximum gap is 51mm.
between the hopper exit and the cylinder. The minimum gap is 14 mm at the bottom. The size of the gap is gradually reduced from top to bottom, so it can be applied to different sizes of COF.

3.3. Design of screening mechanism

The screening mechanism is composed of screen, crank and eccentric wheel, which mainly realizes the screening and separation of tea seeds and broken fruit shells. The screen mesh diameter of the first layer is 22mm, the diameter of the second layer is 20mm, the height of each layer of screen is 60mm, and the length of the screen is 1000mm. Five convex circles with the length of 15mm are designed on both sides of the screen to connect four rockers and eccentric wheels respectively. The diameter of the convex circle connected with the eccentric wheel is 15mm, and the diameter of the remaining four convex circles is 35mm.

3.4. Design and calculation of transmission mechanism

3.4.1 Design and calculation of the belt wheel of shelling mechanism.

Considering the power is 3.28kW, the rotating speed is 288r/min, the working condition coefficient $K_p=1.1$, A-type belt is selected.

1) Determine the reference diameter of the belt pulley

- Preliminary set the reference diameter of small belt pulley $d_1=75mm$.
- Calculate the speed of the conveyor belt according to equation (3).

$$v= \frac{\pi d_1 n_1}{60 \times 1000} = \frac{\pi \times 75 \times 1440}{60 \times 1000} = 5.65 \text{m/s}$$

The value of $v$ meets the requirements of $5 \text{m/s} < v < 30 \text{m/s}$.

- According to the speed of the motor and cylinder, the transmission ratio of the belt is selected as 5. $d_2\div i = 5 \times 75 = 375 \text{mm}$  \hspace{1cm} (4)

Therefore, the reference diameter of large belt pulley is selected as $d_2=400mm$.

2) Calculate the center distance between belt pulleys and reference length of conveyor belt

According to $0.7(d_1+d_2) \leq a_0 \leq 2(d_1+d_2)$, the initial center distance is set to $a_0 = 400 \text{mm}$.

- Due to $L_0 = a_0 + \frac{\pi}{2} (d_1 + d_2) + \frac{(400-75)^2}{4a_0} = [2 \times 400 + \frac{\pi}{2} (400+75) + \frac{(400-75)^2}{4 \times 400}] \approx 1612 \text{mm}$ \hspace{1cm} (5)

Where, $L_0$ is the length of conveyor belt. Select the reference length of conveyor belt $L=1640 \text{mm}$.

- Calculate the actual center distance $a$ according to the following equation.

$$a \approx a_0 + \frac{L - L_0}{2} = (400 + \frac{1640 - 1612}{2}) \approx 414 \text{mm}$$ \hspace{1cm} (6)

According to $a_{min}=a-0.015L$, $a_{max}=a+0.03L$, the actual center distance can be taken in the range of 389-463 mm.

3) Calculate the number of conveyor belts required

- Basic power rating $P_r$ of a single V-belt

According to $d_1=75\text{mm}$, $n_1=1440\text{r/min}$ and reference [8], the basic rated power $P_0=0.67\text{kW}$.

According to $n_1=1440\text{r/min}$, $i=5$, A-belt and reference [8], the power increment $\Delta P_0=0.17\text{kW}$.

Select coefficient $K_a=0.88$, $K_L=0.99$

$$P_r = (P_0 + \Delta P_0) \cdot K_a \cdot K_L = (0.67+0.17) \times 0.88 \times 0.99 = 0.82 \text{kW}$$ \hspace{1cm} (7)

- Calculate the number $x$ of V-belts

$$\frac{P_r}{P_r} = \frac{0.82}{3.61} = 4.41$$

Round numbers, $x=5$.

4) Preload of single V-belt

Mass per unit length of A-belt $q=0.105\text{kg/m}$, hence
\[
F_n = 500 \left( \frac{2.5 - \alpha}{K_{\alpha} x v} \right) P_{\text{ca}} + q v^2 = [500 \times \frac{(2.5 - 0.88) \times 3.61}{0.88 \times 5 \times 5.65} + 0.105 \times 5.65^2] = 121N
\]

Where, \(F_0\) is preload, \(P_{\text{ca}}\) is calculated power.

5) Checking the wrap angle on the small pulley \(\alpha\)

\[
\alpha \approx 180^\circ + \left( \frac{d_2 - d_1}{a} \right) \frac{57.3^\circ}{414} = 180^\circ - \left( 400 - 75 \right) \frac{57.3^\circ}{414} = 135^\circ > 120^\circ
\]

Therefore, the selection of small pulley is reasonable.

3.4.2 Design and calculate the belt pulley of screening mechanism.

The design and calculation process of belt pulley in screening mechanism are similar to that in shelling mechanism. It can be concluded that five A-type V-belts should be selected for the conveyor belt, and the reference length is 1250mm. The small belt pulley is solid type and the reference diameter is 75mm. The middle belt pulley is selected as orifice plate, and the reference diameter is 224mm. The center distance between the two belt pulleys is 265-322 mm, and the preload \(F_0\) of single belt is 113N.

4. Conclusion

According to the characteristics of COF, the COF sheller is designed based on EBD method. Firstly, the EBD method is used to determine the design scheme of the sheller. The squeeze type is used to remove the shell of COF, and the cylinder and grating concave plate are chosen as the shelling mechanism. The three-layer screen structure is selected for the screening mechanism, which can better filter and separate the tea seed and the COF shell layer by layer, and directly collect the removed fruit shell and tea seed. The shelling gap between the cylinder and grating concave plate, and the size of the mesh on the screen can be adjusted according to the actual size of the COF. Then, according to the overall design of the sheller, the structure design and calculation of the shelling mechanism, screening mechanism and their transmission part are completed. It provides a new idea for the design of sheller.

Acknowledgments

This work was supported in part by the National Natural Science Foundation of China under Grant No.51505049 and Chongqing Research Program of Basic Research and Frontier Technology under Grant No. cstc2018jcyjAX0690.

References

[1] Zhu, G.F., Ren, J.J., Wang, Z., et al. (2016) Design of shelling machine for camellia oleifera fruit and operating parameter optimization. Transactions of the Chinese Society of Agricultural Engineering, (7): 19-27.
[2] Huang, F.H., Li, W.L., Xia, F.J., et al. (2006) Research and application of dehulling machine for camellia oleosa seed. Transactions of the Chinese Society of Agricultural Engineering, 22(11): 147-151.
[3] Li, X.X., Guo, Y.M. (2007) Actuality of the Decladding Method and Sheller of Shell Fruit. Academic Periodical of Farm Products Processing. (4): 83-86.
[4] Li, W.L., Peng, X.Y., Yang, B., Huang, F.H.. (2018) Dehulling technology and device for oil-tea camellia fruit. China oils and fats, 43(4): 158-160+163.
[5] Zeng, Y. (2015) Environment-Based Design (EBD): a Methodology for Transdisciplinary Design+. Journal of Integrated Design & Process Science, 19(1):5-20.
[6] Tan, S., Zeng, Y., Chen, B., et al. (2012) Environment Based Design Approach to Integrating Enterprise Applications. Journal of Computing and Information Science in Engineering, 12(3):031003.
[7] Cheng, D.X. (2007) Mechanical design handbook. Chemical Industry Press, Beijing.
[8] Pu, L.G., Chen, G.D., Wu, L.Y. (2016) Machine Design. Higher Education Press, Beijing.