Design and finite element analysis of thick shell mussel shell opener

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Abstract. In order to obtain fresh mussel meat, this paper comes up with a design of mechanical automatic thick-shell mussel open shell machine. According to the physiological parameters and structural characteristics of thick shell mussel, it is determined that the scheme of automatic shell opening and the related parameters of open shell cutter tool. At the same time, Using Solidworks simulation and ANSYS Workbench on the open shell tools and pneumatic cylinder and other major component of finite element analysis, which is ensure that thick-shell mussel open shell machine open shell with stable and efficient. And the relevant part of parameters are confirmed that the thick shell mussel open shell machine avoid some adverse vibration frequency in theory. The purpose of the thick-shell mussel open shell machine is to replace manual opening shell, improve the efficiency of mussel shell opening and provide further reference for the production design of the automatic thick shell mussel opening shell equipment.

1. Introduction

Mussel meat has high nutritional value, rich in protein, a variety of essential amino acids, vitamins and trace elements, and enjoys the reputation of "eggs in the sea", which is a rare nutritional and health food [1,2]. Fresh mussels are a favorite of seafood lover, but they're hard to obtain. In order to meet the demand of consumers in the market, the mussel processing industry in China still use the traditional method of manually opening shells to obtain fresh mussels [3,4] (figure1).

However, this method has high labor intensity and low production efficiency, and it is difficult to ensure the integrity and cleanliness of fresh mussels. Therefore, many researchers have carried out a lot of research: He. H [5] and Gipsy [6] et al. proposed a method to obtain fresh mussels by using ultrahigh pressure technology. Zhu [7], Wang [8] et al. also used ultrahigh pressure technology to obtain fresh mussels, and confirmed some key parameters of ultrahigh pressure treatment for mussels. This technology can process a large number of mussels and obtain fresh mussel meat with good meat quality, but it is difficult to promote the mussel processing industry in China due to the high cost of equipment and difficult maintenance. Wheaton [9] and Singh [10] et al proposed infrared shell opening method and laser shell opening method respectively. They tested that their respective schemes could obtain relatively perfect fresh shell meat. But these high-tech technologies are not yet ready for opening thick shells mussel now. Hiroaki. S [11] and Hu [12] et al. carried out an experiment to open shell processing of mussels by means of high-pressure water jet. After the experiment, fresh mussel meat are available but
badly damaged. Because this method is still immature and many key parameters have not been obtained, far from being applied in practice.

In order to improve the efficiency of obtaining intact fresh shellfish, this paper puts forward a design of thick-shell mussel open shell machine. It is beneficial to improve the open shell efficiency and reduce the wear of the open shell cutter that the size parameters of thick-shell mussel open shell machine are designed in a good adaptability. And the open shell cutter of thick-shell mussel open shell machine is verified by finite element analysis, and the strength failure and mechanical resonance failure of the open shell cutter are avoided [13-17].

Fig. 1 Opening thick shell mussel with a knife

2. Structure and working principle of the thick-shell mussel open shell machine

2.1. The key to opening thick-shell mussel
The physiological structure of thick shell mussel was analyzed, the adductor muscle is the most important factor to control the closure and opening of the mussel shells (figure2). When the thick shell mussel is in the state of death, the adductor muscle loses its activity and the thick shell mussel is always in the state of open shell. Therefore, the thick shell mussel is to destroy the adductor mussel by cold-processed, so as to achieve the autonomous shell opening of thick shell mussel [18].

Fig. 2 the adductor muscle was destroyed

2.2. The Structure design of thick-shell mussel open shell machine
The thick-shell mussel open shell machine is mainly composed of four parts which are respectively thick-shell mussel fixation platform, the open shell cutter tool, Angle adjustment device and pneumatic cylinder system (figure3 and figure4). The function of thick-shell mussel fixing platform is to fix the thick-shell mussel to be processed, avoid the movement of the thick-shell mussel in the process of processing. The function of the open shell cutter tool is to cut the adductor muscle connecting the two shells; The Angle adjusting device is to adjust the deviation Angle of the shell cutter, so as to ensure the best deviation Angle when the shell cutter enters the mussel body to cut off the adductor muscle. The pneumatic cylinder system provides the power to cut off the adductor muscle.
2.3. Working principle of the thick-shell mussel open shell machine

Here's how open shell machine works (figure 5): The staff place the thick shell mussel to be processed on the fixed table, and then start PLC control program. Under the instruction of PLC control program, the pneumatic cylinder push the open shell cutter tool to move down to the designated position to cut off the adductor muscle. After cutting off the adductor muscle, the PLC control program continues to run, and the piston in the pneumatic cylinder moves up which drive the open shell cutter tool to move back to the position. The above is the overall workflow.
Fig. 5 Workflow diagram of shelling machine for the thick shell mussel

3. The design of open shell cutter tool

The open shell cutter tool is the key component of the thick-shell mussel shell opener. Therefore, the open shell cutter tool is accurately designed and checked. The pointer type digital display tension meter was used to perform the posterior closed shell muscle pulling experiment on 20 active thick-shell mussel samples (figure6 and figure7), and the maximum value of 600N in the experiment was taken as the external load on the handle end of the shell cutter. Because of pointer display tension meter retractor and closed shell after muscle column tensile process belongs to the surface contact, and in the actual tool edge and the adductor muscle belongs to the line contact. In order to avoid producing larger force analysis error, The force measured by the digital display tensiometer needs to be converted into the force of cutting off the adductor muscle by the open shell cutter tool, then the other related parts are design[19].

Fig. 6 Pointer tensiometer

Fig. 7 Tension experiment of the adductor muscle
The average diameter of the adductor muscle was determined by measuring the diameter of the adductor muscle trace of 10 thick-shell mussels (figure 8), and the contact area between the hook and the adductor muscle was further calculated. The measurement results are shown in table 1.

![Fig. 8 the adductor muscle scar diameter](image)

| No. | Group 1 Diameter (mm) | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 |
|-----|-----------------------|----|----|----|----|----|----|----|----|----|----|
| 1   |                       | 9.9| 5.1| 9.6| 8.4|10.1| 7.9|10.0| 6.1| 9.6|10.2|
| 2   |                       | 5.0| 7.7| 9.8|10.0|10.9| 9.9| 9.8|10.0| 8.9| 9.2|

The average values of the 20 data in table 1 were taken as 8.9mm, rounded to 9mm, and used as the average diameter of the adductor muscle of the thick-shell mussel. In order to improve the cutting efficiency of the shell cutter for the adductor muscle, the width of the designed open shell cutter should be larger than the average diameter of the adductor muscle, and the designed width of the shell cutter should be 12mm.

The height of the cylindrical retractor was measured as 5mm, and the area of the retractor and the rear closed shell muscle was calculated as $S_1 = 5 \times 9 = 45\text{mm}^2$.

The contact area between the cutting edge of the adductor muscle of the rear closed shell was estimated to be $S_2 = 1 \times 1 = 45\text{mm}^2$.

According to the pressure formula [20-22]:

$$\frac{F_1}{S_1} = \frac{F_2}{S_2}$$  \hspace{1cm} (1)

$F_1$: pointer type digital display tension meter tension 600N;
$F_2$: strength of the closed shell after cutting off the adductor muscle.

After solving the cutting edge of the open shell cutter, the muscle strength of adductor muscle is 13N. According to this parameter, the applied load of the pneumatic cylinder to the open shell cutter and related models can be further determined.

To avoid the slippage of the open shell machine in the process of the adductor muscle after cutting, the edge of the shell cutter is designed as a symmetrical semi-arc. In order to facilitate the open shell cutter tool entering from the thick shell mussel abdomen closed gap position, the middle position of the cutting edge is designed as a small square tip (figure 9 and 10).

![Fig. 9 Three-dimensional drawing of open shell cutter tool](image)
At the position where the thick shell mussel develops long filament attachments in its abdomen, there is usually a gap about 2mm wide for the position where the thick shell mussel cannot be completely closed (figure 11). The open shell cutter tool can be effectively reduced the resistance when it insert the open shell cutter tool from this position, and facilitate the open shell cutter tool to enter the shell smoothly. Therefore, the thickness of the open shell cutter tool designed is 2mm.

By measuring the distance between the closed gap position of 10 thick-shell mussels and the center position of the adductor muscle, the average distance was calculated to be 45mm. In order to ensure that the shell cutter can achieve some cutting for most thick-shell mussels, the design length of the open shell cutter tool is 50mm.

4. Finite element analysis of the thick-shell mussel open shell machine

4.1. The open shell cutter tool simulation
Alloy steel was selected as the material of the open shell cutter tool, and Solidworks Simulation was used to simulate the state of the adductor muscle after the cutting of the thick shell mussel. The analysis results are shown in Fig 12-13.
It can be seen from figure 12 that the maximum stress carried by the open cutting tool device is $1.39 \times 10^7$ N, less than the yield limit $W$ of the open cutting tool device material. Therefore, the material of the open shell cutter tool meets the requirements. It can be seen from figure 13 that the offset displacement of the shell cutter is $4.871 \times 10^{-2}$ mm, satisfying the operating requirements.

4.2. Modal analysis of pneumatic cylinder

Modal analysis is the basic content of dynamic analysis, which can avoid resonance before the product is put into production. Assuming that the thick shell mussel open shell machine material is ordinary steel, its vibration is free vibration and the damping is ignored, the equation is

$$\{M\} \ddot{\{u\}} + \{M\} \{u\} = \{0\} \quad (2)$$

When you have a simple resonance, $u = U \sin(\omega t)$, the equation for

$$\left(\{K\} - \omega_i^2 \{M\}\right) \{\phi_i\} = \{0\} \quad (3)$$

The above formula is a classical eigenvalue problem, and the square root of the eigenvalue of the equation is $\omega_i^2$. The square root $\omega_i$ is the natural circular frequency of the structure. The natural frequency is $f_i = \frac{\omega_i}{2\pi}$. The range of $I$ is 1 degree of freedom and the corresponding vector is $\{u\}_I$. It's also called an eigenvector. The eigenvalue $\omega_i$ is the corresponding eigenvector $\{u\}_i$, which are the natural vibration frequency corresponding mode. ANSYS was used to conduct the six-order modal analysis of the thick-shell mussel open shell machine as a whole. The analysis results are shown in figure 14-19 and table 2.
Fig 14. The first stage vibration mode

Fig 15. The second stage vibration mode

Fig 16. The third stage vibration mode

Fig 17. The fourth stage vibration mode

Fig 18. The fifth stage vibration mode

Fig 19. The sixth stage vibration mode

Table 2. Sixth-order modal analysis table of the thick-shell mussel open shell machine

| Mode | Frequency [Hz] |
|------|----------------|
| 1    | 0              |
| 2    | $7.6178 \times 10^{-4}$ |
| 3    | $1.5988 \times 10^{-3}$ |
| 4    | 1.0795         |
| 5    | 1.6943         |
| 6    | 1.9802         |
As can be seen from table 2, the reversing frequency of pneumatic cylinder and solenoid valve should mainly avoid 1.0795Hz, 1.6943Hz and 1.9802Hz frequencies to prevent damage caused by resonance with the thick-shell mussel open shell machine.

5. Conclusion
In the design process of this thick shell mussel opening shell machine, the following conclusions are drawn,

(1) The length and width of the open-shell cutter are related to physiological parameters and structure of thick shell mussel, which are determined to be 50mm and 12mm respectively.

(2) Finite element analysis is carried out to confirm that the selected alloy steel open shell cutter meets the requirements.

(3) It was concluded that the air pressure cylinder and electromagnetic valve should avoid the three frequencies of 1.0795Hz, 1.6943Hz and 1.9802Hz, which prevent the thick-shell mussel open shell machine from resonating with air pressure cylinder and electromagnetic valve.

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References
[1] Sun C, Niu T T. International competitiveness analysis of Chinese shellfish products [J]. Chinese agricultural science bulletin, 2015(20):44-50.
[2] Guo W. Changes of ripe mussel quality at different storage temperatures [D]. Zhejiang university of technology, 2018.
[3] Lu X C, Sun X Z, Wang W. Bivalves hulling pretreatment technology present situation and development trend of [J]. Modern agricultural machinery, 2015 (9):74-76.
[4] Hu J Y, Li Z H, Gu P C, et al. Research progress on the method of mussel shucking [J]. Scientific fish farming, 2017(05):73-74.
[5] He,H, Aams.R,M, Farkas.D.F, et al. Use of high-pressure processing for oyster shucking and shelf-life extension[J].Journal of Food Science, 2010, 67(2): 640-645.
[6] Gipsy Tabilo-Munizaga, Santiago Aubourg, Mario Pérez-Won. Pressure Effects on Seafoods [J]. High Pressure Processing of Food. 2016(01):625-669.
[7] Zhu S M, Yu Y, Wang M. Methods of mussel shell removal [P]. China, CN105851195A. 2016.08.17.
[8] Wang M. Effects of ultra-high pressure on mussel hulling and quality [D]. Zhejiang university, 2012.
[9] Wheaton, F.W. Oyster Processing Study[J]. National Marine Fisheries Service, 1971:57
[10] Singh G. Laser modernizes oyster shucking [J]. Food Technology, 1972(26):60-61.
[11] Sugiyama. H. Shell processing method and shell processing device used in the method [P]. United States Patent: No.09,787425.2004-05-18
[12] Hu J Y, Tan J L, Li Z H. Numerical simulation study on the internal flow field of water jet mussel single-side shelter nozzle [J]. Electromechanical engineering, 2018.35(8): 828-832.
[13] Zhu B W, Xue C H. Marine aquatic product processing and food safety [M]. Beijing: science press, 2016.
[14] Li N S, Xue C H. Modern processing technology and quality safety of Marine aquatic products in China [M]. Beijing: ocean press, 2010.
[15] Xin H Z, Chen L, Wu J, et al. Internal quality traceability system for shengsi mussel processing enterprises [J]. Chinese fishery quality and standards, 2013,3(3):88-92.
[16] Duan W W, Luo W, DuanZ H et al. Research progress of mussel processing and utilization [J].
Modernization of fisheries, 2013, 40(3): 51-55.

[17] Song G L. Processing, utilization and development of mussels [J]. Modernization of fisheries, 2003 (3): 30-31.

[18] Hu J Y. Research on new mussel unilateral shell removal technology [D]. Zhejiang: Zhejiang Ocean University, 2018.

[19] Zhang F F, Wang J C. Design and experiment of seedling clamping mechanism of vegetable grafting machine [J]. Research on agricultural mechanization, 2018, (12): 135-138.

[20] Song P W, Liu J. Solidworks and ANSYS finite element comparison of cantilever beam model [J]. Modern manufacturing technology and equipment, 2018, (3): 71-73.

[21] Pu G Y. ANSYS Workbench basic course and detailed explanation of examples [M]. Beijing: China Water Conservancy and Hydroelectric Press, 2014.3: 240-242.

[22] Liu X H, Liu J H, et al. Modal analysis of knife plate operation of circular orchard trenching machine [J]. Research on agricultural mechanization, 2016,(6): 102-105.