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Research Article

Strength Study on Screw Assembly of Food Screw Press Based on FEA

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Abstract: Screw press is a kind of dehydration machines of simple structure, low cost and reliable operation and is widely used in the food processing industry. Screw assembly is the core component of screw press, the force applies on its blade is very complex and prone to failure. This study analyzed the working principle of a type continuous screw press and established mathematical model of its screw mechanism. With the help of large-scale finite element software Patran/Nastran, the screw was analyzed and stress and deformation contour were obtained. It's found that the largest stress appears on the blade root near the discharging end. This study can provides a certain theoretical basis and basic methods to design the more stable screw press.

Keywords: Blade, finite element analysis, screw press, surface treatment method

INTRODUCTION

Press is a kind of material solid-liquid separation device widely used in food processing industry (Francis *et al*., 2004; Savoire *et al*., 2013). Among them, the screw presses are commonly applied in fruit pomace secondary extraction, vegetable juice squeeze and dehydration of vinasse waste and bean dregs, etc. for its advantages of low cost, simple operation and compact structure (Pradhan *et al*., 2011; Sarkar *et al*., 2011). Especially it has particularly evident dewatering effect for fiber materials and its dehydration rate can reach 60 to 65% (Gopalakrishnan *et al*., 2014).

Screw assembly is an important part of a screw press, it's not only under powerful torque, the spiral surface is also under huge friction and extrusion of the material, therefore, screw strength analysis is very necessary (Pöschl *et al*., 2010). The existing research mainly pauses on the screw on the traditional strength check to the screw strength. Due to the actual stress situation is more complex, the strength check in the traditional sense is far from satisfying the needs of the actual design and production. Because the finite element analysis software is powerful, its result is intuitive and its analytical cost is low (Yongyong, 2014), it has been widely applied in engineering practice. In this study, we used large finite element analysis software Patran/Nastran to study the spiral strength, obtained its stress distribution and deformation contours under normal work and find out the risk parts on the spiral structure (Li *et al*., 2011).

The results can be used to improve the mechanism and production process of the screw, to design a screw structure of more excellent performance, prolong its use life and reduce the cost (Ihsan *et al*., 2013).

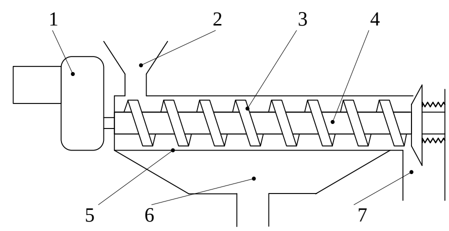

Fig. 1: The schematic diagram of screw press
1: Reducer; 2: Feed hopper; 3: Screw blades; 4: Screw shaft; 5: Strainer; 6: Juice tank; 7: Discharging end

MATERIALS AND METHODS

Structure and working principle of screw press: Screw press structure diagram is shown as in Fig. 1 (Olaniyan and Babatunde, 2012), it is mainly composed of reducer, feed hopper, screw blades, strainer, juice tank and discharging end. The core component of screw press is the screw assembly composed of shaft and screw blades which screw pitch continuously decreases along the discharging direction, screw assembly and strainer constitute the a closed squeezing space, where the pressing process mainly carries out.

The pre-crushed material is put into the press through the feed hopper and constantly be pushed toward discharging end driven by the rotating screw. Because the screw pitch of blades decreases, the squeezing space becomes smaller and smaller, the extrusion effect gets increasingly stronger and the liquid of the material will be gradually squeezed out

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and then flows into the juice tank through the strainer. Finally, the dried material will be expelled out from the discharging port which is at the end of the press and equipped with adjustable pressure springs that can change the resistance of the discharging port to regulate the desired squeeze degree, i.e., the slag rate.

RESULTS AND DISCUSSION

Analysis and calculation of the screw:

Force analysis: Screw blades are mainly acted upon by normal pressure P and the friction force of material applied on the blades F. The normal pressure P (MPa) blades applied on the material while working is:

$$P = \frac{2.47\xi \cdot \varepsilon_n^{5.5}}{e^{0.022w}}$$

where,

w = Water content of material

ξ = Correction coefficient, often 0.0045

e = The base of natural logarithm

The friction force blades applied by material $F = \mu \cdot P \cdot A$, where μ is the friction coefficient, often 0.4, A is force bearing area.

In Fig. 2, X is the axial direction of screw shaft, Y is radial direction of screw shaft, W is tangential direction of spiral blade, Z is normal direction of spiral blade, α is the spiral angle. Because the friction force applied on screw blade is tangential, it might be difficult to apply load on the finite element model, it's necessary to decompose the friction force F.

First decompose the friction force F into X and Y direction:

$$F_X = F \sin\alpha \quad (1)$$

$$F_Y = F \cos\alpha \quad (2)$$

Then F_Y is resolved into Z and W direction of the blade:

$$F_{YZ} = F_Y \sin\alpha = F \cos\alpha \sin\alpha \quad (3)$$

$$F_{YW} = F_Y \cos\alpha = F \cos^2\alpha \quad (4)$$

Then F_{YW} is decomposed in X and the Y direction, due to α is small, so sinα can be negligible:

$$F_{YWX} = F_{YW} \sin\alpha = F \cos^2\alpha \sin\alpha \quad (5)$$

$$F_{YWY} = F_{YW} \cos\alpha = F \cos^3\alpha \quad (6)$$

Finally, add the all forces in X and Y directions respectively:

The force applied on X axis direction of the spiral blade:

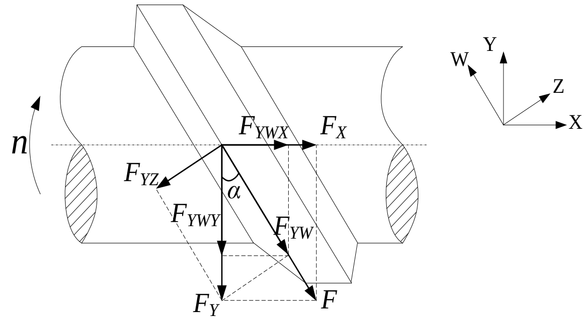

Fig. 2: Diagram of normal force on the screw blade

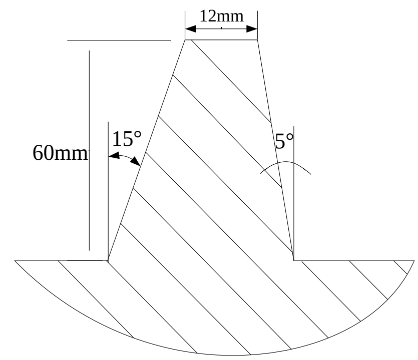

Fig. 3: Cross-section of spiral tooth

Table 1: Stress applied on each screw blade

Screw stage	Pitch (mm)	Nomal pressure P(MPa)	Axial pressure (MPa)	Nomal pressure (MPa)
1	200	3.78	2.16	1.08
2	190	8.28	4.73	2.36
3	180	14.67	8.37	4.18
4	170	24.95	14.24	7.11
5	160	35.88	20.48	10.23
6	150	43.65	24.91	12.44
7	140	52.33	29.87	14.91

$$F_X + F_{YX} = F \sin\alpha (1 + \cos^2\alpha) \quad (7)$$

The force applied on normal direction of the spiral blade includes:

Normal pressure P and F_{YZ}:

$$F_{YZ} = F_Y \sin\alpha = F \cos\alpha \sin\alpha \quad (8)$$

Stress calculation: The Screw assembly of a certain type screw press studied in this study is a standard Unequal pitch structure, its shaft diameter is 200 mm and it has seven threads, their pitches respective are 200, 190, 180, 170, 160, 150 and 140 mm, respectively. The cross-section of spiral tooth is shown as Fig. 3, it's a trapezoidal type and the width of tooth tip is 12 mm, the height is 60 mm, the front angle is 5° and the back angle is 15°.

The stress applied on each screw blade calculated according to function (1)-(8) are shown in Table 1.

FINITE ELEMENT MODELING AND SIMULATION

The three-dimensional model of the screw is established within Solidworks, as shown in Fig. 4.

Save it as x_t format and import it into the large finite element analysis software Patran/Nastran. The model is meshed in tet10 unit and there are 261,561 elements and 384,430 nodes. The steel material parameters are inputted as: elastic modulus $E = 2.09\times10^5$MPa, Poisson's ratio $\varepsilon = 0.29$ and density $\rho = 7800$ kg/m^3.

The screw is driven to rotate by the power source on its axis and its ends are fixed to the bearing on the frame, so it is need to apply the full constraint except the one rotate on its X-axis on both of the spiral ends (Li and Hu, 2012).

According to the results of stress analysis and calculation of the spiral in section II, we apply the normal and axial pressure on the screw blades respectively.

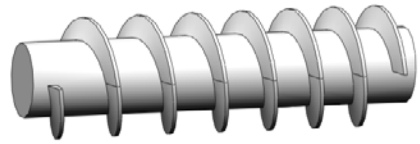

Fig. 4: The 3D structure of screw assembly

Then simulation is carried on and the stress and deformation contour of screw assembly are gotten as shown in Fig. 5 and 6.

It can be seen from Fig. 5, the minimum stress of the spiral is 0.691 MPa, occurs in the middle of the screw, the maximum stress is 675 MPa, it's on the root of the outlet thread. And the stress applied on the blades varies with the spiral, it gradually decreases from the root to tip, this is because the ratio of the thickness and height of the blade is small, the stress concentration is likely to happen. In general, the screw blades are mode of 40Cr or other higher strength materials, so although the stress is closed to the material allowable stress, the plastic deformation does not occur.

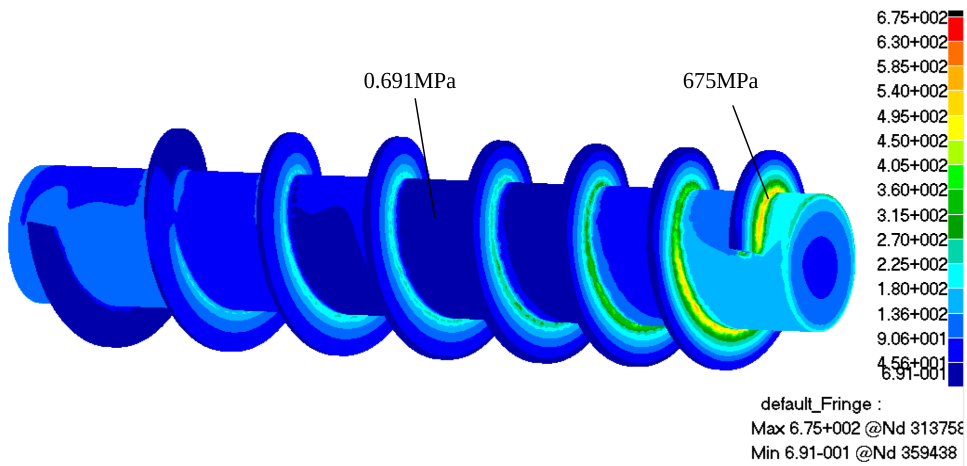

Fig. 5: Stress contour of screw assembly

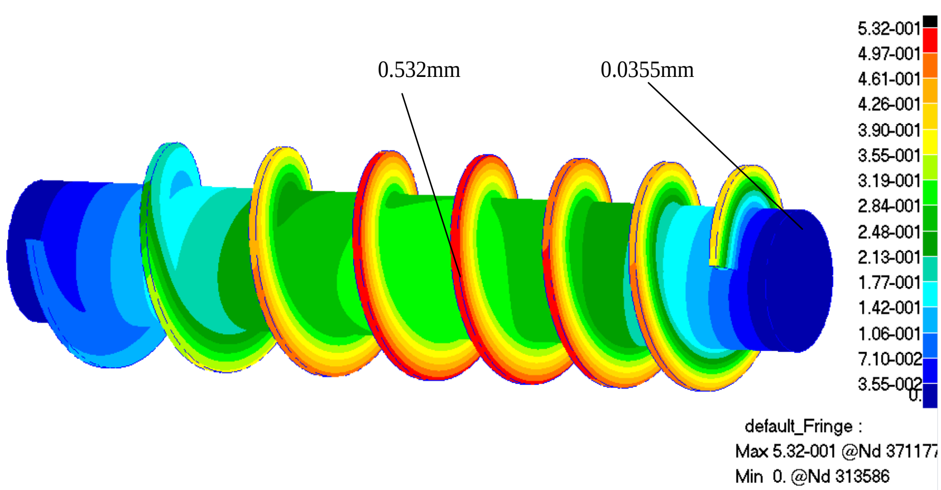

Fig. 6: Deformation contour of screw assembly

In Fig. 6, it is obviously that the deformation of screw mainly appears at the top of the blades and the gradually alters along the spiral direction. The maximum deformation happens at the top of the middle blade, the displacement is 0.532 mm. This is due to the fact that the screw blades are both subjected to axial and circle press while each end of the shaft is under 5 DOF and the length-diameter ratio is great, so the amount of deformation in that place increases. from the point of view of all parts, The deformation of the screw has no excessive deformation, which is consistent with the actual situation.

CONCLUSION

With finite element analysis software Patran/Nastran, this paper studied the stress and its distribution of the screw assembly and some conclusions has been drawn. According to the analysis, the spiral strength of this screw press for food material completely meets the requirements. It also provides reliable basis for the further improvement and optimization for more efficient and stable squeezing screw.

The analysis shows that the joint between the root of the blade and screw shaft is tend to be broken, this may be caused by Stress concentrations. So it should pay more attention to design the screw and the thickness of blade root can't be over reduced; it had better choose the material with higher mechanical strength; what’s more, carburizing, plating process and other surface treatment process can be great help to increase its wear resistance.

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