Simulation Analysis of Dough Wrapper Rolling Device for Large-scale Production of Alkaline Noodle

Qiang Yin, Feiyu Zhao and Guoquan Zhang

***Abstract*—**At present, the process of large-scale production of alkaline noodles is very complex, and more often depends on manual production, which greatly reduces the production efficiency and scale. Therefore, the development of automation equipment surface is necessary. As the key Components of the large-scale production of alkaline noodles, the paper has designed the dough wrapper rolling device in detail. The structure and principle of the dough packing rolling device are introduced. On the basis of determining the main technical parameters, the face press is emphatically studied. The model analysis theory is used to model the coiling device, and then the modal analysis is carried out by the ANSYS analysis software. According to the simulation results, there is no resonance phenomenon in the normal operation of the roller, which indicates that the design is reasonable and reliable.

***Keywords*—**alkaline noodle, dough wrapper device, roller modal analysis, ANSYS software.

I. INTRODUCTION

AT present, the alkaline noodle, as a representative of fresh wet noodle, has a complex production process, which are largely dependent on hand-working. Even the key process of the process there is no specific quantitative criteria. Thus, according to the specific production process, the suitable automated production line with certain production device should be developed to realize the automatic production of the alkaline noodle.

Similar to the production of the alkaline noodle, Japanese antique instant noodle is called as "Udon", manufacturing business of this noodle-making machine has begun on 1883 in Japan, but now today it is evolutionary developed into an industry of some magnitude, and instant noodle-maker is abroad [1]. The main features of noodle making equipment are mixer for blending wheat flour and water, dough rolling mill for making thin raw-noodle sheets, and slitting devices for the final cutting. Japan has been leading the trend in the noodle industry. As the world's largest noodle machinery equipment manufacturers, Japanese TOM LTD. always stands in the forefront of the wet instant noodles equipment, and focus on research and development of the world's top fresh noodle automation devices [2]. Japanese Nissin Food Products Co., Ltd. has developed automatic production lines of the fresh wet noodles, in which rolling device has played a very important role. Currently, there are few manufacturers that could develop automatic device of the dough wrapper rolling for alkaline noodle in the domestic market. Take Chinese Wuhan hot-dry noodles as an example, the technology of alkaline noodles has significant difference compared with fried instant noodles. Because its process is complex, Japanese wet noodle production line cannot be directly imported to produce alkaline noodle. Combined with the characteristics of production technology of alkaline noodle, Chinese Henan Nanjiecun Group has invented a kind of industrial production method of hot-dry noodles with the water content between 50% and 70% [3]. However, Henan Nanjiecun Group has imported wet noodle production line from Japan for production of hot-dry noodles. After a certain improvement, the produced hot-dry noodles were significantly different in mouth feel from Wuhan hot-dry noodles, which suffered from the destiny of being eliminated by market.

It can be seen from the above facts that our country's noodle industry has just started and lacks related equipment technology research and development. In particular, China's traditional noodles, the study of industrial production is still not enough. The research on the production technology of alkaline noodles has guiding significance to the existing noodle industry. Dough wrapper rolling device is the core module of the dough wrapper cutting rolling device, and the design difficulty is also very high. Therefore, the key components of dough wrapper rolling device are analyzed and designed in this paper. First, the working principle and the structure of the key components are analyzed. Then, according to the determined parameters, we simulate and analyze the specific conditions of the components in normal work, so as to ensure that the designed rollers are qualified and available, and their progressiveness and stability are better.

This work was supported by Educational Commission of Hubei Province of China (D20161706). The research reported in the paper was also supported by Foundation of Wuhan Polytechnic University (No.2017y02).

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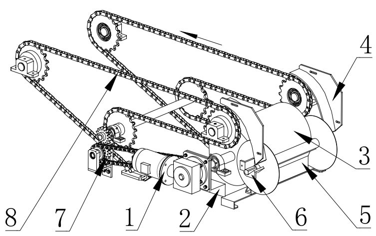
II. 2. STRUCTURE AND PRINCIPLE OF DOUGH WRAPPER ROLLING DEVICE

The structure of dough wrapper rolling device is shown in Fig. 1. The dough wrapper rolling device mostly consists of motor reducer, mounting plate for motor reducer, roller, roller rising guide rail of roller die, guide plate for dough wrapper rolling, supporting plate for roller die rolling, reversing device and backward conveyer [4].

When the device is in a state of work, the motor reducer rotates the roller counter-clockwise, rolling dough wrapper up on the roller die. The roller die is climbing upward trajectory of rising guide rail, while it is rolling dough wrapper. When the volume of the rolls is 300 millimeters, the roller die is just at the top of the roller. Because the backward conveyer is moving in the direction of the arrow in Fig. 1, the roller die with wrapper in is exactly being carried by the backward conveyer.



1. Motor reducer 2. Mounting plate for motor reducer 3. Roller 4. Roller rising guide rail of roller die 5. Guide plate for dough wrapper rolling 6. Supporting plate for roller die rolling 7. Reversing device 8. Backward conveyer

Fig. 1. Dough wrapper rolling device

According to the production requirements of equipment, the linear speed of the dough wrapper is 25*m/min*. Because the wrapper and roller being in pure rolling contact, the linear speed of the roller is also 25*m/min*. Based on this, the motor reducer with the type YXK37Y71D4 is selected. The rated power is 0.37*KW* and the rated speed is 36 *RPM*. Lastly, the speed is adjusted to 24.505 *RPM* by frequency control.

III. DESIGN OF DOUGH WRAPPER ROLLING DEVICE

According to the production requirements of equipment, efficiency of rolling wrapper is 100 volumes per hour. The function of the dough wrapper rolling device is to roll the fixed-length dough wrapper on the roller die. The dough wrapper is sent to the fermentation box for dough recovery after its diameter is up to 300 *mm*. The device should work smoothly without human intervention from start rolling to finish, with high level automation [5].

The dough wrapper is wound on a drum mold by a continuous rotating roll, and the roll mold continuously rolls on the roll surface and is covered by the dough wrapper. When the dough wrapper is rolled until up to its diameter of 300 *mm*, at this time, the roller dies just climbs to the top of the roller. Then the dough wrapper is taken to the fermentation box by conveyor chain [6]. Climbing trajectory of the roller die is not regular curves. According to the actual situation to obtain irregular curves, and then designed according to the irregular curve of the roller climb the limit parts. The dough wrapper, with a thickness of 6*mm* and a width of 450*mm*, can enter the fermentation box only after its wrapped diameter is up to 300*mm*. If the roller diameter is less than 300*mm*, it is possible that the roller die has climbed to the top of the roller, but its wrapped diameter is not yet up to 300*mm*. So the roller diameter must be greater than or equal to 300*mm*.

Considering flexibility of dough wrapper, there is possible mutual extrusion between the dough wrappers in the process of rolling. Although the length of dough wrapper has reached the theoretical length, the actual rolling diameter has not yet reached 300 mm. Therefore, the roller diameter d_r must be appropriately enlarged and initially set to 325*mm*, and the roller width b_w is initially set to 455*mm*. d_r and b_w are defined as follows:

$$d_r = 325mm,\ b_w = 455mm$$

IV. MODELING OF ROLLER BASED ON MODAL ANALYSIS THEORY

In the dough wrapper rolling device, the roller has played an important role in supporting power for rolling dough wrapper. The working area of the drum is 325 millimeters, which the size is larger and the roller rotates continuously. If the frequency of the continuous rotary motion is nearly equal to the natural frequency of the roller, it will cause resonance, thus, the roller deformation will increase rapidly, and the complete machine might be seriously damaged [7]. Therefore, the modal analysis must be carried out on the roller to find out each natural frequency and its critical speed. Then determine whether the design speed it's farther away from the critical speed. If not, the structure has the possibility of resonance, and need to be optimized. The solution formula of the critical speed is as follows:

$$n = 60f \tag{1}$$

In the formula (1), f refers to frequency, measured in *Hz*. n refers to rotating speed, measured in *RPM*.

A. The Theoretical Basis of Modal Analysis

Dynamic analysis is a technique to determine the dynamic behavior of structures when inertia and damping play an important role in the system. Dynamic analysis can simulate many physical phenomena, such as vibration impact and alternating load [8]. The equation of balance for dynamic problems is as follows:

$$[M]\{x''\}+[C]\{x'\}+[K]\{x\}=\{F(t)\} \tag{2}$$

In the formula (2), $[M]$ is the mass matrix, $[C]$ is the damping matrix, $[K]$ is the stiffness matrix, $\{x\}$ is the displacement vector, $\{x'\}$ is the velocity vector, $\{x''\}$ is the acceleration vector, $\{F(t)\}$ is the vector.

Modal analysis is a numerical technique used to calculate the vibration characteristics of structures. The natural frequency of the structure and vibration modal belong to structure vibration characteristics, so the modal analysis can help the designer to solve the natural frequency and vibration modal of the structure, and then according to the actual movement of the structure, to determine whether resonance would happen and to predict structure modal under different load. Further, these data can help designers optimize the structure and avoid resonance.

Modal analysis is the most basic dynamic analysis, but also the basis of other dynamic analysis, such as harmonic response analysis, response spectrum analysis. Therefore, modal analysis is of great practical value.

Modal analysis can be divided into two categories: unimodal modal analysis and prestress modal analysis. Undamped modal analysis is a classic eigenvalue problem [9]. With equation (2), the dynamic equation is changed into another form as follows:

$$[M]\{x''\}+[K]\{x\}=\{0\} \tag{3}$$

In dynamic analysis, the vibration form of the structure is generally considered to be simple harmonic vibration, namely the displacement function satisfies the sine function expression:

$$x = x\sin(\omega_i t) \tag{4}$$

Put the equation (4) into the equation (3), the equation (5) is obtained as follows:

$$([K]-\omega_i^2[M])\{x\}=\{0\} \tag{5}$$

The self-oscillation circular frequency w_i is the square root of the eigenvalue ω_i^2 of the equation (5), and the self-oscillation frequency f_i can be calculated by solving the formula (6):

$$f_i = \frac{\omega_i}{2\pi} \tag{6}$$

The eigenvector $\{x_i\}$ corresponding to the self-oscillation circular frequency w_i is the mode shape corresponding to the self-oscillation frequency f_i .

B. Simulation Analysis of Roll Based on ANSYS

According to the first six frequencies of the modal analysis, the corresponding critical speeds are obtained. By judging whether the working speed of the roller is close to critical speed, it is decided whether the structure need to be optimized. The first six modal analysis of the roller are analyzed, as described below.

3D modeling of roller was set up by using SolidWorks software and was saved as STEP format, which can be easily imported into ANSYS software, as shown in Fig. 2.

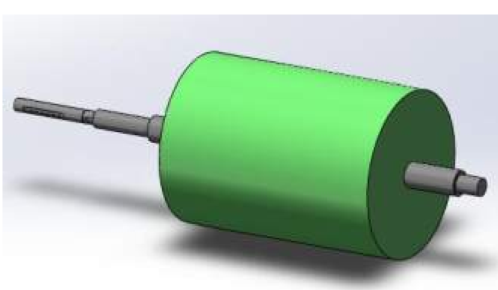


Fig. 2. The modeling of roller

C. The Definition of Material Property

The roller is in direct contact with the dough wrapper at work, belonging to one of the important parts that contact with the food directly. So the choice of 316 # stainless steel roller material is in compliance with GMP standards and HACCP regulations. Relevant material properties are as follows:

Young's Modulus $E = 210\times10^9 Pa$;

Density $\rho = 7820 Kg/m^3$;

Poisson's ratio $\mu = 0.3$.

D. Adding Constraint

The two ends of the roller are respectively supported by two bearings, so the roller's five degree of freedom , including translation in three coordinates and rotation in X coordinate and Y coordinate, are limited in ANSYS, So the roller can only make rotary movement around the Z axis. In addition, without initial prestress the roller's modal analysis is free of damping. According to the above characteristics, constraints are added to support segments of bearing, as shown in Fig. 3.

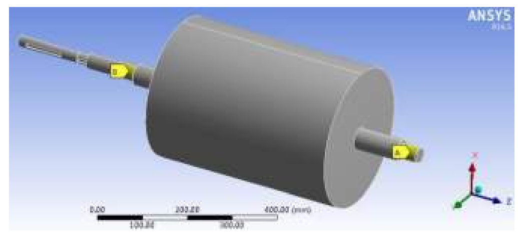


Fig. 3. Add constraints to roller

E. Roller Meshing

The model minimum size of 1.2*mm* is measured by ANSYS, according to the principle of meshing, the smallest unit size should be less than or equal to half of the minimum, that is the size of 0.6*mm*. The result is shown in Fig. 4.

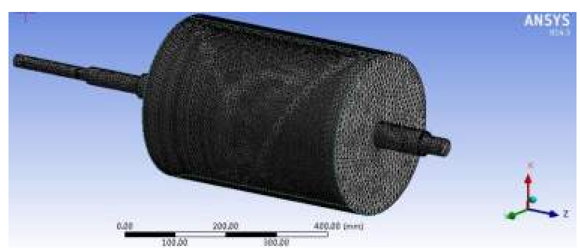
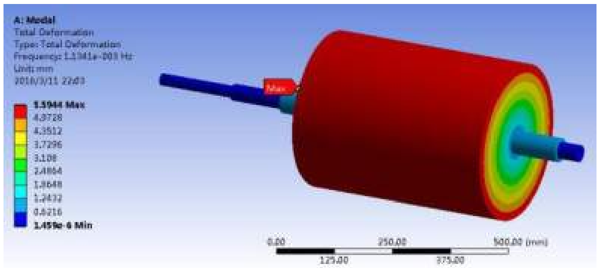


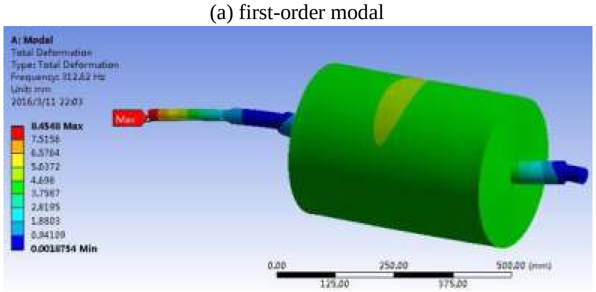
Fig. 4. Roller Meshing

F. Simulation Results

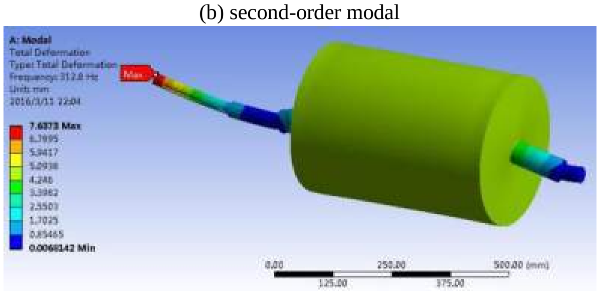
After the modal analysis, the first six nature frequencies and mode shapes of roller were obtained. According to the first six order frequencies, each order critical speed is calculated, as shown in Fig. 5 and Table 1.



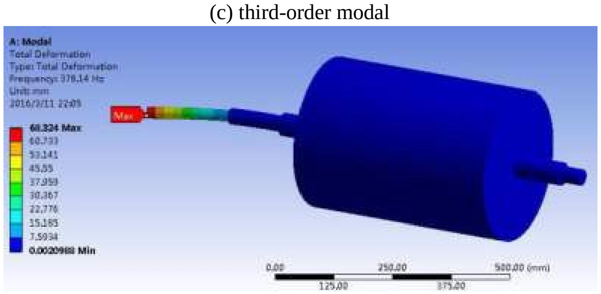
(a) first-order modal



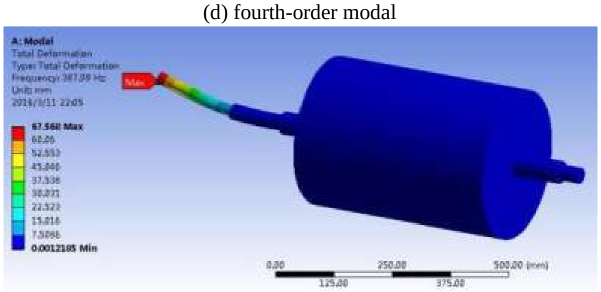
(b) second-order modal



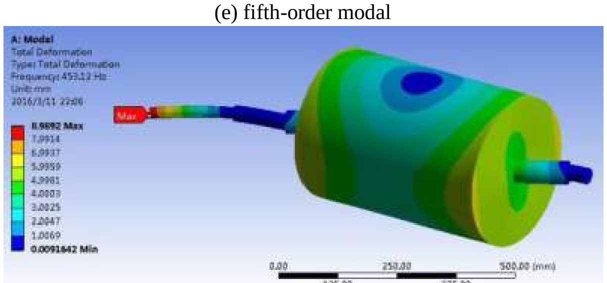
(c) third-order modal



(d) fourth-order modal



(e) fifth-order modal



(f) sixth-order modal

Fig. 5. Mode shapes of roller

Table 1. The roller natural frequencies and critical speed

Order	1	2	3	4	5	6
Frequency /Hz	1.1341e-3	312.62	312.8	378.14	387.99	453.12
Critical Speed/*RPM*	0.0680	18757.2	18768	22688.4	23279.4	27187.2

The design speed of the roller is 24.505*RPM*, far below critical speed, from 2th to 6th order. When the motor of roller starting, its rotational speed will accelerate from 0*RPM* to 24.505*RPM*, crossing first order critical speed of roller in acceleration process. However, motor starting time is shorter, and the roller is not work for long hours near the first order critical speed, so the roller can be considered in normal work without resonance. And the design is reasonable and reliable.

V. Conclusions

As the key technology of large-scale production of alkaline noodle, the dough wrapper rolling device is designed in detail in this paper. First, the structure and principle of dough wrapper rolling device are described. Secondly, the main technical parameters are determined. Finally, the modal analysis of the cylinder, which is the key component of the dough wrapper rolling device, is analyzed. The modal analysis is carried out on the roller by ANSYS software. According to the first six frequencies of the modal analysis, the corresponding critical speeds are obtained. The result of modal analysis shows that the roller has no resonance in normal work, so the design of the roller is reasonable and feasible.

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