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The solution of taking net-wrapper automatically by using principle of suction fan

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ABSTRACT— Currently, the automatic production for net-wrapper spring rolls is not yet available, many operations are still done manually, such as loading the cake exactly on the conveyor, supplying the core on the cake and curling up the spring rolls on the conveyor. In fact, there is a device that can take the net-wrapper, but it is not satisfied with the requirements of line automatic production spring rolls. The paper presents a solution for the design and development of the mechanical mechanism with the principle of a centrifugal fan and using PLC control technique to take the cake from the shaping equipment to the nominal position on the conveyor. This solution replaces the robotic manipulator for automatic net-wrapper production, which is not satisfied with the requirements of the automatic production line for net-wrapper spring rolls.

KEYWORDS: PLC; Net-wrapper; Pneumatic; Centrifugal fan; Robotic manipulator.

1. INTRODUCTION

The net-wrapper is used to produce spring rolls, the net-wrapper has a round shape made from the interwoven dough. According to the VNR report in 2018, one of the three main trends in the food industry in Vietnam is convenience food [1]. More than half, in response to the Industrial Revolution 4.0, the automation of production methods is essential in the food industry in general and in the production for spring rolls in particular. Nowadays, there is an automatic net-wrapper picker, using the principle of a robotic manipulator [2]. However, the position of the net-wrapper after dropping onto the conveyor is not correct, which makes it difficult to put the core in the right place for the automatic spring rolls production process. In order to achieve the position accuracy and stability when taking the net-wrapper on the conveyor, the device using the suction principle has been researched, tested, and developed.

2. Materials and methods

Net-wrappers are produced on semi-automatic equipment that manufactured by Ho Chi Minh University of Technology. Net-wrapper has a diameter of 160 mm and production time from 2.5 to 3 seconds depending on the weight of the cake. Net-wrapper after being made has the shape as shown as figure 1 [2].

Figure 1. Net-wrapper cake [2]

2.1 Parameter requirements

- The suction is just enough to be able to overcome the gravitation and sticky force of the cake on the hot disk.
- The suction is not too great to damage the cake.
- In case the force is large enough to suck the cake, but this force causes damage to the cake, there must be a solution to protect the cake.
- The time to suck and release the cake must be less than the cake forming time, usually 2.5 s to 3s.
- To reduce the power of fan, the suction position needs to be determined regarding density of the cake, it is necessary to choose a suction position with a large density [2].

3. Design of the manipulator arm

Manipulator includes two parts: Mechanism of suction funnel and structure of manipulator arm.

3.1 Design of suction funnel

Determining the position suction: In order for the centrifugal fan to work at high efficiency, the net-wrapper suction position is also considered. Since the net-wrapper is in the form of net (not tight), if suction funnel dimension is too large, some of the pressure will be lost in the hollow parts of the net-wrapper. Therefore, it is necessary to determine the suction position - the place where the density of the cake is the biggest, and the density of the empty space is the smallest. According to [3], [8] those positions are determined. It is found that the density of the cake is the largest at the dark green rim in the Figure 2. To protect the cake from damage caused by suction, we use stainless steel net, as shown in Figure 3.

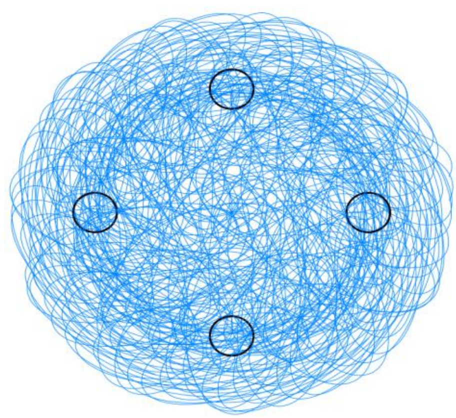

Figure 2. Net-wrapper shape and suction positions

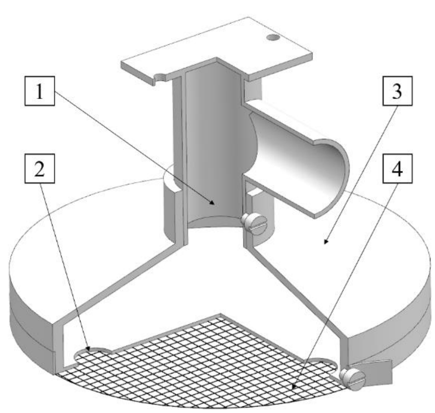

Figure 3. The suction funnel structure

Notation: (1) Air duct; (2) Hole of Suction funnel; (3) Cover; (4) Support net

3.2 Determine specifications of centrifugal suction fan

In order for the device to be able to suck the cake on demand, the design of the funnel and related specifications are extremely important.

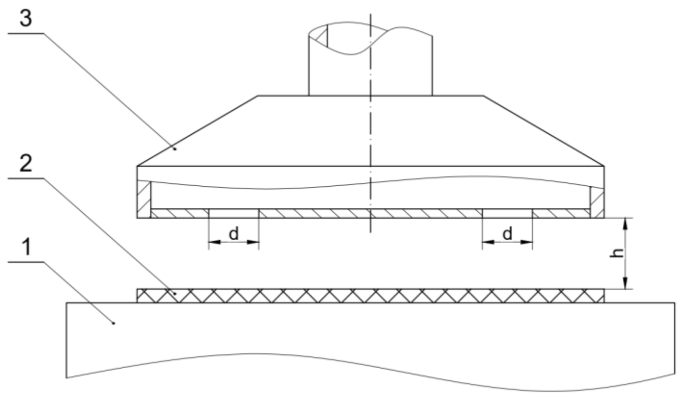

Figure 4. Calculation suction funnel
Notation: (1) Plate; (2) Cake; (3) Suction funnel
h: distance required to suck the cake (adjustable)

Quantity of the air flow is required:

$Q_1 = \mathrm{V} \times \mathrm{A} = 2 \times 10^{-5}\ (\mathrm{m}^3/\mathrm{s})$ [4]

V: velocity of the air: $\mathrm{V} = \frac{\mathrm{h}}{\mathrm{t}} = \frac{5\times10^{-3}}{0,3} = 0{,}02\ (\mathrm{m/s})$ (h: distance required to suck the cake, t: time required to suck the cake).

A: hole area (there are four 16 mm diameter holes).

Calculate the quantity of the centrifugal fan:

Assume:

Pressure of fan: H = 30 mm H_2O.

Speed of propeller: n=1000 rpm.

Select the fan based on graph 3.3 a [5]. Therefore:

$Q_2 = 8000\, m^3/h = 2{,}2\, m^3/s > Q_1$.

Calculate specifications of the fan

Power for propeller:

$$N = \frac{10^{-3} \times Q \times g \times H}{\eta} = \frac{10^{-3} \times 2{,}2 \times 10 \times 30}{0{,}4} = 1{,}65\ kW$$

Power of motor: $\mathrm{N_m} = \mathrm{k.N} = 1{,}2 \times 1{,}65 = 1{,}98(\mathrm{kW})$ (with k = 1,2 [5])

In order for the suction funnel to work stably during the cake-taking process, a centrifugal fan with the capacity of 2.2 kW should be chosen because there are many other confounding factors than the density of the cake such as pressure loss in pipe, sticky force of the cake distance required to suck the cake, etc.

Inside diameter:

$$D_1 = k\sqrt[3]{\frac{Q_2}{n}} = 3{,}25.\sqrt[3]{\frac{2{,}2}{1000}} = 0{,}42m = 420mm$$

Outside diameter:

$$D_2 = \frac{D_1}{m} = \frac{420}{0{,}85} = 494mm$$

(with m = 0,85 [5])

Length of blade:

$$z = \frac{D_2 - D_1}{2} = \frac{494 - 420}{2} = 37mm$$

Pitch of blade: t = z = 37 mm

Number of blades:

$$n_1 = \frac{\pi D_2}{t} = \frac{\pi.494}{37} = 42$$

3.3 Design of the Manipulator arm

The device needs to respond to the requirements in section 1.2. For an easy installation and accurate operation, the tolerance and accuracy of the parts must be appropriate. In addition, level buckling of device must be within the allowing approx. The detailed design process is below.

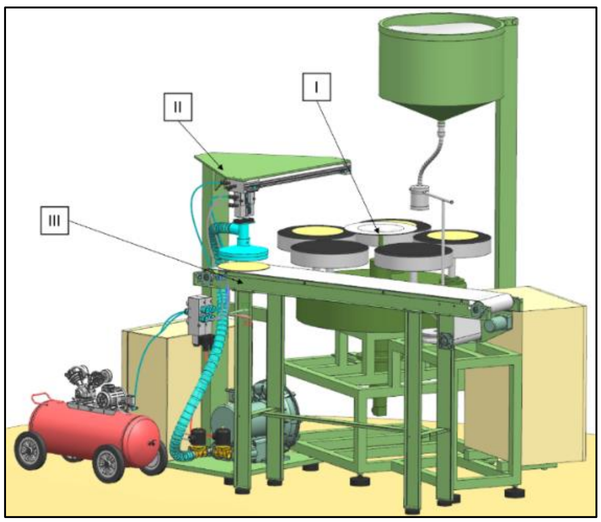

Figure 5. Layout diagram of equipment in spring rolls automatic production line.
Notation: (I) Semi-automatic machine; (II) Manipulator arm; (III) Conveyors.

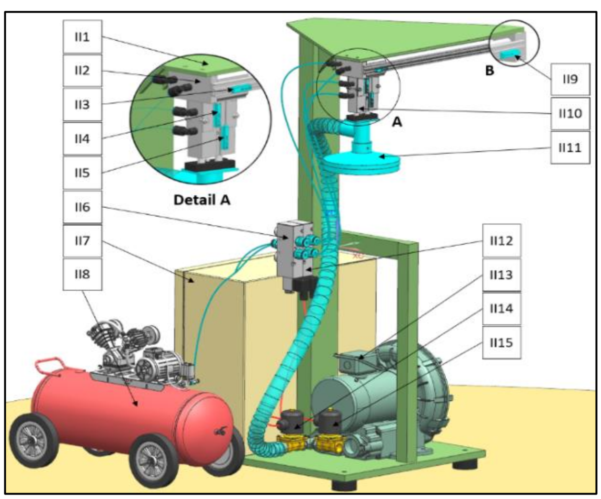

Figure 6. 3D model of the manipulator arm
Notation: II1 - Body; II2 - Horizontal movement cylinders; II3, II9 - Magnetic sensors mounted on horizontal cylinders; II4, II5 - Magnetic sensors mounted on cylinders moving up and down; II6, II12 - Pneumatic valve, II7 - Control cabinet, II8 - Pneumatic pump, II10 - Up and down movement cylinder, II11 - Suction funnel, II13 - Exhaust fan, II14, II15 - Solenoid valve.

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3.4 Detail design

The structure of the cake grab handle is shown in Figure 6, the device is controlled by PLC. In which, two pneumatic cylinders (II2) & (II10) are used to control the suction position (II11). In addition, two solenoid valves (II14) & (II15) have the function to switch the net-wrapper suction state to suck the cake out of the heating disk position and release the cake at the conveyor position (III). The operating principle is shown in the flowchart below.

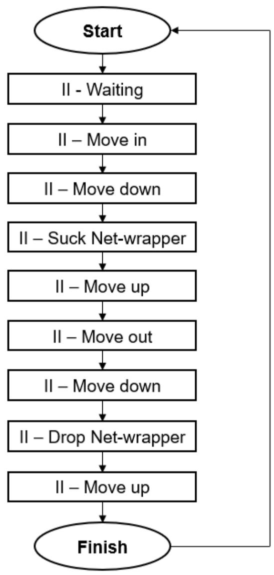

Figure 7. Block diagram of the operation principle of manipulator arm

4. Manufacturing and developing of manipulator arm

Equipment manufacturing consists of 2 parts: Machining the details that are not available such as the machine body, the suction funnel, ... and assembling them with the details or assemblies provided by manufacturers such as the exhaust fan, PLC, electronic, and pneumatic components. The research team has completed a model of the manipulator arm machine as shown in Figure 8.

Figure 8. The manipulator arm after fabrication.

4.1 Experiment not loaded

The experiment process's aim is to synchronize the manipulator arm after fabrication with a semi-automatic machine during idling operation [6]. The results show that the machine operates well and synchronously with the production time for spring rolls of machine [2]. The working principle is shown in Figure 9.

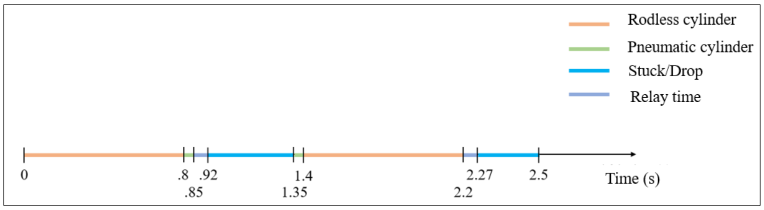

Figure 9. Time chart of the operation of manipulator arm

4.2 Experiment loaded

The purpose of this experiment was to test the reliability of the suction funnel in removing the cake from the heating plate and the accuracy of the time of dropping the cake onto the conveyor (III). In this paper, the author introduces a testing process that includes the following steps:

4.2.1 Identifying factors and criteria for quality assessment

The main factors affecting cake taking efficiency are: Suction pressure (P), baking time (t) and cake diameter (D) (Table 1). In addition to the above three factors, the effectiveness of taking cakes is also influenced by other factors such as: viscosity of the dough, baking temperature, distance of cake suction…

Table 1: Values of factors in the experiment

N_0	Factors	Factors code		Levels			Tolerance
		Symbol	Encoding	-1	0	1	
1	Pressure (cmHg)	P	X_1	10	15	20	10
2	Time (s)	t	X_2	2.5	3.0	3.5	1
3	Diameter (mm)	D	X_3	160	190	220	60

4.2.2 Experimental arrangement

The experiment used a high-pressure exhaust fan with a maximum pressure of 20 cmHg Figure 10. to adjust the suction pressure, the experiment uses a solenoid valve (1) through the pipe connecting to the suction head. When the solenoid valve is open, the pressure at the suction head will decrease, proceed to adjust the valve opening angle and use the pressure gauge to determine the appropriate pressure value.

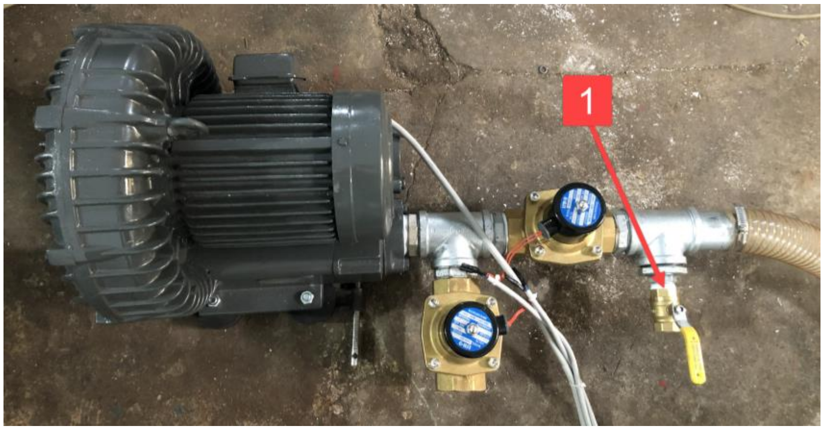

Figure 10. Solenoid valve arrangement to adjust pressure to suction head

To adjust the baking time, we proceed to adjust the time rheostat (2) on the PLC electrical cabinet of the Figure 11 the semi-automatic machine.

Figure 11. PLC electrical cabinet controls the operation of the semi-automatic machine

To change the diameter of net-wrapper, the experiment was conducted to adjust the rheostat of the rotary speed of the dough spreader (3) and the rotation speed of the heating plate (4) on the PLC electrical cabinet of the semi-automatic machine Figure 11.

4.2.3 Selection of orthogonal tables, matrix of experimental planning

Applying Taguchi method, we choose the orthogonal planning matrix L9 with N = 3^2 = 9 experiments [11]. Each experiment was reassembled n = 5 times to measure the cake taking efficiency.

To evaluate the efficiency of taking cakes, we are based on 3 criteria:

- No phenomenon of cake abandonment;
- Do not break the cake;
- The drop position falls into the range of the concentric figure Figure 8.

The planning matrix table with the experimental results is given in Table 2. The experiment process is recorded in [7].

Table 2: L9 orthogonal array for 3 factors each at 3 levels each with efficiency

N_0	Experimental factors			Encryption factor			Efficiency (%)
	Pressure (cmHg)	time (s)	Diameter (mm)	X_1	X_2	X_3	
1	10	2.5	160	1	1	1	63
2	10	3.0	190	1	2	2	63
3	10	3.5	220	1	3	3	47
4	15	2.5	190	2	1	2	93
5	15	3.0	220	2	2	3	100
6	15	3.5	160	2	3	1	93
7	20	2.5	220	3	1	3	80
8	20	3.0	160	3	2	1	93
9	20	3.5	190	3	3	2	80

The requirement is that the efficiency of taking the cake is the highest, so the signal to noise ratio is determined according to the optimal value [10].

The calculation results on Minitab are as follows:

Table 3: Response Table for Signal to Noise Ratios

Larger is better

Level	Pressure	Time	Diameter
1	35.14	37.81	38.24
2	39.58	38.45	37.81
3	38.50	36.96	37.17
Delta	4.44	1.49	1.07
Rank	1	2	3

Table 4: Response Table for Means

Level	Pressure	Time	Diameter
1	57.67	78.67	83.00
2	95.33	85.33	78.67
3	84.33	73.33	75.67
Delta	37.67	12.00	7.33
Rank	1	2	3

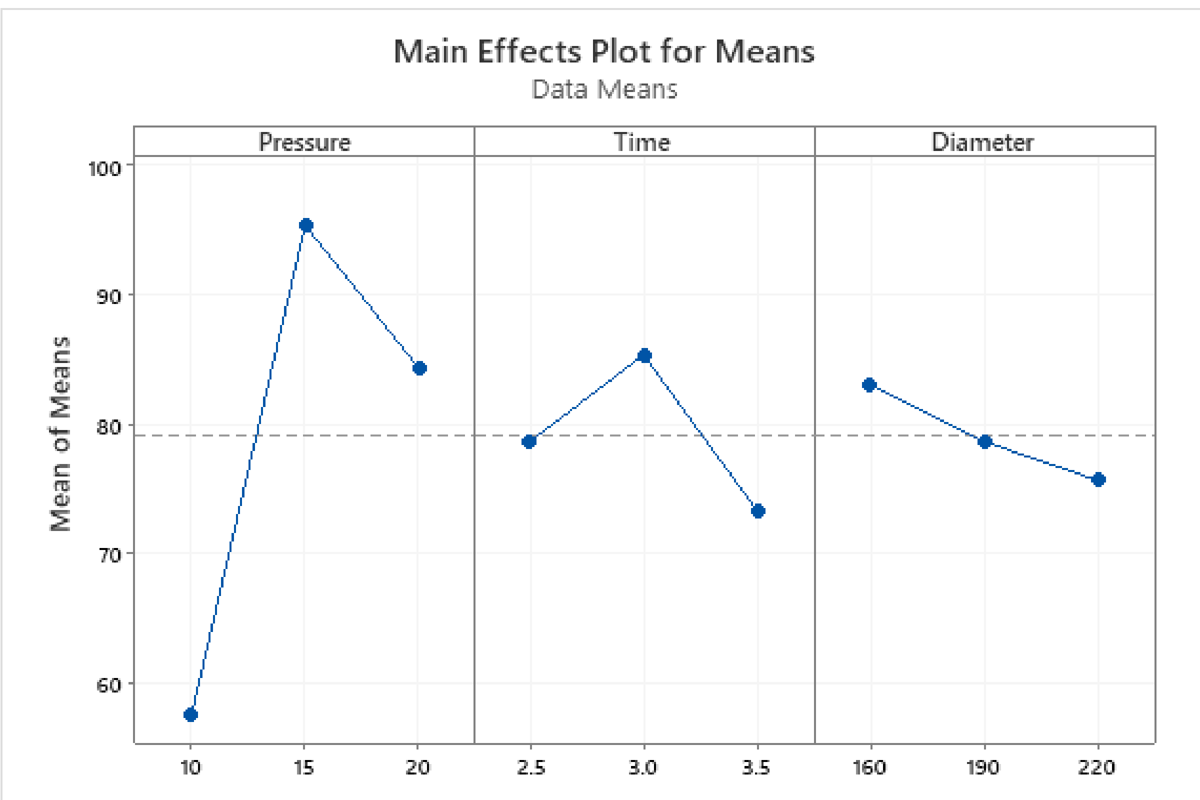

Figure 12. Main effects plot for means

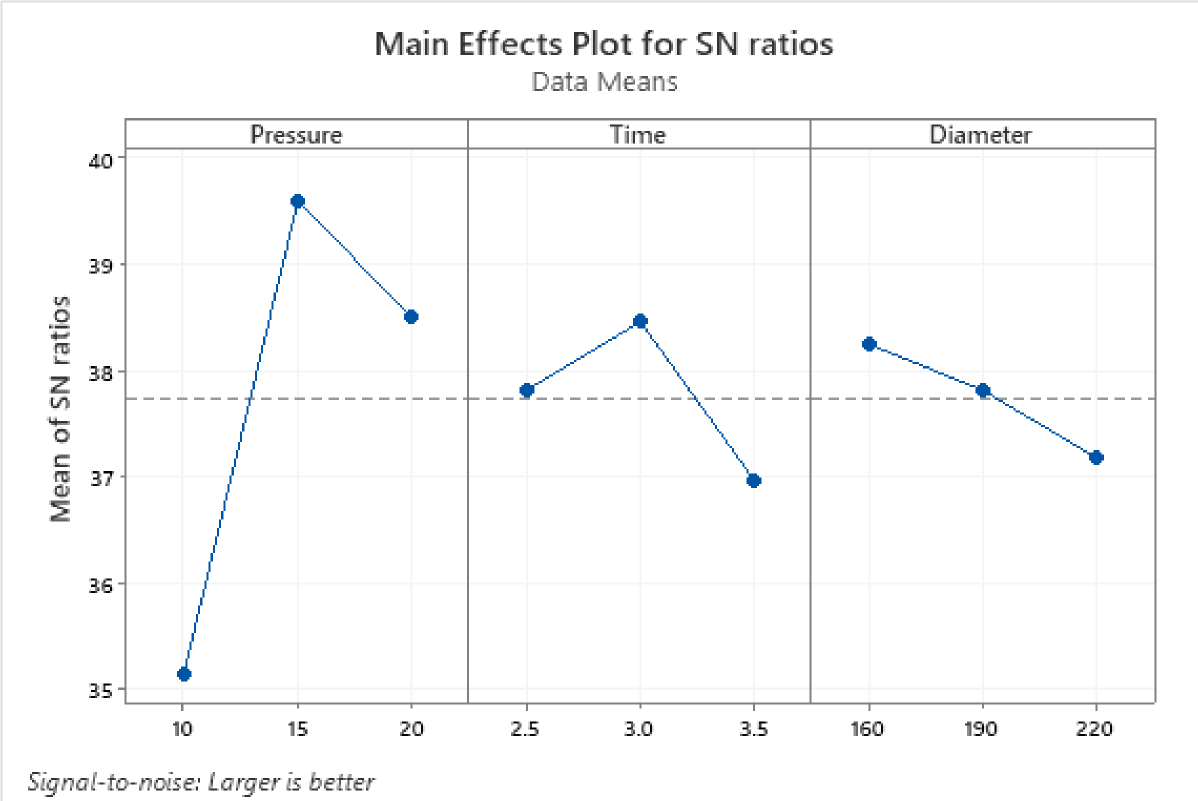

Figure 13. Main effects plot for SN ratios

4.3 Results

The manipulator arm after making works rhythmically, in synchronously with the shape time of the net-wrapper. Moreover, Experiment loaded found a baking efficiency of more than 95% with suction pressure P = 15cmHg, baking time t = 3.0s and cake diameter D = 160mm. In addition, the fall position on the conveyor is quite accurate and the eccentricity compared to the specified location is negligible (about ± 2mm). This result meets the operational requirements of the next operation of the automatic spring roll production line.

5. Conclusion

The manipulator arm uses a high-pressure exhaust fan with high reliability in operation and no errors. It can completely replace the previous mechanism and is applied in automatic spring roll production. The operating structure brings high productivity and easy maintenance of product quality and organizes the production plan more optimally in the age of technology 4.0.

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