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Research and Realization of Automatic Dynamic Balance for Cross-Flow Fan by NC Drilling

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***Abstract*—The dynamic balance of cross-flow fan was primarily implemented by manual balance sheetmetal, and there are some shortcomings that low precision and easily fall off. In this paper, firstly, the mechanism of dynamic balance of cross-flow fan was elaborated. Then, the collection of unbalance is achieved by four pressure sensors, and the equivalent unbalances of end faces was obtained by the mechanisms of two end-face equivalent balance. And then, the NC drilling method was brought in cross-flow fan, and one or more holes drilling model were built, respectively. After that, the automatic dynamic balance equipment of cross-flow fan was developed by the PLC control system. Last, a set of experiment was come true on the independent equipment, and the result of experiment showed that the decrement rate of unbalance can reach 90%.**

Keywords-dynamic balance; cross-flow fan; NC drilling; PLC; two end-face equivalent balance

I. INTRODUCTION

Cross-flow fan plays an important role in the air supply system of the air condition, and it primarily molded by ABS, AS and modified plastics. The advantage of cross-flow fan includes: 1) without limit of the axle length; 2) large wind amount; 3) no turbulent flow and low noise; 4) air supply smoothly and steady. The manufacturing operation of cross-flow fan contain: injection molding, weld (ultrasonic welding) and handling of dynamic balance [1]. The handling method of dynamic balance mainly includes adding counterbalance and de-weight on the end faces, its aim is to improve the asymmetrical weight distribution of cross-flow fan. So the precision of dynamic balance handling has a close relation with lifetime, air output and comfort level.

Many researches have been done on dynamic balance handling by many scholars, Liu developed an intelligent drilling system for dynamic balance based on R-drilling and V-drilling, and the decrement rate of unbalance can reach 92%, and the arithmetic speed of intelligent system can meet real time request[2]. Kang used double ethoxy resin as counterbalance to handle the dynamic balance of train wheel, and good actual effect had been got in the real production process [3]. Sun analyzed and modified the dynamic balance theory of the rigid rotor from the mechanism of dynamic balance, and an analysis software of dynamic balance had been developed on the basis of theory [4]. Qu introduced a novel theory (holospectrum analysis) for dynamic balancing, and this theory can 3D analysis static force and phase position of unbalance [5]. Ouyang designed an electromagnetic type auto-balancing head, and the optimal dimension parameters were obtained by chaos optimization algorithm [6]. In above studies, most of papers focus their attention on the metal rotor, while the dynamic balancing of plastic rotor was ignored, and this fact is because the density of plastic is lower and the necessary precision of dynamic balancing is higher.

In this paper, firstly, the unbalance causes of cross-flow fan were expounded. Secondly, the collection of unbalance was achieved by four pressure sensors, and the equivalent unbalances of end faces were obtained by the mechanisms of two end-face equivalent balance. Then, the NC drilling method was brought in cross-flow fan, and one or more holes drilling model were built, respectively. After that, the automatic dynamic balance equipment of cross-flow fan was developed by the PLC control system. Finally, a set of experiment was implemented on the independent developed equipment.

II. DYNAMIC BALANCE MECHANISM OF CROSS-FLOW FAN

Cross flow fan is also called transverse flow fan, and it is an important part of wall-mounted air conditioning. The structure of cross flow fan is multiple-blade and long cylindrical, and the blades is in cross distribution, Fig.1 is the physical map of it.

When the cross-flow fan is rotating, the airflow is blown into inside from onside, and the airflow is blown out

after turbulent flow. In the process of injection molding and welding, the mass distribution of cross-flow fan is uneven because of asymmetrical plastic thermal-shrink, extrusion and overflow of welding, so the support part must bear unbalance force in the rotating process, then some bad phenomenon maybe occur, such as lower expectancy, lower air flow and louder noise.

As shown in Fig.2 (a), the particle (mass of m) revolves around point O at angular speed of ω in the plane, and the phase position of particle is θ, and centrifugal inertia force (F) will be occurred according newton theorem, as shown in equation 1. The methods of drilling or adding counterbalance are usually used to balance the centrifugal inertia force (F), and concrete steps as follow:

$$\vec{F} = mw^2\vec{r} \tag{1}$$

- Drilling: the material (mass of m') is removed by drilling or milling at the direction of θ and the distance of r' from rotation center, and the follow condition must be met, m'*r'=m*r.
- Adding counterbalance: the material (mass of m'') is added by paste or bolt at the negative direction of θ and the distance of r'' from rotation center, and the follow condition must be met, m''*r''=m*r.

As shown in Fig.2 (b), the particles (mass of m_1 and m_2) revolve around point O at angular speed of ω in two planes, and the phase positions of particles is θ_1 and θ_2, respectively. The centrifugal inertia force (F_1) of m_1 particle will be occurred according newton theorem, as shown in equation 2.

$$\vec{F_1} = m_1 w^2 \vec{r}_1 \tag{2}$$

Taking the drilling as an example, to balance the centrifugal inertia force (F_1), the material (m'_{A1}) should be removed at the direction of θ_1 and the distance of r'_{A1} from rotation center in the A end face. At the same time, the material (m'_{B1}) should be removed at the direction of θ_1 and the distance of r'_{B1} from rotation center in the B end face. The equation 3 and equation 4 must be met:

$$m'_{A1} r'_{A1} = \frac{L - L_1}{L} m_1 r_1 \tag{3}$$

$$m'_{B1} r'_{B1} = \frac{L - L_2}{L} m_1 r_1 \tag{4}$$

Figure 1. The physical map of cross-flow fan

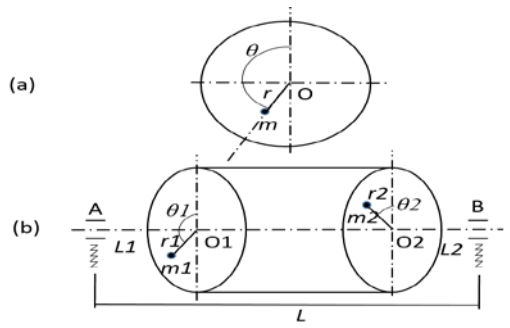


Figure 2. The theory schematic diagram of rotor unbalance

In the same way, the centrifugal inertia force of m_2 particle can also be balanced.

Based on above principle, the cross-flow fan can be treated as n disks (thickness of Δh), and the material (mass of m_A and m_B) need to be removed on the A and B end faces, respectively, and the vectors ($\vec{R}_A$ and $\vec{R}_B$) from rotation center to drilling point, and equation 5 and equation 6 must be met.

$$M_A \vec{R_A} = \sum_{i=1}^{n} \frac{L - L_i}{L} m_i \vec{r_i} \tag{5}$$

$$M_A \vec{R_A} = \sum_{i=1}^{n} \frac{L - L_i}{L} m_i \vec{r_i} \tag{6}$$

III. MODELING

According to the dynamic balance theory of cross-flow fan, if the product of drilling material mass and its distance (between rotation center and drilling point) remains equal, the dynamic unbalance can be balanced. So, we can set the distance between rotation center and drilling point as maximum value (R) for convenience, and the mass of drilling material is adjusted by NC system.

Concrete implementation method: face milling cutter (diameter of d) is used as drilling tool in this research, and the mass of drilling material varies with drilling depth to balance the cross-flow fan. Otherwise, the density of cross-flow fan is ρ.

A. Modeling of Single Hole Drilling

When the number of drilling hole is single, the eliminated unbalance ($\vec{U}$) of once drilling is as shown in equation 7:

$$\vec{U} = \frac{1}{4}\rho\pi d^2 \vec{R}h \tag{7}$$

B. Modeling of Two Holes Drilling

When the unbalance cannot be eliminated by single hole drilling, we can employ two holes drilling, and the drilling depths of two holes are the same. The included angle of two

vector (from rotation center to drilling points) is α, and the eliminated unbalance ($\bar{U}$) of once drilling is as shown in equation 8:

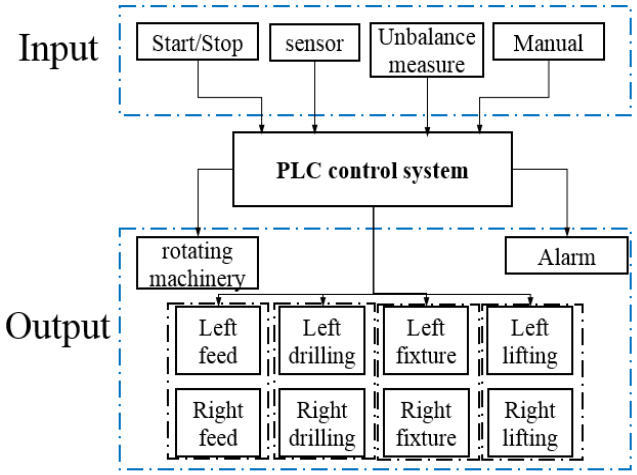
$$\left|\vec{U}\right| = \frac{1}{2}\rho\pi d^2 Rh\cos\frac{\alpha}{2} \tag{8}$$

C. Modeling of Multi-Holes Drilling

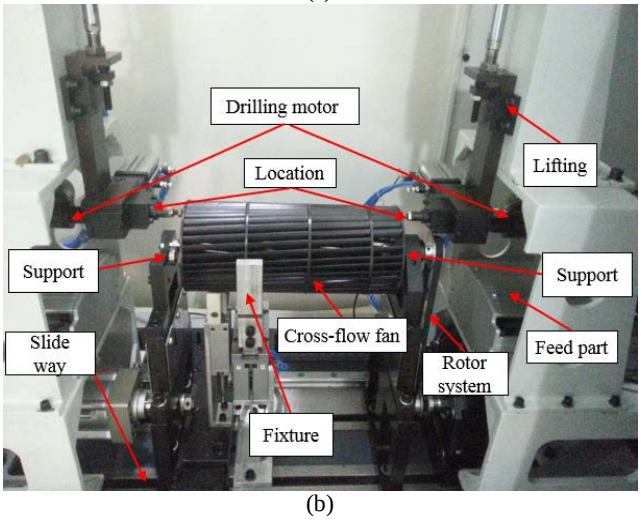
When the unbalance cannot be eliminated by two holes drilling, we can use multi-holes drilling, and the multi-holes drilling is actually once or repeatedly superposition of single hole and two holes drilling.

IV. Developing of Automatic Dynamic Balancing Equipment

On the basis of above theoretical analysis, an automatic dynamic balancing equipment has been independent developed. In addition, Fig.3 (a) and Fig.4 (b) are the schematic diagram and physical map of the automatic equipment.



(a)



(b)

Figure 3. The schematic diagram and physical map of the automatic dynamic balancing equipment

As shown in Fig.3, the components of the automatic dynamic balancing equipment mainly include following three parts:

- Input: the input signals consist mainly of operational order (start, stop, manual manipulation), sensor signal, measurement of unbalance. Thereinto, the measurement of unbalance is completed by four pressure sensors (X and Y direction).
- PLC control system: PLC control system is the brain of the automatic equipment, and its main duties include: receive input signal, operate and process input signal, realize some logic control and motion control according to system procedure. Therein, the PLC control system receive the signal of four pressure sensors, and the pressure signal is converted to unbalance of end faces after being processed by the digital filter, and the corresponding strategy of drilling is obtained to balance.
- Output: the output signals mainly include some orders, such as electric rotating machinery, feed motor, drilling motor, air cylinder of clamp and lift, alarm.

V. Experiment

To verify the efficiency and precision of the automatic equipment, a set of dynamic balancing experiment is finished on this equipment, the experiment condition is shown in Table I, and the result of experiment is shown in Table II:

TABLE I. Dynamic Balancing Experiment Condition

Project	Content	unit
Material	ABS	-
Density	1.03	g/cm^3
Node number	3	-
Length	384	mm
Diameter	80	Mm
Center distance	30	mm
End face thickness	7	mm

TABLE II. Dynamic Balancing Experiment Result

No.	Unbalance (g•mm)			Decrement rate of unbalance (%)	
	Initial	Surplus			
		Manual	Automatic	Manual	Automatic
1	20.2	2.3	1.9	0.89	0.91
2	14.3	2.1	1.6	0.85	0.89
3	22.4	3.2	2.4	0.86	0.89
4	28.2	3.1	2.6	0.89	0.91
5	19.1	1.9	2.0	0.90	0.90
6	25.7	1.5	1.3	0.94	0.95
7	23.5	2.5	2.0	0.89	0.91
8	16.2	3.2	2.4	0.80	0.85
9	26.1	3.4	1.5	0.87	0.94
10	23.5	2.4	1.4	0.90	0.94
11	12.6	3.5	1.3	0.72	0.90
12	25.3	1.8	1.5	0.93	0.94
13	24.1	2.2	1.8	0.91	0.93
14	15.2	1.9	1.4	0.88	0.91
15	11.2	2.5	1.1	0.78	0.90

From Table II, it can be confirmed that the decrement rate of cross-flow fan unbalance can reach 90% on the independent developed dynamic balancing equipment; moreover, decreament rate of balance by automatic equipment is apparently higher than manual device.

VI. CONCLUSION

In this paper, firstly, the mechanism of dynamic balance of cross-flow fan was elaborated. Then, the collection of unbalance is achieved by four pressure sensors, and the equivalent unbalances of end faces was obtained by the mechanisms of two end-face equivalent balance. And then, the NC drilling method was brought in cross-flow fan, and one or more holes drilling model were built, respectively. After that, the automatic dynamic balance equipment of cross-flow fan was developed by the PLC control system. Last, a set of experiment was came true on the independent equipment, and the result of experiment showed that the decrement rate of unbalance can reach 90%, and decrement rate of balance by automatic equipment is apparently higher than manual device. Therefore, this independent developed automatic dynamic equipment has engineering promoting value in the field of air condition.

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