

Design and Analysis of Rotor Line Type for Three-lobe Roots Blower

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Abstract. In order to improve and solve the capability of small and medium enterprises to design new products, the principle of operation of the three-lobe Roots blower rotor was firstly analyzed, and the characteristics of meshing of the rotor profile were analyzed. The meshing design formula was given. Based on this, the 3L41WD involute Roots blower design was taken as an example to calculate its full line type and to analyze and determine the meshing tolerance. Finally, the field test proved the rationality of the design, and provided guidance for SMEs to rapidly design the involute Roots blower rotor.

1. Introduction

The Roots blower is a type of rotary blower, which was invented in 1854. The volumetric fan has the advantages of simple structure, strong pressure bearing capability, good hard air performance, low energy consumption and easy-to-manufacture, and thus becomes the most widely used blower [1]. The rotor of the Roots blower is the core component, and the two rotors combined with the pump body form a closed section, which transports gas from the inlet to the outlet, so the rotor's linear shape is essential for operating efficiency, overall performance and safety. Although the researchers have done a lot of research on the profile of the rotor [2-4], there is still a lack of a complete process from the working principle → meshing situation → profile design → field test. Small and medium-sized roots blower companies have certain development difficulties due to the limitation of technical strength.

In view of the weak design ability of small and medium-sized enterprises, this paper focuses on the optimization design of 3L4 series Roots blower of a certain fan company. Firstly, based on the working principle of the three-leaf Roots blower rotor, the characteristics of the rotor-type wire meshing are analyzed, and the meshing design formula is given. In this case, the 3L41WD involute Roots fan design is taken as an example, and all the line types are given. Finally, the field test proved



the rationality of the design, optimized the existing products for SMEs, and provided guidance and technical support for the rapid development of new energy-efficient products.

2. Analysis of meshing condition of Roots blower

2.1 working principle

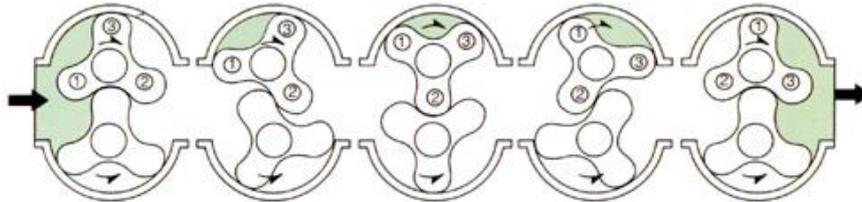


Figure 1. Working principle of Roots blower

As shown in figure 1, the two rotors of the Roots blower move synchronously in opposite directions, and the rotor and the fan casing form a closed space to surround a certain amount of gas, and the gas is transported from the inlet to the outlet as the rotor rotates (The shaded portion of figure 1 shows the process of a rotor conveying air volume.). The amount of air delivered is proportional to the number of revolutions. At present, the common line types of Roots blower rotors are: involute, arc, cycloid and the combination of the above-mentioned line types, wherein the arc-shaped rotor type wire tip seal performance is poor, and the cycloid type area utilization coefficient is low. Involute type is easy to cause linear interference due to improper design. Therefore, the most widely used combination of various line types is the involute.

Figure 2 shows the operation of the multi-line combined Roots blower with the involute as the main body in the 0° - 60° meshing section. The rotor meshing involute follows the following rules during the meshing process:

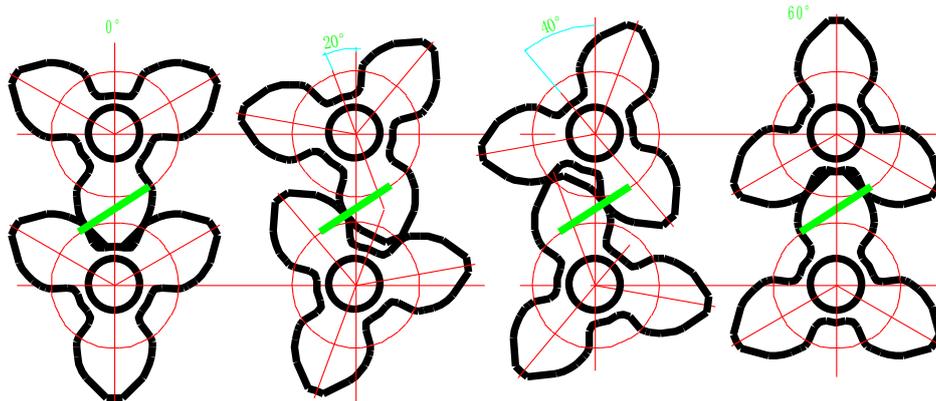


Figure 2. Schematic diagram of the involute type of leaf rotor

1) The meshing points on the two involute rotor blades always slide on the inner tangent line of the two involute base circles, and the meshing points do not exceed the range of the inner tangent line and the two base circle tangent points;

2) Each of the rotor blades of the three-leaf Roots blower is responsible for meshing 120° during the rotation, and one side of the involute profile of each of the rotor blades is responsible for the

engagement angle of 60° , thereby completing the 360° engagement process for one week. The operation of the fan is the cyclical engagement of the synchronous rotor blade and the involute profile of the rotor.

3) The radius of the base circle of the two involute lines determines the length of the inscribed line of the two base circles [5], and the length of the inscribed line affects the length of the involute. The smaller the radius of the involute base circle, the farther the initial meshing point of the two rotors is from the pitch circle position, so the wider the rotor bottom (the area formed on the base circle) and the sharper the top of the rotor; Conversely.

2.2 Meshing analysis

As shown in figure 3, the inner tangent of the two rotor base circles has a base circle radius of R_0 ; $2a$ is the center distance of the two rotors, The meshing point of the two rotor involutes at 0° is K_1 , and the meshing point at 60° is K_2 . When the rotor is in operation, the involute line is switched from one side to the other side every 60° , and the meshing relationship satisfies the requirement of equation (1).

$$\begin{cases} \frac{PP'+K_1K_2}{2R_0} = \alpha'+\alpha \\ \cos \alpha = R_0 / a \\ PP' = 2\sqrt{a^2 - R_0^2} \\ K_1K_2 = \pi R_0 / Z \end{cases} \quad (1)$$

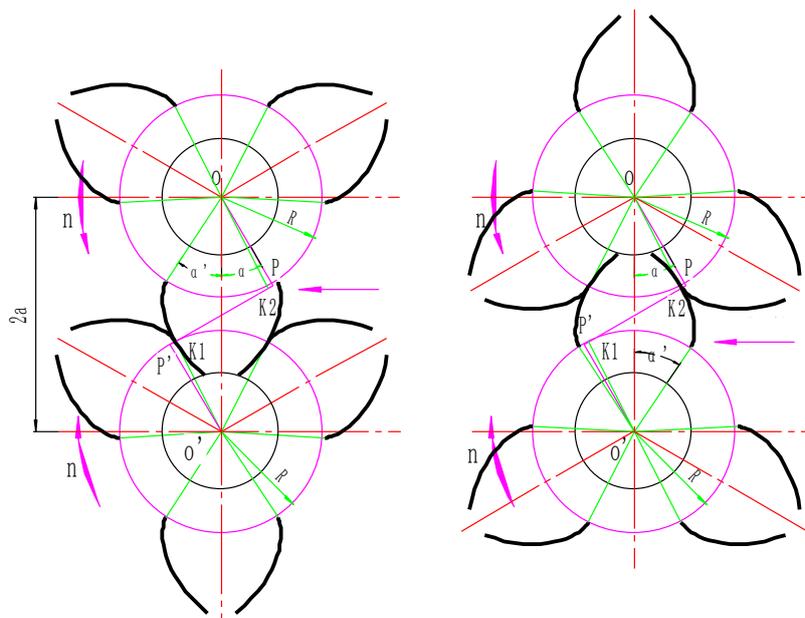


Figure 3. Involute rotor engagement process

According to the document [7]: $R_0 = \frac{2Z}{\pi}(R-a) \cdot \xi$, ξ should be between 0.7878~0.9277. In order to reduce the amount of machining of the rotor and increase the area utilization factor of the rotor, the blade shape with a larger radius of the base circle should be selected as much as possible.

3. Typical rotor design analysis

Taking a 3L41WD rotor of wind turbine company as an example, the number of rotor blades is 3, the center distance is $2a=160$, and the outer diameter is $2R=240$. The radius of the base circle that satisfies the meshing requirement can be selected in [60.1858, 70.8726]. According to the analysis of the second part, the larger value $R_0=70$. Figure 4 shows the blade pattern of the rotor in the range of $30^\circ \sim 150^\circ$. The control points in the $30^\circ \sim 90^\circ$ range are A, B, C, D, E, F, G. The specific coordinates are as follows: A(0, 40), B (5.4168, 39.6315), C (25.9049, 50.2885), D (32.0557, 62.2289), E (71.2138, 76.6541), F (100.6405, 63.3567), G (103.9230, 60).

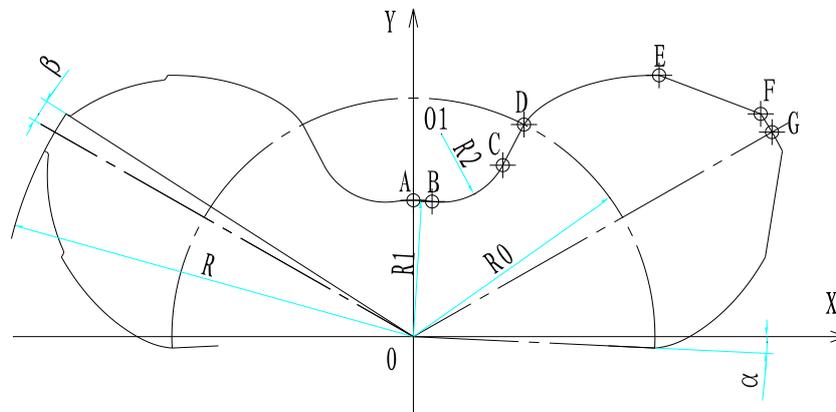


Figure 4. 3L4 series involute Roots fan rotor line type and control point ($30^\circ \sim 90^\circ$)

3.1 Rotor blade equation

1) The AB segment is an arc of radius R_1 and the equation is as shown in equation (2):

$$x^2 + y^2 = R_1^2 \tag{2}$$

$$\text{among them: } \begin{cases} 0 \leq x \leq 5.4168 \\ 39.6315 \leq y \leq 40 \end{cases}, R_1=40.$$

2) The BC segment is an arc of radius R_2 and the equation is as shown in equation (3):

$$(x - x_{o1})^2 + (y - y_{o1})^2 = R_2^2 \tag{3}$$

$$\text{among them: } \begin{cases} 5.4168 \leq x \leq 25.9049 \\ 39.6315 \leq y \leq 50.2885 \end{cases}; \begin{cases} x_{o1} = 8.1253 \\ y_{o1} = 59.4473 \end{cases}; R_2=20.$$

3) The CD segment is a straight line and the equation is as shown in equation (4):

$$\frac{y - y_c}{x - x_c} = \frac{y_d - y_c}{x_d - x_c} \tag{4}$$

$$\text{among them: } \begin{cases} 25.9049 \leq x \leq 32.0557 \\ 50.2885 \leq y \leq 62.2289 \end{cases}; \begin{cases} x_C = 25.9049 \\ y_C = 50.2885 \end{cases}; \begin{cases} x_D = 32.0557 \\ y_D = 62.2289 \end{cases}$$

4) The DE segment is the involute of the base circle R₀, and it's equation consists of equations (5)(6)(7):

$$\begin{cases} x_1 = R_0(\cos \theta + \theta \sin \theta) \\ y_1 = R_0(\sin \theta - \theta \cos \theta) \end{cases} \quad (5)$$

$$\text{among them: } 0 \leq \theta \leq \frac{l}{\pi R_0} \times 180^\circ, l = 77.7641, R_0 = 70$$

$$\begin{cases} x_2 = x_1 \cos \alpha + y_1 \sin \alpha \\ y_2 = y_1 \cos \alpha - x_1 \sin \alpha \end{cases} \quad (6)$$

$$\text{among them: } \alpha = -2.7732^\circ$$

$$\begin{cases} x = x_2 - L \sin 30^\circ \\ y = y_2 + L \cos 30^\circ \end{cases} \quad (7)$$

$$\text{among them: } L = \sqrt{(x - x_2)^2 + (y - y_2)^2}$$

5) The EF segment is a straight line and its equation is as shown in equation (8):

$$\frac{y - y_E}{x - x_E} = \frac{y_F - y_E}{x_F - x_E} \quad (8)$$

$$\text{among them: } \begin{cases} 71.2138 \leq x \leq 100.6405 \\ 65.3567 \leq y \leq 76.6541 \end{cases}; \begin{cases} x_E = 71.2138 \\ y_E = 76.6541 \end{cases}; \begin{cases} x_F = 100.6405 \\ y_F = 63.3567 \end{cases}$$

6) The FG segment is an arc of radius R, and its equation is as shown in equation (9):

$$x^2 + y^2 = R^2 \quad (9)$$

$$\text{among them: } \begin{cases} 100.6405 \leq x \leq 103.9230 \\ 60 \leq y \leq 65.3567 \end{cases}; R=120.$$

3.2 Rotor blade engagement and tolerance control

Figure 5 shows the complete meshing of a rotor of the linear Roots blower rotor within 90 degrees. The rotor meshing clearance varies continuously from 0.036-0.0121-0.0105-0.0129-0.037. The problem is that the two ends are small (0°, 60°), the middle gap is larger and more uniform. The reason for the formation is to ensure the full meshing closure, the length of the involute has a certain amount of redundancy, at 0°, 60°, the meshing between the involute with a large radius of curvature and the involute with a small radius of curvature, The meshing gap is uneven, which can be compensated by

the control of the meshing gap or the error compensation during processing. Under normal circumstances, the side clearance of the rotor should be between 0.20-0.30. Considering the assembly error of the rotor and the influence of the medium during the working process, the nominal width of the maximum width of the rotor index circle is set to 80mm. The machining error is controlled between (-0.075, -0.150).

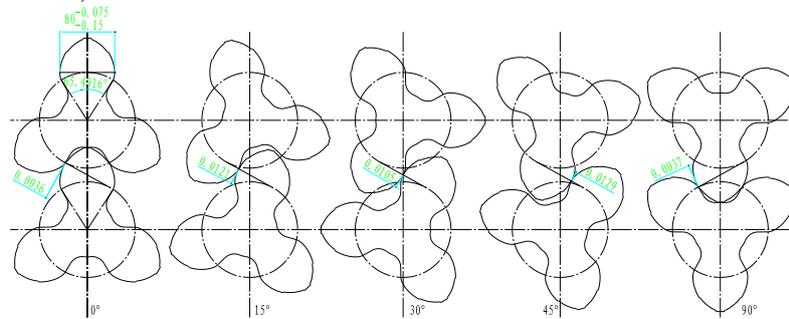


Figure 5. 3L4 series involute roots fan rotor 0°~90° meshing diagram

4. Experiment analysis

In order to test the actual operation of the fan, according to JB/T 8941.2-1999 "General Purpose Roots Blower Part 2 Performance Test Method" and JB/T 8941.1-1999 "General Purpose Roots Blower Part 1 Technical Conditions" standard, the 3L41WD fan was tested on-site. The atmospheric pressure is 101.3 kPa, the intake air temperature is 20C°, and the air density is 1.2kg/m3. The inspection site is shown in figure 6.



Figure 6. 3L41WD type fan inspection site map

The overall inspection of the 3L41WD Roots blower is shown in table 1. The overall operation of the fan is good, and all the indicators are within the technical requirements. Fan flow, volumetric efficiency and boosting changes are shown in figure 7. When the boost is 10 kPa, the fan flow is 11 mm3/min, and the volumetric efficiency can reach about 83%. When the boost reaches 60 kPa, the fan flow rate is 8.4 mm3/min, and the volumetric efficiency is about 64%. Compared with the original line type, the temperature rise, vibration, noise and other aspects have different degrees of decline, the overall performance of the fan has been further improved, so the parameter control of this design is relatively successful.

Table 1. Overall inspection of 3L41WD Roots blower

Serial number	Test items	Unit	skills	test result	Remarks
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			requirement		
1	Boost	kPa	9.8-58.8	9.8-58.8	-
2	Flow	m ³ /min	11.0-8.0	11-8.4	-
3	Flow deviation	%	±5.0	0-0.5	-
4	Bearing temperature	C°	≤95.0	18.0-55.0	< 56
5	Axle box temperature	C°	≤65.0	12.0-40.0	< 48
6	Maximum vibration speed	mm/s	≤11.2	3.3	< 3.5
7	Noise	dB(A)	≤100	81	< 86

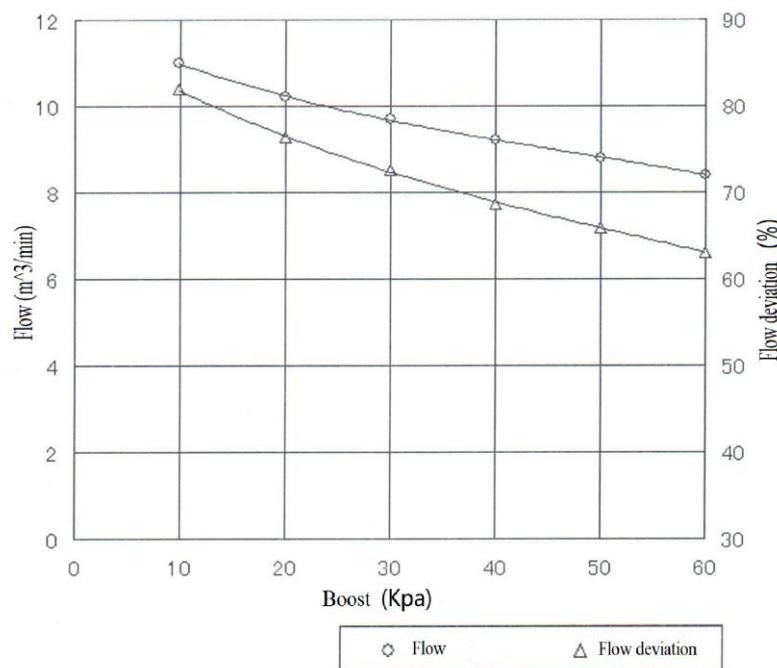


Figure 7. 3L41WD fan boost, flow and volumetric efficiency graph

5. Conclusion

The design of the rotor blade of the three-leaf involute Roots blower involves a large amount of calculation and verification. The workload is large and the cycle is long. It is difficult for SMEs to fully grasp the reasons for their own design strength. This paper combines the optimization design of a 3L4 series Roots blower of a wind turbine company, and introduces the process of meshing analysis, line type calculation and on-site inspection in detail, and provides technical guidance for the rapid development of new product development for SMEs.

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