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Study on Precision Grinding of Screw Rotors using CBN Wheel

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With increasing demands for high-speed and high-precision machining technology, CBN shape grinding is an effective means in the field of precision machining for screw rotors. Aiming at the high precision machining of screw rotors, a mathematical model for the axial profiles of the CBN wheel for machining screw rotors is developed based on theory of gear engagement. Small electroplated CBN wheel is firstly used to grinding screw rotors. Taking the backlash of screw rotors and the coating thickness of CBN layer into consideration, the modification of the base body of the wheel shape is introduced into the design of CBN wheel. For reducing the tooth profile errors of screw rotors induced by mounting errors and wears of CBN wheel, a mathematical model of the error analyses is established and the influence curves of the profile errors affected by mounting errors and radius error of grinding wheel are proposed. The electroplated CBN wheels for the screw rotors are made to verify the validity and effectiveness of the presented method and the machining experiments were performed. Results of this study reveals that the method proposed in this paper can be used as the precision grinding of screw rotors.

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NOMENCLATURE

p = screw parameter of the screw rotor
H =lead length of the screw rotor
Σ = mounting angle of the axes of grinding wheel and the rotors
A_u =distance between axes of the rotors and grinding wheel
φ =rotated angle if one point in the rotors being contact point
δ = modified value of the theoretical axial section of wheel
δ_b = the backlash of two screw rotors
δ_c =the coating thickness of CBN layer
δ_{c1} =the average of grit size
δ_{c2} =CBN basement thickness
x_1, y_1, z_1 = components at the rotor profile in system σ_1
x, y, z = components at the rotor profile in system σ
x_u, y_u, z_u =components at the grinding wheel surface
n_x, n_y, n_z = omponents of the normal vector of axis x, y, z
$\vec{n}$ =normal vector at the screw rotor
n_u, n_u, n_u =components of the normal vector of axis x_u, y_u, z_u
$\vec{n}_u$ =normal vector at the grinding wheel surface
$\vec{\omega}_u$ =angular velocity vector of rotation of the grinding wheel
ω_u =module of angular velocity $\vec{\omega}_u$
$\vec{\omega}_1$ =angular velocity of rotation of the screw rotor
ω_1 =module of angular velocity $\vec{\omega}_1$
$\vec{v}_1$ =velocity of the contact point at the rotor surface
$\vec{v}_1^0$ =initial velocity of the contact point at the rotor surface
$\vec{v}_u$ =velocity of the contact point at the grinding wheel surface
$\vec{v}_u^0$ =initial velocity of the contact point at the wheel surface
R_u =theoretical radius of the grinding wheel
Z_u =theoretical axis position of the grinding wheel
R'_u = modified radius of the grinding wheel profiles
Z'_u = modified axis position of the grinding wheel profiles

1. Introduction

Screw rotors are the key part in screw compressors, screw kneaders as well as screw pumps. The machining precision of the rotors determines the performance of machinery in large scales. Generally, milling cutters are used to machine the screw rotors. Many researchers, such as Xiao et al. and Yao et al., have done a lot of work on machining the screw rotors by using milling cutters;[1,2]

however, the low machining precision and surface accuracy are the main shortcomings. With increasing demands for high-performance technology, some new machining technologies have been developed to machine the screw rotors.

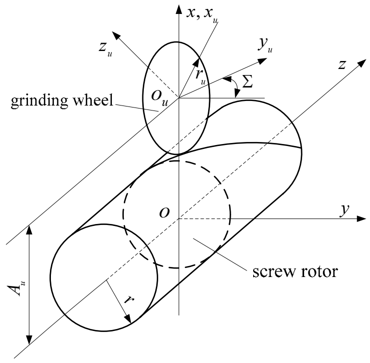
As an effective precision grinding method, cubic boron nitride (CBN) grinding wheels have been widely used in industries for the past few decades, and often they produced very good results.[3] Caglar and Evans analyzed the advantages of this technique as followings:[4] (1) CBN wheels have high accuracy, consistency and high wear-resistance, during the whole grinding process, and there is no necessity for wheel dressing; (2) It has high accuracy profile for a ground workpiece; (3) It has excellent grinding performance, and seldom lead to tooth surface burned or cracked; (4) It has high productivity and the structure of grinding machine is quite simple. For CBN wheels, there is no necessity for wheel dressing and wear compensation unit during the whole grinding. According to the reviews by a state of high-performance grinding, increased wheel speed can be achieved by highly efficient abrasives. Most of the researches on the application of the CBN shape grinding focuses on the material properties as well as on the design of wheel shape for the precision machining of parts such as involute gears, internal gears, etc. Jackson et al. introduced the basic mechanisms and the applications for the technology of high-speed grinding with the CBN wheels.[5] You et al. developed a mathematical model on calculating the profiles of the CBN wheel based on the theory of gear engagement for involute gears and the modification of the gear shape was introduced into the design of the CBN wheel.[6]

In the grinding process, the precision of the grinding wheel directly determines the ground workpiece precision. During grinding processing, those inevitable factors, such as manufacture and assembly errors, deformations, thermal expansions, etc, should be considered. Furthermore, the coating thickness of CBN layer should be considered. Therefore, the design of the modified profile should take into consideration the backlash of screw rotors and the coating thickness of CBN layer account. Aiming at the precision machining of CBN wheel, the authors developed a mathematical model on how to design the axial profiles of the CBN wheel for machining screw rotors based on the theory of gear engagement after considering these factors. Meanwhile, for reducing the tooth profile errors of screw rotors, the profile errors induced by mounting errors and wears of CBN wheel should be considered. In this research, a mathematical model of the error analyses of screw rotors is established and the influence curves of the tooth profile errors affected by mounting errors and radius error of grinding wheel are proposed.

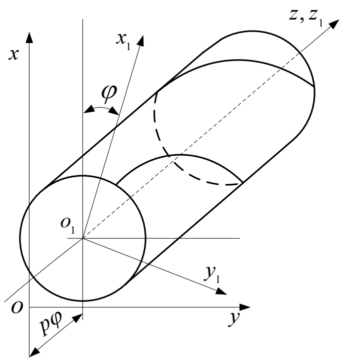
2. Shape Design of CBN wheel

2.1 The tooth surface equation of CBN wheel shape

Based on the theory of gear engagement, Litvin and Fuentes established the coordinate systems of machining of cylindrical worms and reported the contact equation of the grinding wheel with the worm surface.[7] Similarly, the helical surface of screw rotors can be regarded as the one to generate relative movement of a grinding wheel and a helical workpiece.

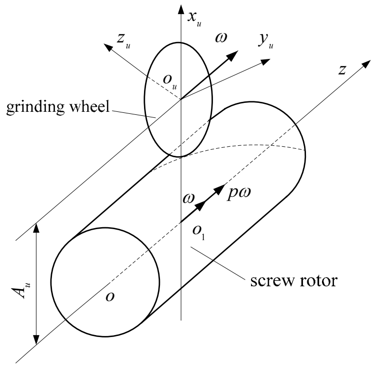


(a) Coordinate setting of the grinding wheel

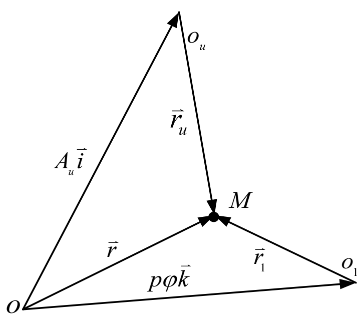


(b) Coordinate setting of the screw rotor

Fig. 1 Geometry relationship between a grinding wheel and a screw rotor



(a) Vectors in screw rotor and grinding wheel



(b) Relationship of different vectors

Fig. 2 Kinematic relationship between a grinding wheel and a screw rotor

In this paper, the coordinate systems are defined as: a fixed coordinate system σ is located in the centre of the end section of the screw rotor. A coordinate system σ_u is fixed at the centre of the grinding wheel. And a moving coordinate system σ_1 is fixed at the rotor blank. The grinding wheel is considered to be at rest in the process of generation and the rotor being generated performs the screw motion around its axis with the screw parameter p, where $p = H/2\pi$; the axes of the grinding wheel and the rotor are crossed forming the mounting angle Σ. Figure 1 shows the geometry relationship between a grinding wheel and a screw rotor.

In the process of grinding, the grinding wheel performs rotation around its axis but this is related to the velocity of grinding only and may be ignored when the mathematical aspects of rotor generation are considered. The radii of a contact point M in coordinate systems σ_1, σ_u are $\vec{r}$, $\vec{r}_u$, respectively. Figure 2 shows the kinematic relationships between a grinding wheel and a screw rotor.

2.2 Theoretical axial section of the CBN wheel

The CBN wheel is a surface of revolution. Therefore, the shape of the CBN wheel will be known if the axial section of the surface of revolution is given. According to Figure 1 and Figure 2, the radii of a contact point M in coordinate system σ_1 and σ_u can be expressed as Eq. (1):

$$\begin{cases} \vec{r}_1 = x_1\vec{i}_1 + y_1\vec{j}_1 + z_1\vec{k}_1 \\ \vec{r}_u = x_u\vec{i}_u + y_u\vec{j}_u + z_u\vec{k}_u \end{cases} \tag{1}$$

Eq. (1) can be transformed as seen in Fig. 2(b):

$$\begin{cases} \vec{r}_1 = \vec{r} - p\varphi\vec{k} = x\vec{i} + y\vec{j} + (z - p\varphi)\vec{k} \\ \vec{r}_u = \vec{r} - A_u\vec{i} = (x - A_u)\vec{i} + y\vec{j} + z\vec{k} \end{cases} \tag{2}$$

The angular and the velocity of the contact point M in the σ_1 and σ_u can be deduced as followings, respectively:

$$\begin{cases} \vec{\omega}_1 = \omega_1\vec{k}_1 \\ \vec{v}_1 = \vec{\omega}_1 \times \vec{r}_1 + \vec{v}_1^{\,0} = \omega_1(-y_1\vec{i}_1 + x_1\vec{j}_1 + p\vec{k}_1) \end{cases} \tag{3}$$

$$\begin{cases} \vec{\omega}_u = \omega_u\vec{k}_u \\ \vec{v}_u = \vec{\omega}_u \times \vec{r}_u + \vec{v}_u^{\,0} = \vec{\omega}_u(-y_u\vec{i}_u + x_u\vec{j}_u) \end{cases} \tag{4}$$

Then transforming Eq. (3) and Eq. (4) into the fixed coordinate system σ:

$$\begin{cases} \vec{\omega}_1 = \omega_1\vec{k} \\ \vec{v}_1 = \omega_1(-y\vec{i} + x\vec{j} + p\vec{k}) \end{cases} \tag{5}$$

$$\begin{cases} \vec{\omega}_u = \omega_u(-\sin\Sigma\vec{j} + \cos\Sigma\vec{k}) \\ \vec{v}_u = \omega_u[(-z\sin\Sigma - y\cos\Sigma)\vec{i} \\ \qquad + (x - A_u)\cos\Sigma\vec{j} + (x - A_u)\sin\Sigma\vec{k}] \end{cases} \tag{6}$$

Substituting $\vec{v}_1$ and $\vec{v}_u$ into $\vec{v}^{1u} = \vec{v}_1 - \vec{v}_u$, the relative speed $\vec{v}^{1u}$ of the contact point M can be given by Eq. (7):

$$\begin{aligned} \vec{v}^{1u} = {} & \omega_1(-y\vec{i} + x\vec{j} + p\vec{k}) - \omega_u[(-z\sin\Sigma - y\cos\Sigma)\vec{i} \\ & + (x - A_u)\cos\Sigma\vec{j} + (x - A_u)\sin\Sigma\vec{k}] \end{aligned} \tag{7}$$

The contact point M should satisfy the equation $\vec{n}\cdot\vec{v}^{1u} = 0$. Substituting Eq. (7) and $\vec{n}$ into the equation $\vec{n}\cdot\vec{v}^{1u} = 0$, where $\vec{n}$ is the normal vector of the helical tooth profile. The contact equation can be expressed as:

$$\begin{aligned} & \vec{n}\cdot\omega_1(-y\vec{i} + x\vec{j} + p\vec{k}) - \omega_u\cdot\vec{n}\cdot[(-z\sin\Sigma - y\cos\Sigma)\vec{i} \\ & + (x - A_u)\cos\Sigma\vec{j} + (x - A_u)\sin\Sigma\vec{k}] = 0 \end{aligned} \tag{8}$$

Taking into consideration the properties of $\vec{n}\cdot\omega_1(-y\vec{i} + x\vec{j} + p\vec{k}) = 0$ and $n_x y - n_y x = pn_z$ of cylindrical helicoids, the contact equation Eq. (10) can be further modified as:

$$zn_x + A_u\cot\Sigma n_y + (A_u - x + p\cot\Sigma)n_z = 0 \tag{9}$$

Hence, the trajectory between the grinding wheel and the screw rotor can be produced by the clustering tooth profile points of helical surface, which satisfy Eq. (9). The theoretical axial section of the CBN wheel can be given as Eq. (10):

$$\begin{cases} R_u = \sqrt{x_u^2 + y_u^2} \\ Z_u = z_u \end{cases} \tag{10}$$

2.3 Modification of the theoretical axial section

Considering those inevitable factors, such as manufacture and assembly errors, deformations, thermal expansions, etc, the backlash δ_b of screw rotors, as well as the coating thickness δ_c of CBN layer should be considered. Therefore, the design of the modified profile should take into account the backlash δ_b of screw rotors and the coating thickness δ_c of CBN layer. The relationship between the modified value δ of the theoretical axial section of grinding wheel and the backlash δ_b as well as the coating thickness δ_c is given by:

$$\delta = \delta_b - \delta_c \tag{11}$$

The coating thickness δ_c of CBN layer is comprised by average grit size δ_{c1} and CBN basement thickness δ_{c2}, shown as Eq. (12):

$$\delta_c = \delta_{c1} + \delta_{c2} \tag{12}$$

Actually, the modified profiles of the grinding wheel can be achieved by three steps. Firstly, to obtain the discrete points of the tooth profile cc from Eq.(10). Secondly, to obtain the normal vectors of the theoretical profiles of the grinding wheel. Thirdly, to obtain the modified axial section $c'c'$ with the surface equidistance method. The modified axial section of CBN wheel is satisfied with Eq. (13):

$$\begin{cases} R_u^{'} = R_u + \delta\sqrt{1 - \cos^2\varepsilon} \\ Z_u^{'} = Z_u + \delta\cos\varepsilon \end{cases} \tag{13}$$

The angle ε between the normal vector $\vec{n}_u$ and the rotation vector $\vec{k}_u$ of the grinding wheel can be obtained from Eq. (14):

$$\cos\varepsilon = \frac{\vec{k}_u\cdot\vec{n}_u}{|\vec{n}_u|} \tag{14}$$

The direction of the normal vector $\vec{n}_u$ and the normal vector $\vec{n}$

in the trajectory between the grinding wheel and the screw rotor is same. In coordinate system σ, $\vec{n}_u$ can be expressed as:

$$\vec{n}_u = n_x\vec{i} + n_y\vec{j} + n_z\vec{k} \tag{15}$$

From the transformation between σ_u and σ :

$$\vec{k}_u = -\sin\Sigma\vec{j} + \cos\Sigma\vec{k} \tag{16}$$

Substituting Eq. (17) and Eq. (18) into Eq. (16), ε can be given by Eq. (19):

$$\cos\varepsilon = \frac{n_z\cos\Sigma - n_y\sin\Sigma}{\sqrt{n_x^2 + n_y^2 + n_z^2}} \tag{17}$$

Figure 3 shows the calculation of modified axial section with surface equidistance method. In Figure 3, the tangent angle θ at each point at the theoretical axial section should satisfy the following:

If $0 \le \varepsilon \le \pi/2$, the tangent angle θ at each point is an obtuse angle. Then the relationship between ε and tangent angle θ is given by: $\theta = \pi/2 + \varepsilon$; when $\pi/2 < \varepsilon \le \pi$, the tangent angle θ at each point is an acute angle, then the relationship between ε and tangent angle θ is given by: $\theta = \pi - \varepsilon$.

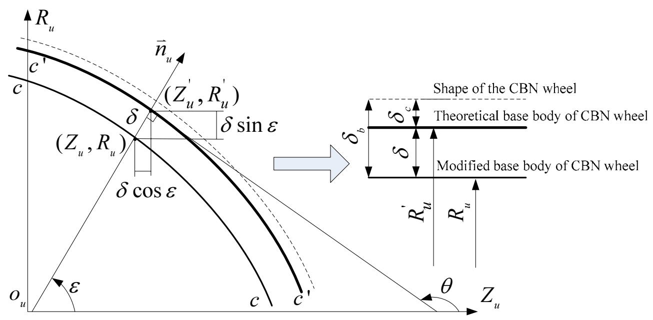
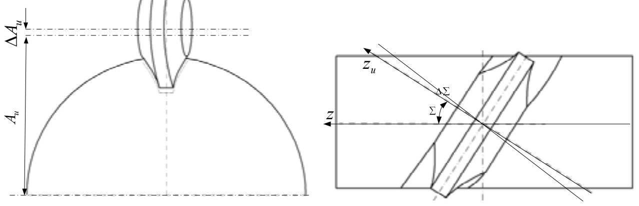


Fig. 3 Modified axial section with surface equidistance method

3. Error analyses of screw rotors using CBN wheel

As a complex system, error compensation is an effective method to improve the machining precision of the workpiece. It is hard to predict which parameter contains error and its corresponding value. The machining error can be obtained through comparing theoretical coordinates with actual coordinates which measured from the coordinate of actual surface of the rotor. In the grinding process, influence of tooth profile errors often affected by mounting angle error and mounting distance error as well as radius error of grinding wheel. The machining error analyses of grinding for screw rotors using CBN wheel are shown in Figure 4. Figure 4(a) and Figure 4(b) show the mounting distance error ΔA_u and mounting angle error $\Delta\Sigma$, respectively.



(a) mounting distance error ΔA_u (b) mounting angle error $\Delta\Sigma$

Fig. 4 Error analysis of grinding for screw rotors

The tooth surface of screw rotor machined by the grinding wheel without any machining errors can be expressed by

$$\begin{cases} \vec{r}^{\,1} = x_1\vec{i}_1 + y_1\vec{j}_1 + z_1\vec{k}_1 \\ x_1 = x_1(k,\zeta,\varphi_u,\varphi) \\ y_1 = y_1(k,\zeta,\varphi_u,\varphi) \\ z_1 = z_1(k,\zeta,\varphi_u,\varphi) \end{cases} \tag{18}$$

where, φ_u, φ are the parameter varies of tooth surface of screw rotor, and ζ is the parameter varies of surface of grinding wheel. $k = [z_u, R_u, A_u, \Sigma]$ is defined as the processing parameter of screw rotor. The tooth surface of screw rotor with machining errors can be expressed by

$$\begin{cases} \vec{r}^{\,1e} = x_{1e}\vec{i}_1 + y_{1e}\vec{j}_1 + z_{1e}\vec{k}_1 \\ x_{1e} = x_{1e}(k_e,\zeta,\varphi_u,\varphi) \\ y_{1e} = y_{1e}(k_e,\zeta,\varphi_u,\varphi) \\ z_{1e} = z_{1e}(k_e,\zeta,\varphi_u,\varphi) \end{cases} \tag{19}$$

In Eq. (4), $k_e = [z_u + \Delta z_u, R_u + \Delta R_u, A_u + \Delta A_u, \Sigma + \Delta\Sigma]$ denotes the processing parameters of screw rotor considering machining errors. Δz_u is the axial position error of grinding wheel. ΔR_u is the radius error of grinding error in axial position. ΔA_u is the error of mounting distance. $\Delta\Sigma$ is the error of mounting angle.

For any contact points M in theoretical surface, if the coordinate (x_M, y_M, z_M) and unit normal vector (n_{xM}, n_{yM}, n_{zM}) are given, the coordinate of the corresponding point M' in actual tooth surface is (x_{eM}, y_{eM}, z_{eM}), the distance from M to M' is λ_M along its normal direction.

The relationship among (x_M, y_M, z_M), (x_{eM}, y_{eM}, z_{eM}), (n_{xM}, n_{yM}, n_{zM}) and λ_M is

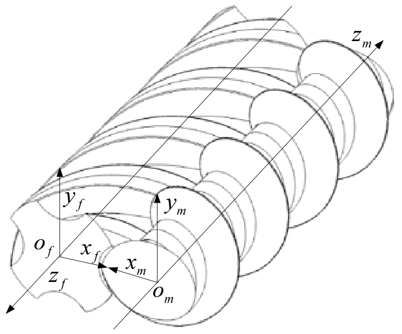
$$\begin{cases} x_M + \lambda_M n_{xM} = x_{eM} \\ y_M + \lambda_M n_{yM} = y_{eM} \\ z_M + \lambda_M n_{zM} = z_{eM} \end{cases} \tag{20}$$

Solving nonlinear Eqs. (20), the errors induced by those errors Δz_u, ΔR_u and ΔA_u can be calculated. On the contrary, the mounting errors can be calculated if the profile errors are known.

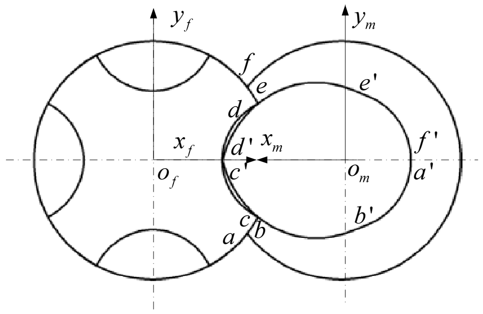
4. Calculation and Experiment

4.1 Calculation of CBN wheel

In order to mix and malaxate high viscosity materials, the authors have presented a novel differential twin-screw kneader.[8,9] The teeth of female rotor (right hand) and male rotor (left hand) are 4 and 1, respectively; both the outer diameters of the female rotor and the male rotor are 60 mm; the lead length of the rotors are 200 mm and 50 mm, respectively; the backlash between the female and male rotor is δ_b' = 0.2 mm ($\delta_b = \delta_b'/2$). Figure 5 shows the end section of the female and male rotors of the novel differential twin-screw kneader.



(a) 3D profiles of screw rotors



(b) End section of screw rotors

Fig. 5 Rotor profiles of one novel twin-screw kneader

The grinding efficiency of CBN tool depends, to a greater extent, on the grit size of tools. The term "grit size" here means the sizes of CBN crystals. CBN abrasive material spec DLII, grit size No. 150# was selected, with the nominal particle size range of 75~106 µm. The average of grit size is δ_{c1} = 0.0905 mm. Given the CBN basement thickness δ_{c2} = 0.05 mm and the backlash of δ_b = 0.1 mm. Thus, the coating thickness δ_c = 0.1405mm. Given different mounting distances A_u and angles Σ, different profiles of the CBN wheel can be obtained. In this study the mounting distance A_u and angle Σ for the female rotor are A_u = 150 mm and Σ = 45°, the mounting distance A_u and the angle Σ for the male rotor are A_u = 150 mm and Σ = –45°, respectively. The theoretical diameters of CBN wheel D_u for female rotor is 82.50 mm and for male rotor is 85.427 mm, respectively. The Design parameters of the CBN wheel for the female and male rotors are listed in Table 1.

Table 1 Design parameters of the female and male rotors

Parameters	Female rotor	Male rotor
Lead H(mm)	200	50
Teeth number	4	1
Screw direction	Right	Left
Lead angle in reference circle(°)	53°16′20″	18°31′27″
Axial modulus	15.9154	
Length L(mm)	400	
Outer diameters of rotors D_r(mm)	60	
Distance between two rotors A(mm)	47.5	
Mounting distance A_u(mm)	150	
Mounting angle Σ(°)	45	-45

One can obtain a series of arcs according to arc interpolation segments by using the arc spline fitting method or the biarc spline method.[10,11] In this study, the biarc segments are used to approximate the profile of grinding wheel by using the allowed maximum deviation distance between the wheel shape and the biarcs as the approximation criterion.[12] The arcs generated by the biarc method can be post-processed for NC code generation on machining the base body of the CBN grinding wheel. These arc segments can be used as the NC code which will be obtained by using the biarc approximation method after the tangent value of each point is calculated. For all the arcs, if the radii of arc segments are positive, the arc interpolations should be in anticlockwise direction; otherwise, if the radii of the arc segments are negative, the arc interpolations should be clockwise direction. Meanwhile, the radii of the arc interpolations should be calculated to check whether they are greater than the maximal radius of the interpolation of machine controller. Lines, instead of arcs, should be used in NC code generation directly if the radii are greater than the maximal radius.

The selected CBN materials were electroplated on the wheel base body after the base body was completed. The base body of the CBN wheel and the CBN wheel for machining the rotors of the twin-screw kneader are shown in Figure 6.

(a) Base body of CBN wheel

(b) Electroplated CBN wheel

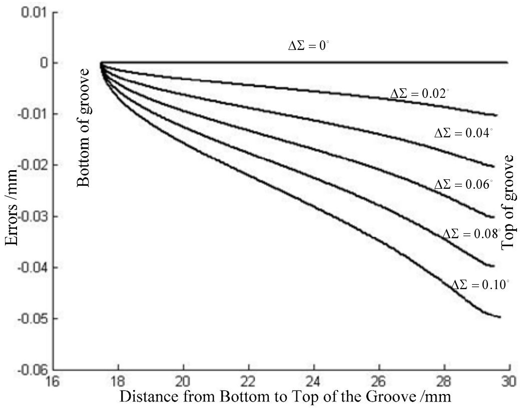
Fig. 6 CBN wheel for machining the rotors

4.2 Error analyses of rotors using CBN wheel

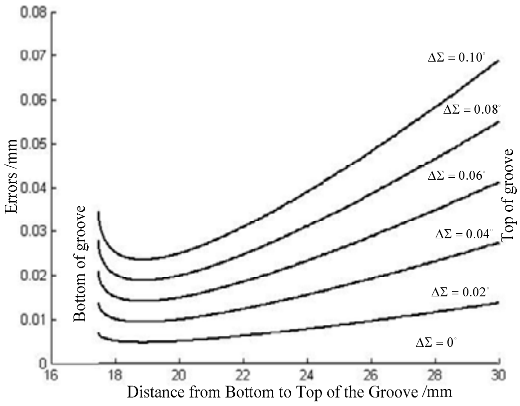
In order to evaluate the machining error, the influences of tooth profile errors affected by mounting angle error and mounting distance error as well as the wear of CBN wheel are analyzed as followings.

4.2.1 Influence of profile errors affected by mounting angle error

The tooth profile error of in rotor surface increased with the increasing of mounting angle error $\Delta\Sigma$. However, for the male rotor mentioned above, the tooth profile errors of the rotor first decreased then increased from bottom to top of screw groove when given same mounting distance error ΔA_u (see Figure 7(b)). The influence curves of profile errors f_n with mounting angle error are shown in Figure 3.



(a) Female rotor



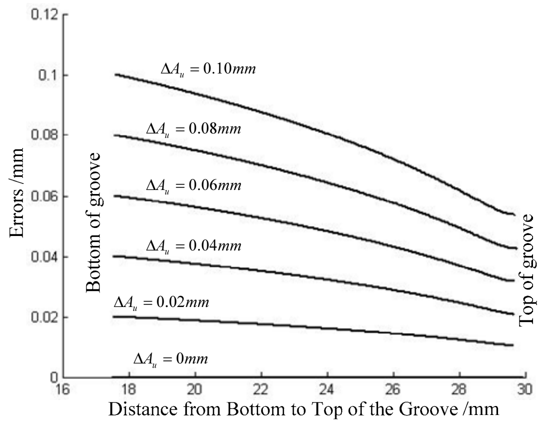
(b) Male rotor

Fig. 7 Influence curves of profile errors f_n with mounting angle error

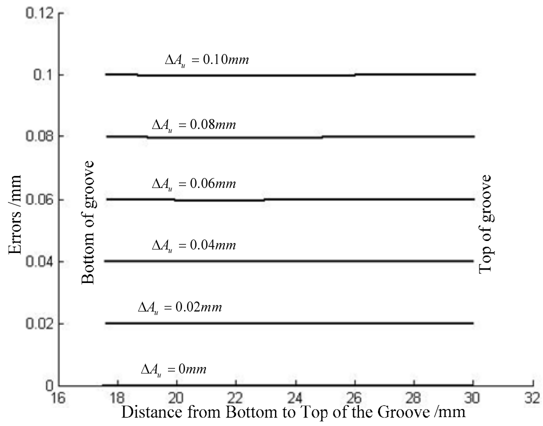
In Figure 7, the profile error of female rotor is negative error, while the profile error of male rotor is positive. It is the different mounting angle lead to such difference, that is: the screw direction of female rotor and the mounting angle $\sum$ is a positive value, while screw direction of male rotor is left and the mounting angle $\sum$ is a negative value.

4.2.2 Influence of profile errors affected by mounting distance error

Generally, the profile errors in rotor surface increased with the increasing of mounting distance error ΔA_u. According to the calculation, the influence trendency of the tooth profile error affected by mounting distance error ΔA_u will be changed with different rotor surface. For the same mounting distance error ΔA_u, the influences of tooth errors affected by mounting distance error ΔA_u on above rotors are different: the profile error of female rotor decreased gradually while the profile error of male rotor are not changed from bottom to top of the screw groove in the cross section of rotor. The influence curves of tooth errors f_n with mounting distance error are shown in Figure 8.



(a) Female rotor



(b) Male rotor

Fig. 8 Influence curves of profile errors fn with mounting distance error

4.2.3 Influence of profile errors affected by radius error of grinding wheel

The influence curves of tooth errors f_n of above female and male rotors with decreasing of grinding wheel radius are shown in Figure 9. In Figure 9, 1 and 1' denote the profile errors at addendum and dedendum of male rotor, respectively. 2 and 2' denote the profile errors at addendum and dedendum of female rotor, respectively.

Some conclusions can be obtained as followings according to Figure 9:

(1) For a same rotor with a same grinding wheel, the profile errors in top region are greater than that in bottom region of the rotor.

(2) For a same rotor, the tooth profile error will be increased in an exponential relation with the radial wear of grinding wheel.

(3) For the same wear in axial direction of grinding wheel, the tooth profile errors in female rotor is greater than that in male rotor.

The results showed that: the profile errors of the rotor surface can be controlled within 1~10μm if the grinding wheel surface wears slightly. Higher accuracy of rotor surface can still be obtained if a grinding wheel is dressed using CBN wheel under such circumstances. It verified the conclusion presented in Reference[4] that during the whole grinding process and there is no necessity for wheel dressing.

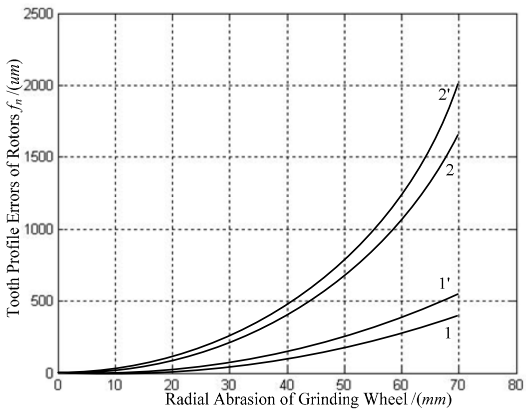


Fig. 9 Influence curves of profile errors f_n with decreasing of wheel radius

4.3 Experiment

In this study, screw rotors were ground by following means: trial grinding → error measurement → processing parameters amendment → final grinding → final error measurement. Grinding experiments were performed on a native vertical milling machine XKA5040A. One self-made high-speed grinder is connected with the main shaft of the milling machine. The main shaft of the grinder can reach 180 revolutions per second. Oil injection cooling method was used during ground. Grinding machining of the screw rotors using CBN wheel machined by the CBN wheel are shown in Figure 10.

(a) Grinding machining of the male rotors

(b) Grinding machining of the female rotors

Fig. 10 Grinding machining of the screw rotors using CBN wheel

The accuracy of the screw rotors was measured on the profile checking instrument ZC/668H CMM, the Measuring strokes is 600mm×800mm×600mm. The accuracy according to ISO10360-2 is: maximum permissible indication error, MPEE = 1.2 μm+L/1000, maximum permissible probing error, MPEP = 1.2 μm.

Measured in CMM after trial grinding, the profile errors of female and male rotors are 17.5 and 25 μm, respectively. The profile errors of rotors are larger than required precision, therefore, the processing parameters needs to be modified. According to the theory presented in Section 3, the amendments on $\Delta\Sigma$ and ΔA for female and male rotors can be calculated. The amendments are listed in Table 2.

Table 2 amendments of processing parameters

	Female rotor	Male rotor
$\Delta\Sigma$ (°)	0.013	0.008
ΔA (mm)	0.012	0.010

Then re-ground the screw rotors after modified the mounting parameters according to the amendments in Table 2. Final measurement results are: helix tolerance of female and male rotors is 17.5-21 μm; Total composite tolerance of axial pitch is 8.5-13.5 μm; Limit deviation of axial pitch is 65.5-72.5 μm; profile error is 6.5-8 μm; surface roughness is Ra0.5-0.65 μm. The measurement results are listed in Table 3. The final accuracy of the profiles of screw rotor reaches the fifth class of Chinese Standard GB10095-88 according to the worm standard.

Table 3 Grinding accuracy of the rotors using CBN wheel

	Female rotor	Male rotor
Helix tolerance (μm)	21.0	17.5
Total composite tolerance of axial pitch (μm)	13.5	8.5
Limit deviations of axial pitch (μm)	72.5	65.5
Profile error (μm)	8	6.5
Surface roughness (μm)	0.65	0.5

5. Conclusions

From the research in this paper, some conclusions can be obtained as followings:

(1) small CBN wheels can be used to machine screw rotors. During the grinding process, the backlash of screw rotors and the coating thickness of CBN layer should be taken into consideration.

(2) according to the results of error analyses, the profile errors f_n increased with increasing mounting distance error and mounting angle error as well as with decreasing of grinding wheel radius. The calculation results provide data support to the error compensations of screw rotor using CBN wheel.

(3) the precision can be proved greatly for screw rotors ground if the mounting parameters were amended on the basis of error compensation.

(4) according to accuracy of the rotors ground by CBN wheels, the profiles of the CBN wheel can be designed correctly and accurately. The experimental results confirmed that the method presented here can be used in the precision machining of screw rotors using CBN wheels.

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