Research on Reverse Measuring Method of Screw Drill Rotor Based on Axis Section

Daqi Li\textsuperscript{1}, Xuetong Wei\textsuperscript{1*}, Lingyi Yang\textsuperscript{1}, Yujie Song\textsuperscript{1} and Dalong Bi\textsuperscript{2}

\textsuperscript{1}College of Mechanical Science and Engineering, Northeast Petroleum University, Daqing, Heilongjiang, 163318, China
\textsuperscript{2}Daqing Oilfield Production Technology Institute, Daqing Oil Field Co, Daqing, Heilongjiang,163453,China
\textsuperscript{*}Xuetong Wei: 1813799909@qq.com

Abstract. The screw drilling tool is an important underground power tool in the oil fields. During the working process, the rotor will be damaged or unevenly worn. The repair and reuse of the damaged area of the rotor will greatly improve the utilization rate of the screw drilling tool and reduce the mining cost. To this end, based on the formation principle of the rotor surface of the five-head screw drill, the curve coordinates are described by the ray length and the rotation angle. The axis relationship equation is characterized by exploring the intrinsic relationship between the two coordinates, and the reverse model of a single screw drill rotor was constructed by point collection. At the same time, the experimental research was carried out to verify the feasibility of modeling the screw drilling tool according to the axial section. In order to provide an effective way to reverse the entire body based on the unworn area of the screw drilling tool, the inverse modeling theory of the spiral surface entity is greatly enriched.

1. Introduction
In the early 1980s, screw drilling tools were introduced to China. The screw-type drilling tool is a power tool that uses a drilling fluid as a power source to drill downhole in an oil field in a volumetric way [1]. It is widely used in major oil fields due to its small rotational speed, but it can produce large torque and displacement [2], and it is simple and convenient in field operation. It can be used in the drilling and workover process of directional Wells, high-slant Wells, horizontal Wells and long-displacement Wells. The screw drilling tool has achieved an irreplaceable position in the drilling and workover of oil fields [3]. In operation, the rotor of the screw drill and the rubber bushing inside the stator are in constant interference fit, and this large amount of interference further deteriorates the wear of the rotor. Zhang, F.M. [4] statisticied on the failure rate of screw drilling tools in the Chang Qing Oilfield, and learned that the wear on the rotor surface was serious, and the percentage of corrosion points was as high as 3\% of the rotor surface.

The wear of the rotor seriously affects the production efficiency of the oil fields. In order to repair the damaged screw drilling tools, improve the output efficiency and save money, it is extremely important to seek a method to repair the surface of screw drilling tools [5]. In terms of modeling, it is difficult, has a long period, requires high assembly accuracy, and has a large design volume [6]. Moreover, the spiral surface can not be modeled by analytical and simple surfaces, and the use of reverse engineering technology to model the screw drill rotor is the preferred choice [7]. At present, there are few researches on reverse modeling method of screw drill tool rotor. In this paper, an inverse
modeling method based on axial section curve is presented, which aims to make the modeling process simple and easy to implement, and has higher implementability.

2. The principle of the formation of spatial spiral surfaces
Taking the worm as an example, the formation principle of the space spiral surface is explored. The space track surface is formed when the curve of the axial section of a pitch is uniformly rotated around the \(Z\) axis, accompanied by a uniform linear motion along the \(Z\) axis direction. Select a point \(A\) on the shaft section curve of the worm, and do the above-mentioned compound motion to obtain the motion trajectory curve. Actually, this trajectory curve is a corresponding curve on the worm surface. Its parametric equation is:

\[
\omega(\theta) = re^{j\theta}
\]

\[
Z = p\theta
\]  

(1)

\(\omega(\theta)\) is the curve of worm, \(r\) is the radius and \(p\) is the pitch, \(\theta\) is the angle, \(Z\) isthe distance along the \(Z\) axis direction.

In fact, the formation principle of the screw drilling surface is the same as that of the worm curved surface. As long as the shaft section curve of the worm is replaced by the shaft section curve of the single-screw drilling rotor, the rotor surface of the screw drilling tool can be obtained.

3. Method of shaft section interception of screw drill tool rotor
In the case of a five-head screw drill rotor, the model surface is cut with \(Y = 0\) along the \(Z\) axis, and the shaft section curve is obtained on the \(XZ\) plane, that is,

\[
\text{Im}(R_r(\theta, r) \cdot e^{j\phi}) = 0
\]

(2)

\(R_r(\theta, r) \cdot e^{j\phi}\) is an equidistance curve, \(r\) is an equidistant radius, \(\theta\) is a rounded corner, \(\phi\) is the angle between the vector and the polar axis.

So we get the relationship between \(\theta\) and \(\phi\), which is \(\phi\) in terms of \(\theta\), and we substitute back into the real part of \(R_r(\theta, r) \cdot e^{j\phi}\) and reconnect \(Z\) direction formula in equation (3). The solution is tedious and the amount of calculation is large. In contrast, it is easier to use the method of point set to reverse. As long as the curve is discretized, the desired set of corresponding points can be obtained, that is, the coordinates of the \(X\) direction and \(Z\) direction of the point can be known. In fact, only the set of point coordinates is followed by the axis section curve to be found.

\[
\begin{align*}
R_{sr}(\theta, r, \phi) &= R_r(\theta, r) \cdot e^{j\phi} \\
Z &= \frac{T}{2\pi} \phi
\end{align*}
\]

(3)

\(R_{sr}(\theta, r, \phi)\) is the equidistance curve, \(Z\) is the distance from the contour to the origin.

The coordinates of the \(Z\) direction can be known from the length of the end section in the \(Z\) direction:

\[
Z = \frac{T}{2\pi} \phi
\]  

(4)

In this case, \(T\) is the lead. In a lead, \(\phi \in [0~2\pi]\), \(Z \in [0~T]\). A ray with an endpoint at the origin is rotated around the origin once, and an intersection point is generated with the end section. The distance between the intersection point and the origin is \(D\), and the distance length is the coordinate value in the \(X\) direction. Each value of \(\phi\) corresponds to the corresponding value of \(D\), and each value of \(\phi\) corresponds to each \(D\), so as to obtain the \(X\) coordinate value of each point, and obtain the axial section curve of the rotor.
Figure 1. Corresponding curve of the profile and shaft section of the five-head screw rotating through the angle.

As shown in Figure 1 (a), the rotor profile is rotated counterclockwise from position \( OA \) with \( O \) as the rotation point and rotated by \( \phi_1 \). The new position is denoted as position \( OA' \). The intersection point of rotor profile and \( OA \) is point \( B \). Taking the origin as the origin, the profile of ray \( OB' \) and position \( OA \) intersects at \( B' \), and the included Angle between \( OB' \) and \( OA \) is \( \phi_1' \), that \( \phi_1' = \phi_1 \), \( |OB'| = |OB| \). When the model is cut along ray \( OA \), the ZX curve is obtained, which is the required rotor axial section curve. It can be seen from Figure 1 (a) that, when the profile rotates counterclockwise from \( OA \) to \( OA' \), the distance of \( OB \) is the coordinate size of \( X \) required by \( Z = \frac{T}{2\pi}\phi_1 \), as shown in Figure 1 (b).

The distance \( D \) shown in the figure above is the coordinate value of rotor section \( X \), that is:

\[
|OB'| = D \tag{5}
\]

From equation (5), we can get:

\[
\begin{align*}
X &= \sqrt{X(i)^2 + Y(i)^2} \\
Z &= \frac{T}{2\pi}\phi
\end{align*} \tag{6}
\]

In equation (6): \( \phi = \arctan \frac{Y(i)}{X(i)} \). \( X(i), Y(i) \) are the \( X, Y \) coordinates shown in the figure above. It can be obtained from the \( n \)-head rotor equidistance curve equation (7).

\[
R_r(\theta, r) = \begin{cases} 
R_2(ne^{j\theta} + e^{-jn\theta}) + r\exp\left[\left(-1\right)^M\frac{\pi j}{2} - \frac{n-1}{2}\theta\right] & | \text{I} \\
R_2N\exp\left(\frac{2M\pi j}{N}\right) + re^{i\alpha'} & | \text{II}
\end{cases} \tag{7}
\]

Discretization of equation (7), the expressions of \( X(i), Y(i) \) in part I of equation (7) can be obtained as:

\[
\begin{align*}
X(i)_1 &= R_2n\cos \theta + R_2\cos n\theta + r\cos\left(-1\right)^M\frac{\pi \theta}{2} - \frac{n-1}{2}\theta \\
Y(i)_1 &= R_2n\sin \theta - R_2\sin n\theta + r\sin\left(-1\right)^M\frac{\pi \theta}{2} - \frac{n-1}{2}\theta
\end{align*} \tag{8}
\]

Where \( \theta = 0 \sim 2\pi \). Each \( \theta \) value corresponds to an \( X(i), Y(i) \) coordinate value.

The \( X(i), Y(i) \) expression of part II is:

\[
\begin{align*}
X(i)_{II} &= R_2N\cos\left(\frac{2M\pi}{N}\right) + r\cos \alpha' \\
Y(i)_{II} &= R_2N\sin\left(\frac{2M\pi}{N}\right) + r\sin \alpha'
\end{align*} \tag{9}
\]

\( \alpha' \) is the central Angle from the cusp to the arc. \( M = 0,1,2 \) to \( n - 1 \), \( N \) is the number of stator heads.
Where $\alpha' = 0 \sim \alpha$. Each $\alpha'$ value corresponds to a set of $X(i), Y(i)$ coordinate values of the II part, and the rotor profile curve is discretized by the equations (8) and (9). Put equations (8) and (9) into (6) to obtain the discrete expressions of the axial section curve:

\[
\begin{align*}
X_I &= \left[ (R_2 n \cos \theta + R_2 \cos n \theta + r \cos ((-1)^M \frac{\pi}{2} - \frac{n-1}{2} \theta)) + (R_2 n \sin \theta - R_2 \sin \theta + r \sin ((-1)^M \frac{\pi}{2} - \frac{n-1}{2} \theta)) \right]^{1/2} \\
Z_I &= \arctan \frac{R_2 n \sin \theta - R_2 \sin \theta + r \sin ((-1)^M \frac{\pi}{2} - \frac{n-1}{2} \theta)}{R_2 n \cos \theta + R_2 \cos \theta + r \cos ((-1)^M \frac{\pi}{2} - \frac{n-1}{2} \theta)} \\
X_{II} &= \left[ (R_2 N \cos(\frac{2\pi}{N}) + r \cos \alpha')^2 + (R_2 N \sin(\frac{2\pi}{N}) + r \sin \alpha')^2 \right]^{1/2} \\
Z_{II} &= \frac{T}{2\pi} \arctan \frac{R_2 N \sin(\frac{2\pi}{N}) + r \sin \alpha'}{R_2 N \cos(\frac{2\pi}{N}) + r \cos \alpha'}
\end{align*}
\]

The spheronization angle $\theta$ is divided into $n$ segmented continuous intervals, and the point selection can be performed.

4. Modeling of axial section curves

Modeling the rotor shaft section curve according to the screw drill is actually the inverse process of the rotor shaft section of the single screw drill. The equation of the model is:

\[
\begin{align*}
X' &= Z + \frac{T}{2\pi} \theta \\
Y' &= X \cos \theta \\
Z' &= X \sin \theta
\end{align*}
\]

$X', Y', Z'$ represent the coordinates in the $X, Y, Z$ directions in MATLAB.

Based on the above equation and combined with the screw drill tool rotor modeling program, set $R=7.2, N=5, r=14, L=300$, to establish a five-head screw drill tool model.

![Figure 2. Model of the shaft section of the five-head screw drill.](image)

5. Experimental analysis of the interception of the rotor shaft section of the screw drill

Select a five-head screw drilling tool, and the basic parameters of the rotor screw are: $R_2 = 7.2mm$, $K = 0.9$, $r = 14mm$, $T = 710mm$. As shown in Figure3, the experimental analysis of the shaft section of the screw drilling tool is carried out. The experimental device is a three-coordinate measuring machine, which measures the points of the axial section of the upper part of the rotor, that is, the lossless points in a screw pitch range are measured along the $Y$ axis. A total of 122 points are measured for several times, and the average value is taken to reduce the error.
After data processing, the point of the actual axial transversal of the screw pitch is compared with the point of the theoretically calculated axial transversal, as shown in Figure 4.

It can be seen from the comparison between the actual and theoretical points that the theoretically obtained pitch axis intercept line is basically consistent with the actual obtained axial section line.

The point error between the actual axis cut line and the theoretical axis cut line is shown in Figure 5.

According to the error diagram of theoretical and practical points, the maximum error is no more than 0.14mm, the maximum error is -0.121mm, and the machining error is 0.5mm, which is obviously smaller than the allowable machining error. Therefore, the correctness of the shaft section intercepted by theoretical calculation can be verified.
6. Conclusion

(1) This paper uses the point set method to establish the curve equation of the shaft section of the screw drill, and proposes a method of intercepting the shaft section of the five-head screw drill, which provides a theoretical basis for the establishment of other spiral solid shaft section curves.

(2) The model of the five-head screw drilling tool was obtained by inverse modeling based on the interception curve of the axial section.

(3) Taking the combination of theory and experiment, the experimental research of the five-head screw drilling tool was carried out, and the feasibility of the axial section intercepting method and the correctness of the reverse modeling were verified.

Acknowledgments

This research was financially supported by 2018 Green Manufacturing System Integration Project "Drilling Tools and Drill Remanufacturing Green Design Platform Construction Project".

References

[1] Su, Y.N. (2001) Research and application of screw drill. Beijing Petroleum Industry Press. Beijing.

[2] Lin, Y.H., Zou, B., Shi, T.H. (2004) Failure mechanism and fatigue life prediction of drilling tools. Oil Drilling & Production Technology, 26: 19–22.

[3] Huang, C., Yang, Y. (2011) Discussion on the current situation and development trend of screw drilling tools at home and abroad. Science and Technology Innovation Herald, 31:1–9.

[4] Zhang, F.M., Liu, S.M. (1998) Statistical analysis of failure of screw drilling tools. Oil Field Equipment, 27:31–34.

[5] Liu, J.H., Sun, L.S., Zhang, X. (2014) Technical connotation and key issues of 3D digital design and manufacturing. Computer Integrated Manufacturing Systems, 20: 494–503.

[6] Chen, Y.L. (2014) Research on modeling methods of NURBS complex free-form surface. Chang `an University, Xi `an.

[7] Zhang, W., Lei, X., Xing, F. (2017) Modeling and simulation verification of reflector antenna surface based on NURBS. Journal of Information Engineering University, 18:31–34.