Cmm-based Profile Measuring Method for Unknown Screw Compressor Rotor

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Abstract-**The measurement for unknown screw compressor rotor profile is a nodus in CMM measurement because of the complexity of 3D helical surface, whose surface normal vector is uncertainty. For this reason, conventional 2D measure-ment methods exist theoretical error. This paper provides a quadratic measuring method. The second-measurement is an accurate 3D measurement with the normal vectors of measured points, which can be figured out based on the 3D modeling of the first-measurement. In this paper, some key technologies such as screw pitch solution, 3D path planning on CMM and normalization of measured rotor profile data are resolved legitimately.**

Keywords-Reverse engineering, Coordinate measuring machine (CMM), Screw compressor, Rotor profile, Radius compensation

I. INTRODUCTION

Screw compressor is widely used in air dynamic, industrial refrigeration, central air-conditioning, process flow, et al. The most important parts of screw compressor are a couple of meshing rotors, whose shape, precision and surface quality determine the performance of the compressor directly. The intersection curve of rotor helical surface and vertical plane of rotor axes ia called rotor profile, which is a important standard to judge the quality of rotor. Because every teeth of rotor with complicated structure are overlapping in space, precise and efficient measurement for rotor profile has been a practical puzzle in companies and hotspot in academia.

Liu Zongxian proposed a method for measuring a screw compressor rotor using a coordinate measuring machine. The profile of the rotor is constituted by a number of profile curves that are smoothly connected with each other and the position of each connecting point can be expressed with its radius in cylindrical coordinates. During the measurement, they compared the radius with the distance between the measured point and the z-axis in cylindrical coordinates to identify and distinguish the current curves from the rest. The essence of their method is as follows. First, the coordinates of a number of points on the surface are measured. Second, the probable rotor surface is estimated by the method of least squares, and the errors are determined[1]. Kazuhiro Matsumoto, et al, developed a CMM-based specialized measurement module on the basis of analysis of key technologies of manufacture of screw compressor rotor and commonly employed measuring methods[2]. Sui Tianzhong, et al, proposed a measuring method for freeform surface section based on hemisphere probe. This method can work well without complex process and 3D probe compensation during measuring surface with sphere probe. It has eliminated the interference caused by surface twist during measuring 3D surface, and can convert surface measurement into a curve measurement. As a result, the measurement and data processing is greatly simplified[3]. Fan Yanbing, et al, realized the measurement and modeling to complicated screw of PC single screw compressor with specific CMM, which has indexing mechanism, orientation-locked function and long measuring rod[4]. Zhao Qiancheng presented a CMM-based measuring method to evaluate the precision of measuring screw rotors by simulation[5]. Shi Guorong, et al, put forward a simplified measuring method, which was different from common methods, for freeform surface on the basis of deep research on digitalisation of helical surface and pretreatment of measured data[6].

In consideration of high precision, CMM is used in this paper to measure the rotor profile of unknown screw compressor.

II. FIRST MEASUREMENT FOR SCREW ROTOR

In the process of measurement with CMM, the key technology problem is the probe radius compensation because of the complexity of 3D helical surface. When the nominal values of the rotors are unknown, the radius compensation is more difficult than that is known. We need the accurate surface normal vector to ensure the precision of the measurement of the unknown screw rotor. In order to calculate corresponding normal vector, the unknown screw rotor should be measured firstly to construct the rough 3D CAD modeling. Thus, two important elements, rotor profile and screw pitch should be measured and calculate firstly. This section will elaborate these two problems in details.

A. Preliminary Measurement to Rotor Profile of Unknown Screw Compressor

The unknown screw compressor rotor in question is shown in Figure 1. According to the length of screw rotor, it is usually fixed horizontally[7] or vertically. Because the length of screw rotor in Figure 1 is appropriate, the screw rotor will be fixed vertically and the probe is perpendicular to z axis of CMM. Every toothspace can be measured in a single process with this location mode.

According to the structure of screw rotor, it is more reasonable to choose the center of head face PL_1 as Measuring Coordinate Origin. Take line LN_1 as z axis, which is determined by center of cylinder CY_1 and CY_2, take normal of cutting plane PL_2 as y axis, take the intersection point of LN_1 and PL_1, O, as coordinate origin. Then, the corresponding measuring coordinate system could be established uniquely, as shown in Figure 1.

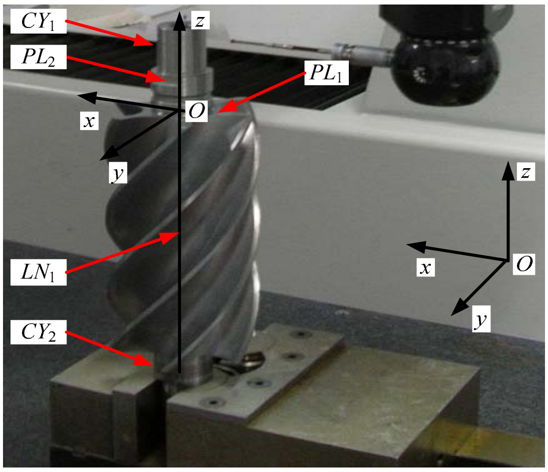

Figure 1. Measured reference elements and coordinate system

Based on this measuring coordinate system, one profile of complete toothspace at z= -20 is measured in a single process. Because the normal vectors of measured points are unknow, probe radius can only be compensated in the direction of approach in a automatic way, which is only 2D radius compensation and exists theoretical error inevitably. The principle of radius compensation is shown in Figure 2. Figure 2 indicates that P_1 is measured points, P_2 is compensated point and δ is theoretical error, expressed by Eq(1).

$$\delta = R(\frac{1}{\cos\alpha} - 1) \qquad (1)$$

In Eq(1), α is included angle contained by measured surface and z axis, R is radius of probe.

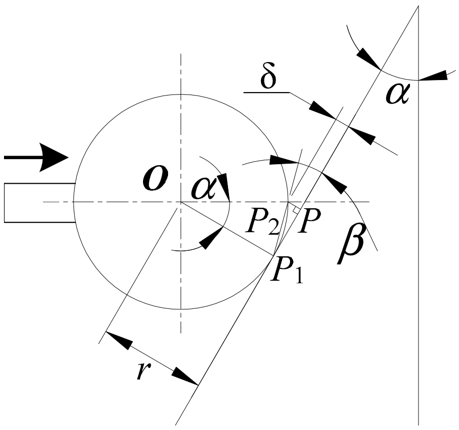

Figure 2. Probe radius compensation in measuring direction

According to Eq(1), compensation error is impacted by angle α greatly. In fact, because the measured surface of screw rotor is helical, the angle α varies with the measured points. As a result, it is very difficult to take compensation error under control. The larger angle α is, the larger compensation error is. Thus, second-measurement is necessary to eliminate theoretical error of radius compensation by 3D compensation. The measured point set of rotor profile is shown in Figure 3.

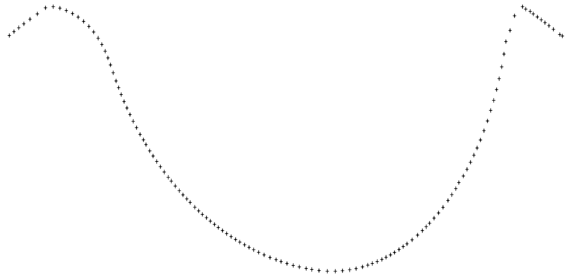

Figure 3. Measured point set of rotor profile

B. Measurement of Screw Pitch

Screw pitch is an intrinsic property of screw compressor rotor. Screw pitch, T, is equivalent to the distance it advances in the direction of z axis after rotor profile revolves round z axis (360°). Thus, screw pitch can be figured out by measuring rotation angle, φ, around z axis between two rotor profiles at a distance of H, as shown in Figure 4.

$$T = \frac{360}{\varphi} H \qquad (2)$$

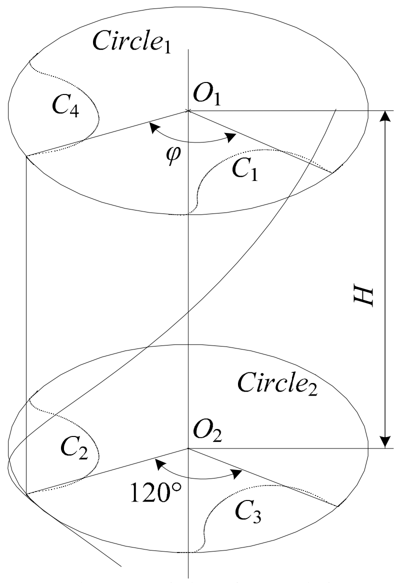

Figure 4. Solution of screw pitch

Concrete realization method is as follows: Firstly, measure two rotor profiles, C_1 and C_2, at the z axis distance of H in a single process. Secondly, calculate rotation angle, φ, around z axis between two rotor profiles. Then, the screw pitch can be figured out easily by Eq(2). In order to ensure the convenience of measurement and the accuracy of calculation, some following measures are taken in this paper:

1) In order to measure these two profiles in a single process without adjustment of probe direction, C_2 is replaced by C_3. The analysis showes that the angle of C_2 and

C_3 around z axis is 120°. If C_3 rotates 120° clockwise, it is equal to C_2.

2) In order to calcurate rotation angle of C_1 and C_2, φ, around z axis accurately, C_2 is projected onto plane determined by C_1, expressed by C_4, as shown in Figure4. The angle of C_1 and C_2 is replaced by the angle of C_1 and C_4, which is easier to calculate.

3) Because there are not reference points, several angles are calculated at the same time to improve precision of angle φ. Draw five concentric circles with center at O_1. The intersection points of concentric circles and C_1 are expressed by P_{11}, P_{12}, P_{13}, P_{14}, P_{15}. The intersection points of concentric circles and C_2 are expressed by P_{21}, P_{22}, P_{23}, P_{24}, P_{25}, as shown in Figure 5.

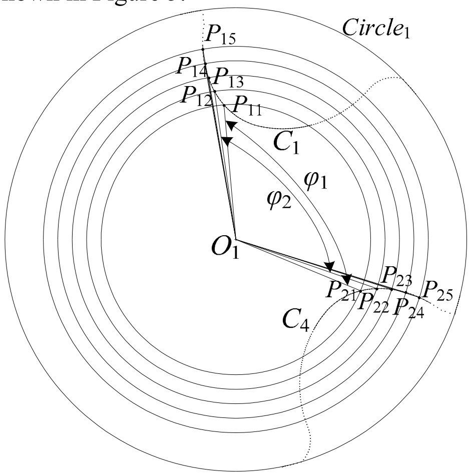

Figure 5. Solution of rotation angle

The angle contained by O_1P_{11} and O_1P_{21} is φ_1, the angle contained by O_1P_{12} and O_1P_{22} is φ_2, the angle contained by O_1P_{13} and O_1P_{23} is φ_3, the angle contained by O_1P_{14} and O_1P_{24} is φ_4, the angle contained by O_1P_{15} and O_1P_{25} is φ_5. The average value of these five angles can be expressed by Eq(3).

$$\varphi = \frac{1}{5}\sum_{i=1}^{5}\varphi_i \qquad (3)$$

φ=(117.349+117.352+117.305+117.344+117.364) /5 =117.3428°

At the same time, the distance between the plane of C_1 and C_3 can be figured out, that is H=110.015. Then screw pitch can be figured out by Eq(2)

$$T = \frac{360}{117.3428} \times 110.015 = 337.519$$

On the basis of rotor profile and screw pitch, 3D modeling of screw compressor rotor can be constructed, as shown in Figure 6.

Figure 6. 3D modeling of screw compressor rotor

III. SECOND MEASUREMENT FOR SCREW ROTOR

Because radius compensation vector is unknow in first-measurement, 2D compensation with theoretical error is adopted reluctantly. On the basis of 3D modeling constructed in above section, normal vectors of measured points can be figured out accurately. By using 3D radius compensation with normal vectors, the compensating error can be eliminated and the measuring accuracy can be improved.

A. *Measured points and corresponding normal vectors*

Firstly, calculate intersecting curve of plane z=-20 and 3D modeling of screw rotor. Secondly, scatter this curve into points at the interval of 0.5. These points are new measured points and will be used in second-measurement. Then, calculate corresponding normal vectors of measured points. Normal vectors are shown in Figure 7 and part of corresponding values are shown in Table.1.

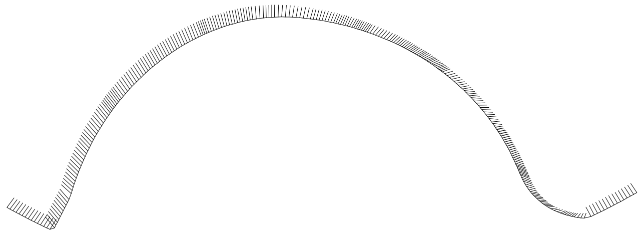

Figure 7. Measured points and corresponding normal vectors

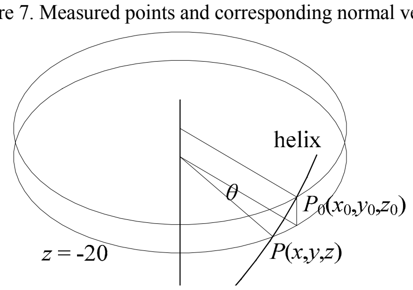

Figure 8. Method for normalization

On the basis of these measured points and corresponding normal vectors, measuring path of second-measurement can be planned by DIMS language. This path planning can output compensated points directly. Part of DIMS program is shown as follows.

```
F(PT1)=FEAT/POINT,CART,-11.250163,46.662338,-20.001508,-0.310648, 0.947468,-0.076173
MEAS/POINT,F(PT1),1
PTMEAS/CART,-11.250163,46.662338,-20.001508,-0.310648,0.947468,-0.076173
ENDMES
T(1)=TOL/CORTOL,XAXIS,-0.1,0.1
T(2)=TOL/CORTOL,YAXIS,-0.1,0.1
T(3)=TOL/CORTOL,ZAXIS,-0.1,0.1
OUTPUT/FA(PT1),TA(1),TA(2),TA(3)
……
```

B. *Normalization of measured rotor profile data*

In fact, measured points compensated in the direction of normal vectors by above path planning become spatial point dataset, all of them stray from reference plane z=-20 slightly. In order to obtain the sectional profile data, all measured points should be transformed to plane z= -20 along helix. According to Figure 8, transformation formula of right-hand rotor can be expressed by Eq(4).

$$\begin{cases} x = x_0 \cos\theta - y_0 \sin\theta \\ y = x_0 \sin\theta + y_0 \cos\theta \\ \theta = (z - z_0) \times 360 / T \end{cases} \tag{4}$$

Here, P_0 is measured point, P is transformed point, θ is angle between P_0 and P in the direction of z asix, T is screw pitch. By this algorithm, measured points can be transformed onto objective plane at z= -20. Part of processed data of rotor profile is shown in Table.2.

Because 3D radius compensation is adopted in the process of second measurement, theoretical error is eliminated. If all measuring specifications are observed in the measuring process, measurement accuracy of rotor profile can be ensured and accepted.

C. CONCLUSION

By means of second-measurement stated in this paper, a rotor profile of unknown screw compressor is measured accurately.

1) Measuring coordinate system is established with the structural feature of screw compressor rotor, so there is no special request for positioning accuracy of screw rotor.

2) There is no theoretical error of radius compensation by second-measurement with normal vector of measured points.

3) Measuring process is automatic with path planning by DIMS language.

4) This is an universal measuring method and can be applied to other similar complex parts widely.

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TABLE I. MEASURED POINTS AND CORRESPONDING NORMAL VECTORS

No.	*x*	*y*	*z*	*i*	*j*	*k*
1	-11.250163	46.662338	-20.001508	-0.310648	0.947468	-0.076173
2	-6.734612	41.607689	-20.002119	0.790704	-0.028680	0.611526
3	-5.963007	34.643340	-20.001998	0.805778	0.230471	0.545532
4	-3.585444	29.426255	-20.00205	0.745639	0.501035	0.439302
5	5.126837	23.392281	-20.002354	0.204608	0.978754	-0.013241
…	…	…	…	…	…	…

TABLE II. NORMALIZATION OF MEASURED ROTOR PROFILE DATA

No.	Measured Points			Transformed Points		
	x_i	y_i	z_i	x	y	z
1	-6.911	46.0364	-20.2348	-7.11325	46.00558	-20
2	-6.8207	45.3878	-20.2296	-7.01456	45.35824	-20
3	-6.7288	44.7733	-20.2132	-6.906368	44.74625	-20
4	6.748	44.1798	-20.2125	-6.922674	44.15276	-20
5	-6.8346	43.5606	-20.2041	-6.999986	43.53433	-20
6	-6.9037	42.9106	-20.1936	-7.058234	42.88545	-20
7	-6.9443	42.2598	-20.1912	-7.094647	42.23482	-20
8	-6.9758	41.6183	-20.1926	-7.124953	41.59303	-20
9	-6.9941	40.9745	-20.1871	-7.136728	40.9499	-20
10	-6.9824	40.3247	-20.1719	-7.111371	40.30215	-20
…	…	…	…	…	…	…