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Rapid Measurement of Involute Profiles for Scroll Compressors

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Scroll compressors are widely used in air conditioners, vacuum pumps and so on. Rapid measurement of flank profile of a scroll compressor is important to improve the compression efficiency and decrease noises. A contact probe made of ruby was used for measurement of flank profile. The probe was moved by a linear slide along the X axis at a constant speed. The scroll workpiece was fixed on a precision rotary stage. The relationship between the stage rotational speed and the X axis moving speed complies with the Archimedean curve. The measurement data of the rapid measurement system were analyzed and measurement errors were removed by compensation of the offset between the coordinates of the rotary stage center and those of workpiece center. The measurement results were compared with those measured by a commercial coordinate measuring machine (CMM). The measurement time for the involute profile of the scroll is shortened to 153 seconds by the developed rapid measurement system from the 10 minutes measurement time by the CMM while the measurement accuracy is kept the same.

Keywords: scroll profile, error separation, involutes profile, scroll compressor, rapid measurement

1. INTRODUCTION

SCROLL COMPRESSORS compress air by orbiting motions of scrolls. The air with a high pressure is taken out from a discharge opening by orbiting scroll. The scroll compressor has a lot of advantages, including small variations of torque, low vibrations and noises. High efficiency can also be achieved because there is no direct fluid path between the suction and the discharge opening [1], [2].

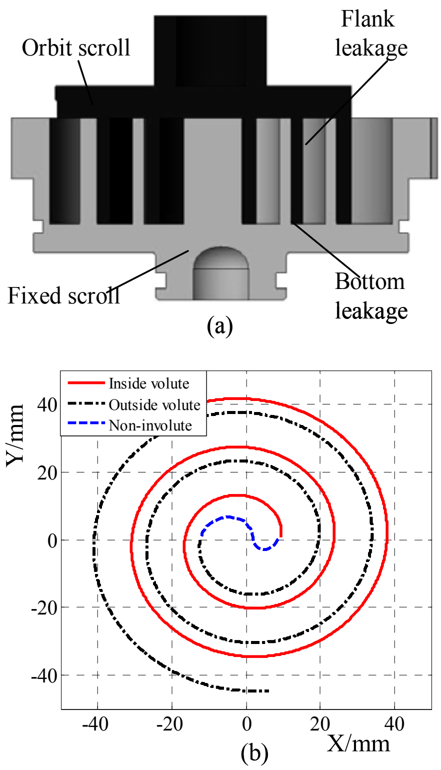


Fig.1 Leakages of scroll compressor and measurement profile

In order to further improve the efficiency of the scroll compressor, it is very important to reduce the leakages. Fig.1 (a) shows mainly two kinds of leakages and gearing principle of the two scrolls. Fig.1 (b) shows flank profile measurement including the inside involute profile, the outside involute profile and the non-involute profile. One of the leakages is flank leakage caused by a gap between the flanks of the two scroll blades. The other is tip leakage caused by a gap between the end plate and the scroll blade of the scrolls. These leakages can be decreased by increasing manufacturing accuracy. Rapid measurements of height and flank profile are important to decrease manufacturing errors. Conventionally, scroll flank profiles were measured by coordinate measuring machine (CMM), which is very time-consuming and expensive. Measurement time of CMM for scroll profiles cannot meet the on-line machining measurement requirement [3]. The paper develops a rapid and accuracy profile measurement system for inside and outside involute scroll profile. Measurement errors are analyzed by simulations. Measurement results of rapid measurement system are compared with those of the CMM. It is verified that the developed rapid measurement system can satisfy required measurement accuracy (±3 μm) and measurement time (300 seconds/per workpiece).

2. MEASUREMENT SYSTEM AND MEASUREMENT METHOD

Fig.2 shows a platform of the developed rapid measurement system for the fixed scroll. The measurement system consists of X-Z-θ stages and a contact type scanning probe. Because there is very limited room for the on-line machining measurement of the scroll, the rapid measurement system was developed based on roundness measurement system. The size of the measurement system is very small. The fixed scroll was fixed on a rotary stage by two taper pins. The rotational angle resolution of the stage is 0.0025 degrees. The

X axis could be moved by a precision control board. When involute profiles for scroll were measured, the moving speed of X axis and rotational speed of the rotary stage were controlled by a PID controller [4]. So the measurement system can realize precision positioning. The positioning error was small enough to be ignored. The positions of each stage were measured by each encoder and taken into a personal computer via multi axis control board.

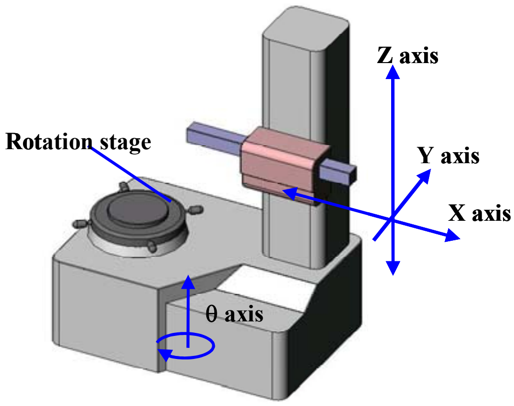


Fig.2 Measurement system of scroll profile

Taking into consideration the influence of cutting oil and chips, a contact-type displacement probe made of ruby in the form of a ball was employed in the developed measurement system. The probe fixed on the end of X axis was used for scanning the flank involute profile mounted on the rotary stage [5]. A ruby ball with a diameter of 5 mm was attached to the end of the probe axis. The scanning probe ball had three scales in the direction of XYZ. The outputs of the X and Y direction were used for measuring the involute profiles and the output of the Z direction was used for determining friction of the Z axis. The voltage outputs of the probe were transferred into a personal computer via an A/D converter [6, 7, 8]. The resolution and measuring range of the probe were 0.1 μm and ±1 mm, respectively. Measuring force was about 0.12 N. According to the required measurement time, rotational speed of the rotary stage was set to 20 degrees/second. The increment of scroll radius can be described by the following equation.

$$r_{\theta 1} - r_{\theta 2} = a \times (\theta 2 - \theta 1) \times \pi / 180 \qquad (1)$$

From the equation (1), X axis moving speed can be calculated. X axis moving speed is set for 0.7923 mm/s.

The involute spiral of base circle can be described by the following equation (2).

$$\begin{cases} x = a[\cos(\varphi + \alpha) + \varphi \times \sin(\varphi + \alpha)] \\ y = a[\sin(\varphi + \alpha) - \varphi \times \cos(\varphi + \alpha)] \end{cases} \qquad (2)$$

Where, a is base circle radius, φ is involute scroll angle, α is the angle of start point for involute profile. The relationship of scroll polar angle and scroll angle can be described by the following equation (3).

$$\varphi = \theta + \tan(\varphi) \qquad (3)$$

Where, φ is scroll angle of each measurement point and θ is the polar angle of each measurement point. Theoretical involute scroll radius of each measurement point can be calculated by equation (2) and equation (3). Measurement scroll radius can be obtained by outputs of probe encoder and X axis encoder. Profile error can be described by the following equation (4).

$$r_{error} = r_{th} - r_{mea} \qquad (4)$$

Where, r_{error} is involute profile error, r_{th} is theoretical scroll polar radius; r_{mea} is measurement scroll polar radius. The same scroll sample was also measured for comparison by a commercial CMM, which was installed in a temperature controlled metrology room. Probing accuracy of CMM was 0.6 μm.

3. MEASUREMENT RESULTS AND ERROR ANALYSIS

A. Measurement results without error separation

The involute profile errors of the fixed scroll were measured by developed rapid measurement system. Measurement results are shown in Fig.3 The measurement error range of the outside profile was about ±20 μm. The measurement error range of the inside profile was about ±40 μm. It can be seen that there were very large measurement errors in the rapid measurement system. The measurement accuracy could not meet the required measurement accuracy (±3 μm).

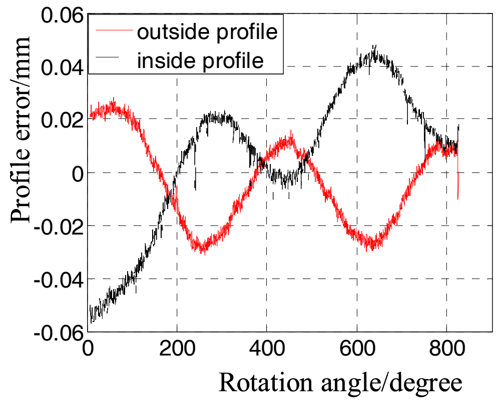
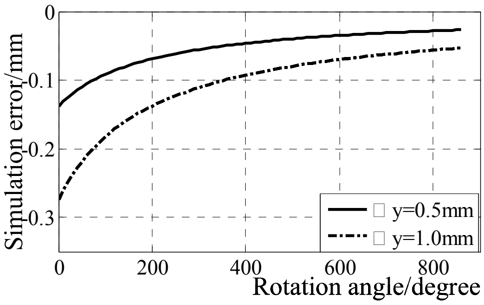


Fig.3 Measurement result without error separation

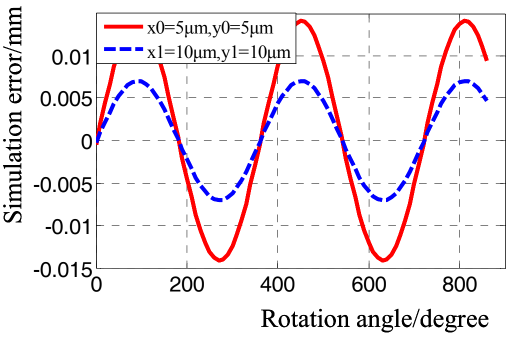
B. Measurement error analysis by computer simulation

The reasons for measurement error must be analyzed. There are the centre offset of coordinates between the workpiece and the rotary stage. The offset value had significant effect on measurement results. The Y-directional offset of contact point □y was caused by the friction between the contact probe and the flank profile. □y has significant influence on measurement results too.

To confirm the influence of coordinate system error, simulations were carried out for analysis of the influence of the offset. Fig.4 shows the simulation results of contact point offset in the case of fixed scroll. The horizontal axis indicates rotational angle of fixed scroll and vertical axis shows simulation profile error. Fig.4 (a) shows the influence of Y-directional offset of the contact point. Here, Δy was defined by Y-directional offset displacement of the contact measurement point. Profile errors were calculated, when considered Δy=0.5 mm and 1 mm. It can be seen that Δy has large influence on the profile results. Influence becomes more significant with an increasing Δy. In order to achieve the required measurement accuracy of involutes profile, it had been confirmed that Y-direction offset error must be removed from the measurement profile error. Fig.4 (b) shows influence of the centre offset of coordinates between the workpiece and the rotary stage. To test the influence of centre coordinate offset, computer simulations were conducted based on the ideal outside involulte and inside involute profile. Here, xn and yn are defined by the centre coordinate offset between the workpiece and the rotary stage. As can be seen in the figure, xn and yn generate a very large periodic measurement error influence even if the centre coordinate offset is very small. The periodic profile error of Fig.3 was caused by xn and yn. It is necessary to separate the centre coordinate offset and y-direction offset under the required accuracy order.



(a) Y-direction offset



(b) Xn and yn offset

Fig.4 Simulation analysis of impacting measurement result

4. MEASUREMENT RESULTS AND COMPARISON WITH CMM AFTER ERROR SEPARATION

A. *Measurement results after error separation*

The measurement profile error of Fig.3 consists of centre coordinate offset and Y-directional offset of contact point. The Y-directional offset of contact point can be measured by the outputs of the probe encoder. The Y-directional outputs of the probe are about 0.1mm. The Y-directional offsets make probe centre deviate from the X axis. There are leaning angles between probe contact point and X axis. The actual scroll polar angle of the measurement contact point can be showed by the equation (5).

$$\theta_{real} = \theta_{mea} + \tan^{-1}(\Delta y / r) \qquad (5)$$

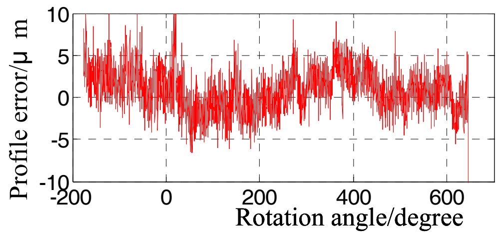
Where, θ_{real} is the real scroll polar angle of measurement point. θ_{mea} is the outputs of rotary stage encoder. The Δy is the Y-directional offset of probe. The r is the theoretical scroll radius of every measurement point. The Y-directional offset of probe centre is compensated by the equation (5).

In order to obtain the centre coordinate offset of workpiece and measurement system, measurement profile error that is shown in Fig.3 is fitted into circle by the following equation (6).

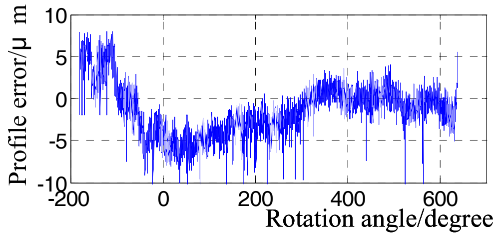
$$a \times x + b \times y + c = -(x^2 + y^2) \qquad (6)$$

Where, $a = -2x_c$, $b = -2y_c$, $c = x_c^2 + y_c^2 - r^2$.

xc and yc can be calculated by a and b. x and y are calculated by measurement profile error. Measurement profile error that is shown in Fig.3 was compensated by xc, yc and △y. Measurement results are shown in Fig.5. Fig.5 (a) represents the outside profile error after compensation. The outside profile error is about ±5 μm. Fig.5 (b) represents the inside profile error after compensation. Inside profile error is about ±6 μm. Measurement error of rapid measurement system basically meets the required accuracy.



(a) Outside profile error



(b) Inside profile error

Fig.5 Measurement result after error separation

B. *Measurement result compared with that of the CMM*

In order to test the measurement result of the rapid measurement system, the outside and inside profile errors for the fixed scroll were measured by a commercial CMM in constant temperature room. About 1560 measurement points were obtained from the inside and outside profiles respectively. The measurement time was about 20 minutes for the inside and outside profile. About 4090 measurement points were obtained from the inside and the outside profiles respectively by the rapid measurement system. The measurement time was about 150 seconds for the inside and outside profile by the rapid measurement system. The measurement results of the outside and inside profile are shown in Fig.6. As can be seen in the figure, the measurement results of rapid measurement system for the outside and inside profile were the same as those of the CMM. But the measurement time of the rapid measurement system was much shorter than that of the CMM. The machining time for a scroll workpiece was about 300 seconds [9]. The rapid measurement system can meet the on-line machining measurement requirement.

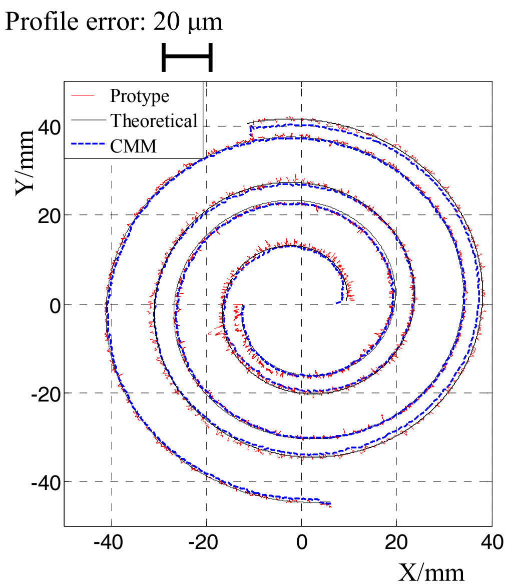


Fig.6 Measurement results for involutes profile of scroll

5. Conclusions

A rapid measurement system for scroll compressors has been developed based on a precision three-coordinate probe. The measurement errors of two kinds of offsets were analyzed by simulations. The measurement results of the rapid measurement system were the same as those of the CMM, but the measurement time of rapid measurement system was much shorter than that of the CMM. The developed rapid measurement system can meet the on-line machining measurement requirement of scroll compressors. The rapid measurement of non - involute profile is the future work.

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