Rapid Measurement of Involute Profiles for Scroll Compressors

J.H. Yang, Y. Arai, W. Gao

Nano-metrology and Control Laboratory, Department of Nanomechanics, Tohoku University. Aramaki Aza Aoba 6-6-01, Aoba-ku, Sendai, 980-8579, JAPAN
E-mail: Jianhong@nano.mech.tohoku.ac.jp

Abstract. *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 is 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 s 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, Measurement, Contact probe, Rapid measurement, Scroll compressor

1. Introduction

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

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. Fig1. (b) shows flank profile measurement including the inside involute profile, the outside involute profile and the non-involute profile. One of the leakages is the flank leakage caused by a gap between the flanks of the two scroll blades. The other is the tip leakage caused by a gap between the end plate and the scroll blade of the scrolls. These leakages can be decreased by increasing the manufacturing accuracy. Rapid measurements of the height and the flank profile are important to decrease manufacturing errors. Conventionally, scroll flank profiles are measured by a coordinate measuring machine (CMM), which is very time-consuming and expensive. The measurement time of the 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 profiles. Measurement errors are analyzed by simulations. Measurement results of the rapid measurement system are compared with those of the CMM. It is verified that developed rapid measurement system can satisfy the required measurement accuracy (±3 μm) and measurement time (300s/per workpiece).

2. Measurement System and Measurement Method

Fig. 2 shows the 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 a 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 stage is 0.0025 degree. The X axis could be moved by a precision control board. The moving speed of the X axis and the rotational speed of the rotary stage were controlled by a PID controller [4]. The positioning error was small enough to be ignored. The position of each stage was measured by each encoder and taken into a personal computer via multi axis control board.

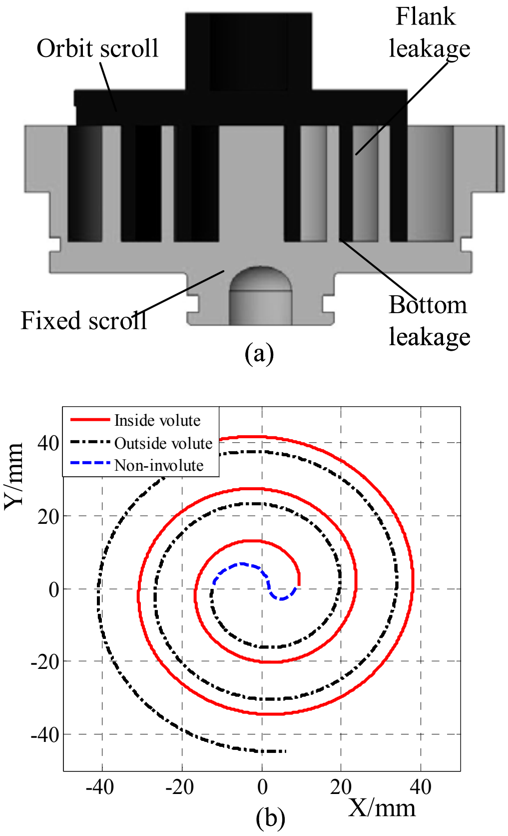


Fig.1.Leakages of scroll compressor and measurement profile

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

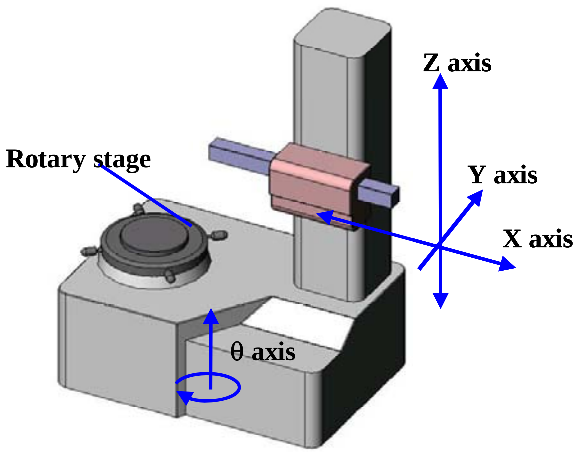


Fig.2. Measurement system of scroll profile

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

where

- r_θ the scroll radius of the polar angle of measurement point
- θ the polar angle of every measurement point
- a the base circle radius of scroll

From the equation (1), the X axis moving speed can be set to 0.7923 mm/s. The measurement polar radius of the scroll profile can be got by the outputs of probe encoder and the outputs of the X axis encoder. Measurement errors of the profile can be described by the following equation (2).

$$r_{error} = r_{th} - r_{mea} \tag{2}$$

where

r_{error} measurement error of involute profile

r_{th} theoretical polar radius of scroll profile

r_{mea} measurement polar radius of scroll profile

The same scroll sample was also measured for comparison by a commercial CMM, which was installed in a temperature controlled metrology room. The probing accuracy of CMM was 0.6 µm.

3. Measurement Result and Error Analysis

The involute profile errors of the fixed scroll were measured by the developed rapid measurement system. Measurement results are showed in the Fig. 3. the measurement error range of the outside profile was about ±20 µm. the measurement error range of inside profile was about ±40 µm. It can be seen that there were large measurement errors in the rapid measurement system. The measurement accuracy couldn't meet the required measurement accuracy (±3 µm). There was an offset between the coordinates of workpiece centre and those of rotary stage centre. The offset had significant effect on the measurement results. The Y-directional offset of contact point △y was caused by the friction between the contact probe and the flank profile.. △y had significant influence on the measurement results too.

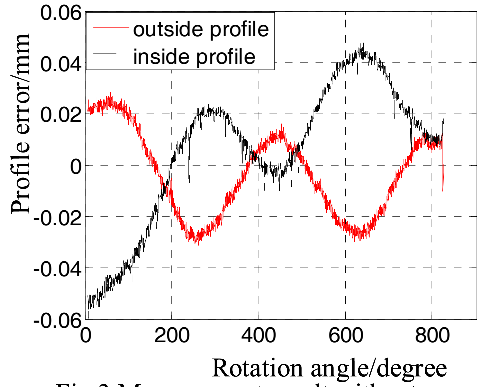
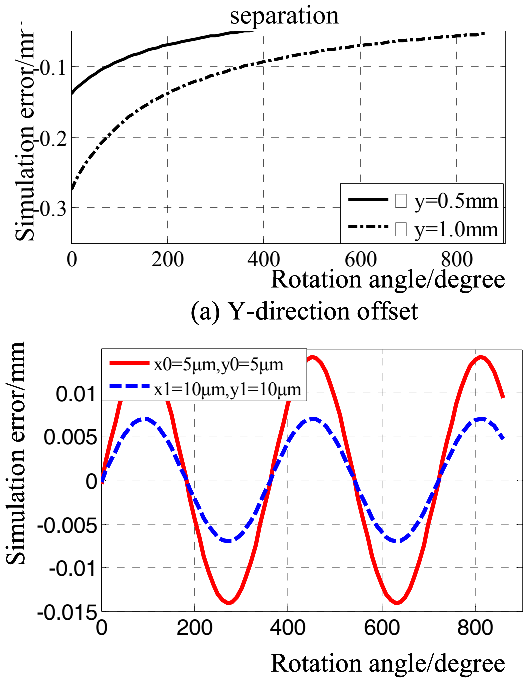


Fig.3.Measurement result without error separation

Simulations were carried out for analysis of the influence of the offset. Fig. 4 (a) shows the influence of the Y-directional offset of the contact point of the probe. Profile errors were calculated when △y=0.5 mm and 1 mm. It can be seen that the △y has large influence on the profile results. Fig. 4 (b) shows the influence of the offset between coordinates of workpiece centre and those of rotary stage centre. Here, xn and yn are defined by the offset between coordinates of workpiece centre and those of rotary stage centre. As can be seen in the figure, xn and yn generate a very large periodic measurement error even if the offset of coordinates is very small. To achieve the required measurement accuracy, it is confirmed that the Y-directional offset of contact point and the offset of coordinates between workpiece centre and rotary stage centre must be separated from the profile measurement result.



(b) Xn and yn offset

Fig.4.Simulation analysis of impacting measurement result

4. Measurement Result Compared with CMM

The Y-directional offset of the contact point can be measured by the output of the probe encoder. The actual scroll polar angle of the contact point can be calculated by compensation of the Y-directional offset. The offset between coordinates of workpiece centre and rotary stage centre can be got by an optimization algorithm of the measurement error shown in Fig. 3.

The outside and inside profile errors of the fixed scroll were also measured by a commercial CMM. About 1560 measurement points were got from the inside and the outside profiles respectively. The measurement time of the inside and outside profiles was about 20 minutes. About 4090 measurement points were got from the inside and outside profiles respectively by the rapid measurement system. The measurement time of the inside and outside profiles was about 150 seconds. The measurement results of the outside and inside profiles are showed by Fig. 5. As can be seen in the figure, the measurement results of the developed rapid measurement system were the same as those of CMM after removing the Y-directional offset and the offset of coordinates. But the measurement time of the rapid measurement system was much shorter than that of the CMM.. The rapid measurement system can satisfy the on-line machining measurement demands of the scroll.

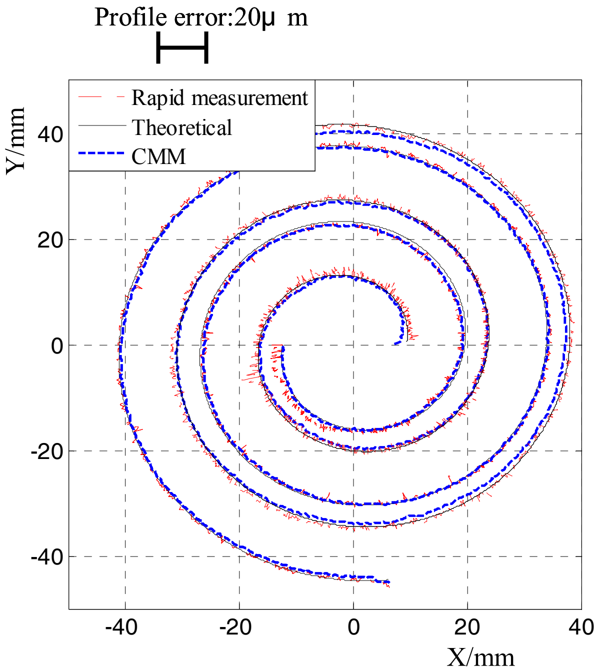


Fig.5.Measurement results of inside and outside profiles

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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