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Mitsuhiro Fukuta
Shizuoka University, Japan, tmmfuku@ipc.shizuoka.ac.jp

Daisuke Ogi
Graduate School of Engineering, Shizuoka University, Japan, disk.og.2917@gmail.com

Masaaki Motozawa
Shizuoka University, Japan, tmmotoz@ipc.shizuoka.ac.jp

Tadashi Yanagisawa
Shizuoka University, Japan, tmtyana@ipc.shizuoka.ac.jp

Shigeki Iwanami
Denso Corporation, SHIGEKI_IWANAMI@denso.co.jp

See next page for additional authors

Authors
Mitsuhiro Fukuta, Daisuke Ogi, Masaaki Motozawa, Tadashi Yanagisawa, Shigeki Iwanami, and Tadashi Hotta

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Mitsuhiro FUKUTA[1]*, Daisuke OGI[2], Masaaki MOTOZAWA[3], Tadashi YANAGISAWA[4], Shigeki IWANAMI[5] and Tadashi HOTTA[6]

[1]Professor, Department of Mechanical Engineering, Shizuoka University, 3-5-1 Johoku, Hamamatsu 432-8561, Japan, Tel&Fax:+81-53-478-1054, E-mail:tmmfuku@ipc.shizuoka.ac.jp

[2]Graduate Student, Graduate School of Engineering, Shizuoka University, E-mail:f0330012@ipc.shizuoka.ac.jp

[3]Associate professor, Department of Mechanical Engineering, Shizuoka University, Tel&Fax:+81-53-478-1058, E-mail:tmmotoz@ipc.shizuoka.ac.jp

[4]Professor, Department of Mechanical Engineering, Shizuoka University, Tel&Fax:+81-53-478-1056, E-mail:tmyana@ipc.shizuoka.ac.jp

[5]DENSO CORPORATION, E-mail:shigeki_iwanami@denso.co.jp

[6] DENSO CORPORATION, E-mail:tadashi_hotta@denso.co.jp

* Corresponding Author

ABSTRACT

Scroll compressors are widely used in room air conditioning cycles, package air conditioning cycles, refrigeration, etc. There are two main leakage paths in a compression chamber formed by a fixed scroll and an orbiting scroll. One is the leakage path through a radial clearance between the wraps of fixed and orbiting scroll. Another leakage path is an axial clearance which is the clearance between a tip of the scroll wrap and a base plate. A tip seal is often used to prevent the leakage through the axial clearance. Although there have been many studies on the tip seal, the seal mechanism of the tip seal is not thoroughly clarified yet. In addition, the relationship between the sealing effect and a frictional loss of the tip seal is also not validated well. In this study, a test apparatus which can evaluate the sealing effect and the frictional force of the tip seal simultaneously is developed. The influence of specification of a tip seal groove on the sealing effect is examined with the test apparatus. When groove angle of the tip seal groove is slightly larger than 90°, since the pressure on outer side of the tip seal becomes low, the tip seal is pressed against the seal groove by the pressure difference between both sides of the tip seal and the leakage is suppressed. As a result, the sealing mechanism of the tip seal is clarified and a design guideline of the tip seal grove is obtained.

1. INTRODUCTION

Scroll compressors are widely used in room air conditioning cycles, package air conditioning cycles, refrigeration, water heater and automobile air conditioning cycles as well as air compressors, helium compressors and vacuum pumps. There are two main leakage paths in a compression chamber formed by a fixed scroll and an orbiting scroll. One is the leakage path through a radial clearance between the wraps of fixed and orbiting scroll. The leakage through the radial clearance is prevented by pressing the orbiting scroll radially against the fixed scroll by a mechanism such as a compliance mechanism. Oil inside the compression chamber also has the sealing effect and reduces the leakage through the radial clearance. Another leakage path is an axial clearance which is the clearance between a tip of the scroll wrap and a base plate. A tip seal is often used to prevent the leakage through the axial clearance as shown in Fig. 1. There are many studies about the leakage characteristics of tip seal. Inaba *et al*. (1986) examined the leakage through three different flow paths, i.e. the radial leakage across the tip seal, the tangential leakage through a back clearance behind the tip seal and the tangential leakage through the clearance between the wrap and the base plate. Ancel *et al*. (2000) investigated the behavior of the tip seals of multi-blade type and mono-bloc type by measuring pressure under the tip seal in a seal groove. Youn *et al.* (2000) studied the leakage at the tip seal in scroll compressor by a model compressor using compressor elements under an actual operating condition and a contact clearance between the tip seal and the base plate was estimated. Lee *et al.* (2002) discussed flow models to estimate the leakage flow across the tip seal and measured tip seal behavior by a laser displacement sensor.

Although there are many studies on the tip seal, the seal mechanism of the tip seal is not thoroughly clarified yet, and the influence of design parameters on effectiveness of the tip seal is unclear. In addition, the relationship between the sealing effect and a frictional loss of the tip seal is also not validated well. In this study, a test apparatus which can evaluate the sealing effect and the frictional loss of the tip seal simultaneously is developed. The influence of specification of the tip seal groove on the sealing effect and the frictional loss is examined by the test apparatus with measuring pressure distribution around the tip seal in the tip seal groove.

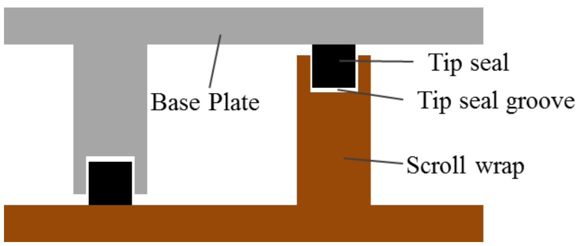

Figure 1: Tip seal in scroll compressor

2. EXPERIMENTSL SETUP

The sealing mechanism of the tip seal in the scroll compressor is examined by a model flow channel equipped with a circular tip seal. Figure 2 shows the schematic view of the model channel. The model channel is composed of a test piece and a bottom plate which model the scroll wrap with the tip seal and the base plate, respectively. Inside of the tip seal is pressurized and outside is opened to the atmosphere. The test piece has a ring groove for the tip seal. Outer diameter of the ring groove is 35 mm, inner diameter is 30 mm and depth is 2 mm. On the other hand, height of the tip seal is 1.9 mm, and width is 2.2 mm. Although outer diameter of the tip seal is about 34.95 mm, i.e. smaller than the outer diameter of the ring groove, the seal ring has a cut and an abutment joint as shown in Fig. 3 and it can expand by pressure to fit against the ring groove.

In this study, the influence of the specification of the ring groove on the sealing effect is investigated. Four test pieces having different groove angle θ (see Fig. 2) are prepared and the experiment is carried out with each test piece. The groove angle θ of each test piece is 93°, 91.5°, 89.4° and 88.5°. In order to measure pressure distribution around the tip seal, six pressure taps of 0.2 mm in diameter are machined on the wall of the ring groove. Among them, three taps are on the upper surface of the groove at different radial positions and the others are on the side wall at different heights as shown in Fig. 4. Two types of the bottom plates are used in the experiment. One is the simple base plate for measurement of the frictional force. The other has three pressure taps of 0.3 mm in diameter at different radial position for measurement of the pressure distribution on the bottom surface of the tip seal (see Fig. 5).

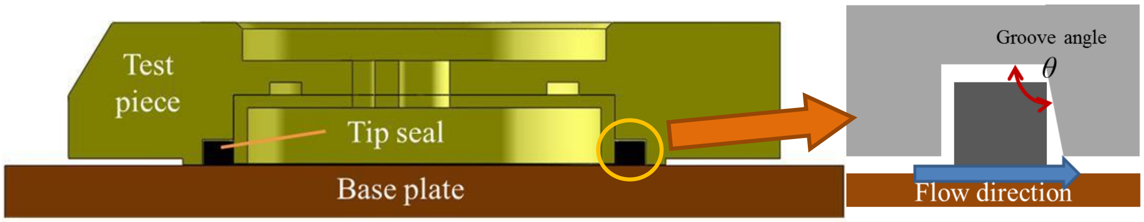

Figure 2: Model flow channel with ring tip seal

Figure 3: Tip seal with abutment joint

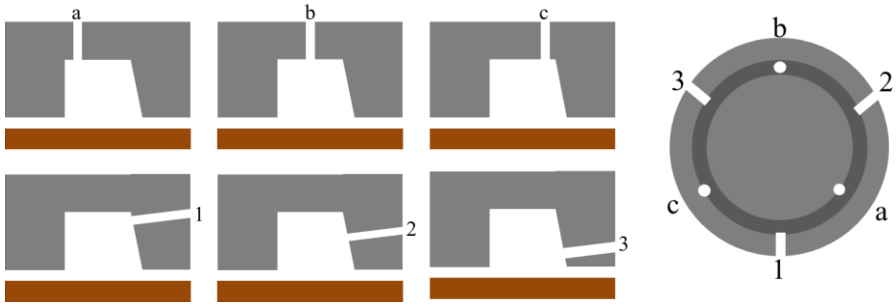

Figure 4: Position of pressure taps

Figure 5: Position of pressure taps for measuring pressure distribution on bottom surface

Figure 6 shows a sectional view of the experimental apparatus. The leakage across the tip seal and the frictional force caused by the tip seal can be evaluated simultaneously by the experimental apparatus. The test piece with the ring tip seal is attached on an end of a linear rod. Clearance between the test piece and the base plate can be adjusted by a lever on the linear rod. The clearance is set to be 10 μm. The base plate is mounted on an orbiting plate and has orbiting motion by an orbiting thrust bearing. The orbiting radius is 6 mm. The base plate is rotatable relatively to the orbiting plate and a torsion spring is attached between the base plate and the orbiting plate. When the frictional force caused by the tip seal acts on the base plate with the orbiting motion, the base plate rotates and the rotational angle of the base plate is proportional to frictional torque by the frictional force. The rotational angle of the base plate is measured by a high-speed camera and the frictional force can be evaluated. The orbiting mechanism is driven by an electric motor. The working fluid, nitrogen, is supplied to an inside of the test piece through a supply port at the top of the linear rod from a bomb. A regulator that is installed in a supplied line controls the upstream pressure. The leakage across the tip seal is measured by mass flow meters having different measuring range.

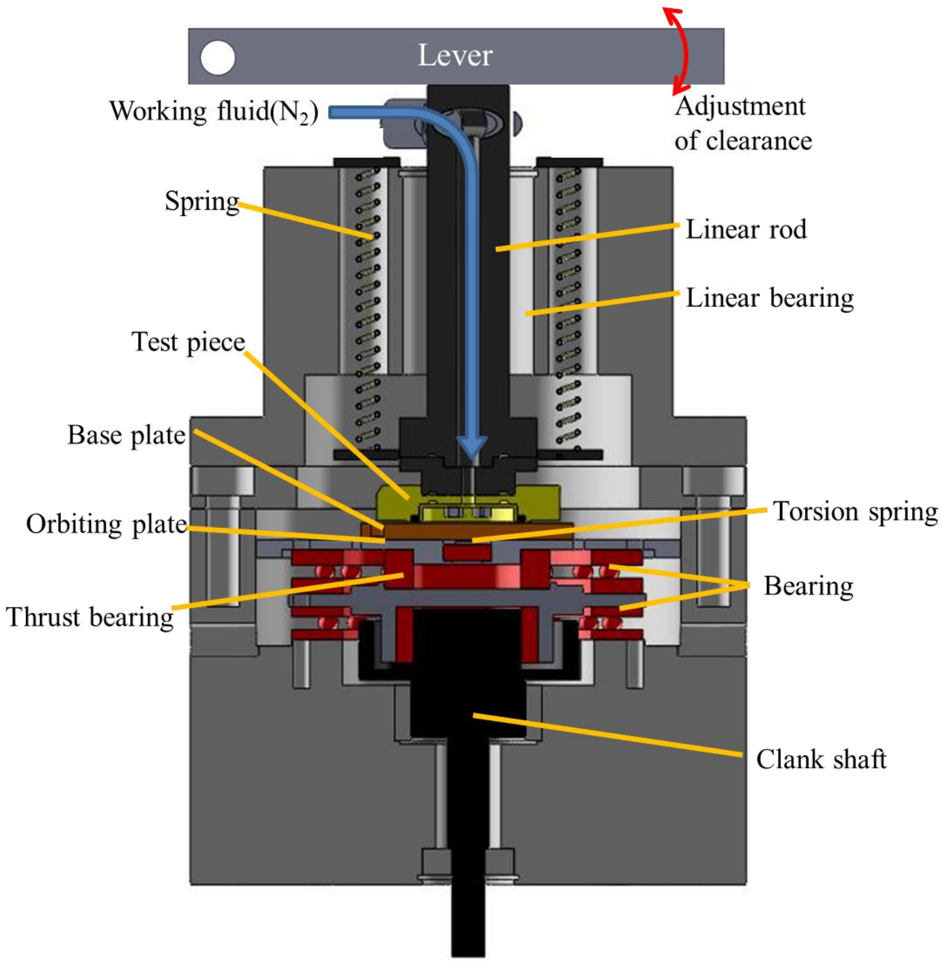

Figure 6: Experimental apparatus

3. EXPERIMENTAL RESULTS

3.1 Hysteresis of Leakage

Figure 7 shows a relationship between the upstream pressure and the leakage mass flow rate through the tip seal. The leakage is measured with increasing the upstream pressure from 0 MPa up to 0.9 MPa at first, and then the pressure is decreased. It is shown that it has hysteresis of the leakage with increasing and decreasing the upstream pressure. Once high pressure is applied to the tip seal, the ring tip seal expands, the seal becomes effective and the leakage is suppressed. In this study, all experiments are done after the upstream pressure is once increased to 0.9 MPa.

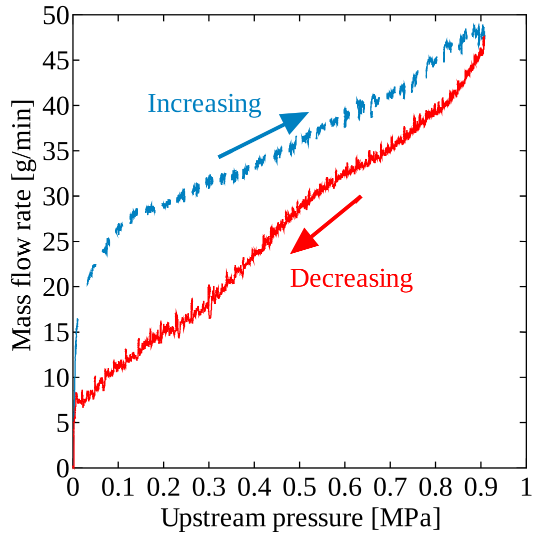

Figure 7: Hysteresis of leakage

3.2 Compensation of Leakage through Abutment Joint

Since the portion of the abutment joint of the ring tip seal acts as a flow path, the leakage increases because of it. The leakage at the joint portion is estimated by checking the influence of length of the joint portion. Figure 8 shows the joint portion having difference length. Figure 9 shows the leakage versus the length of joint portion of each tip seal when upstream pressure is 0.9 MPa. From this figure, it is found that the leakage increases proportionally with the length of joint portion. The leakage for the tip seal without the abutment joint can be estimated by an extrapolation of the linear relationship between the length of joint portion and the leakage as shown with red square in Fig. 9. The difference between the red square and the leakage with the original tip seal is, therefore, considered as the leakage through the joint portion. The following results are processed by subtracting the leakage of the joint portion from the measured leakage.

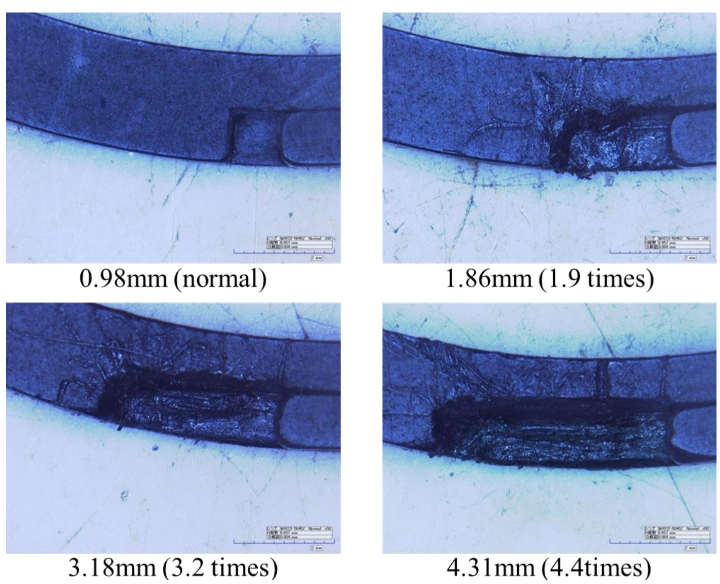

Figure 8: Abutment joint portion of tip seal having different length

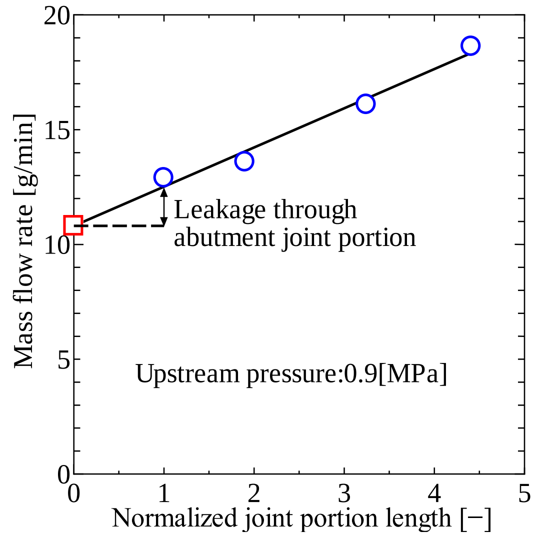

Figure 9: Leakage versus length of joint portion of tip seal

3.3 Influence of Groove Angle on Leakage through Tip Seal

The experimental results are shown in Fig. 10. In this figure, vertical axis is the mass flow rate and horizontal axis is the groove angle. It is shown in this figure that the leakage is suppressed when the groove angle is larger than 90°.

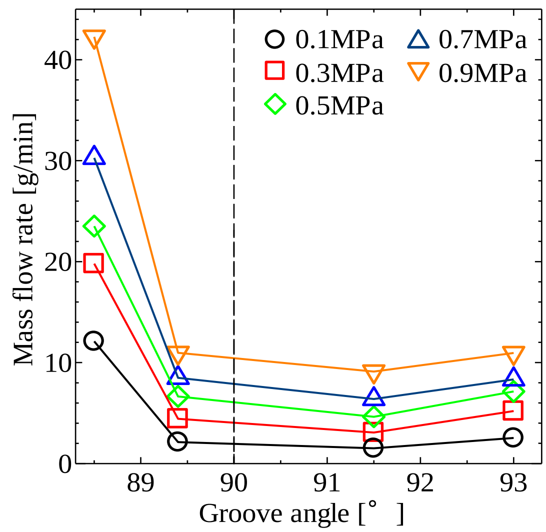

Figure 10: Relationship between groove angle and leakage

The pressure distribution around the tip seal is shown in Fig. 11. In all cases of the experiment, the pressure at the upper surface of the tip seal (position a, b and c in Fig. 4) is equal to the upstream pressure and only the pressure distribution at side of the groove is plotted in Fig. 11. Horizontal axis is the position of the pressure tap shown in Fig. 4 and vertical axis is the pressure. Left figure shows the result for the ring groove whose groove angle is larger than 90° and right one is for the groove angle smaller than 90°. When the groove angle is larger than 90°, the pressure at position 1 is the same as the upstream pressure, and pressures at point 2 and 3 are 0 MPa. The tip seal is pressed against the side wall by the pressure difference acting on both sides of the tip seal and the tip seal works well. On the other hand, when the groove angle is smaller than 90°, the pressures at all positions are almost the same as the upstream pressure. Side force does not act on the tip seal and little sealing effect is obtained in this case as shown in Fig. 10.

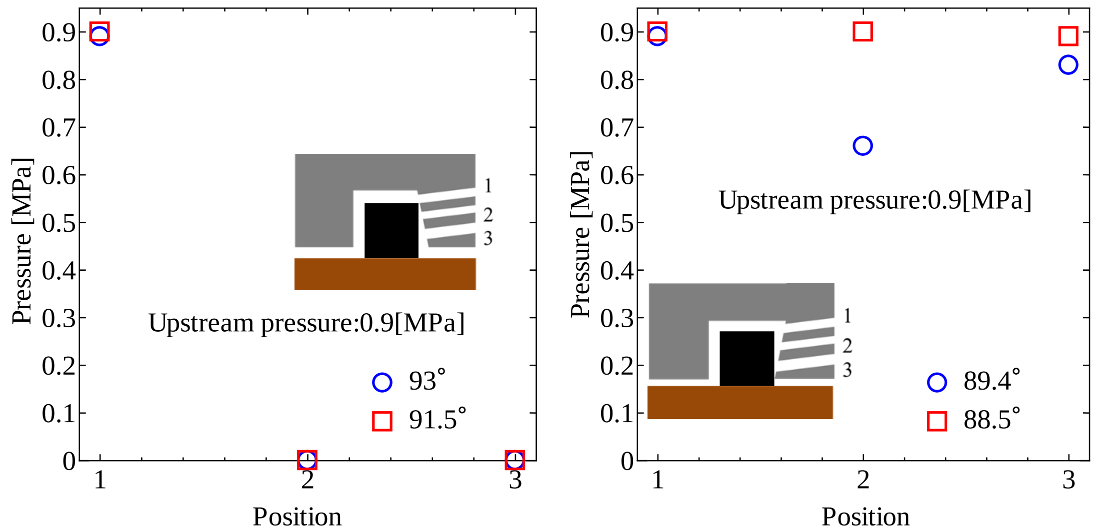

Figure 11: Pressure distribution at side of groove

3.4 Frictional Force

According to the results describe above, the friction test of the tip seal is conducted with the test piece having the groove angle of 91.5°. Lubricating oil of PAG (VG10) is slightly put on the base plate at the beginning of the experiment and orbiting speed of the base plate is 750 rpm. The experimental result is shown in Fig. 12. In this figure, the frictional force and the leakage mass flow rate increase with the upstream pressure.

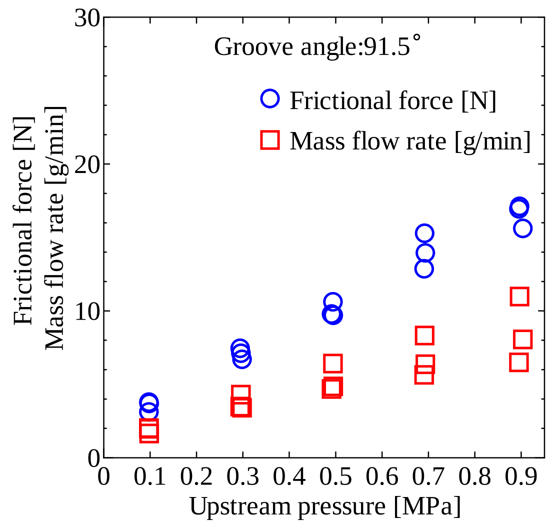

Figure 12: Frictional force

In order to obtain coefficient of friction between the tip seal and the base plate, contact force acting on the bottom of the tip seal is needed as well as the frictional force. Since the contact force is determined from pressure difference between the upper surface and the bottom surface of the tip seal, the pressure distribution on the bottom surface of the tip seal is needed. The bottom plate is replaced by that with the pressure tap for measurement of the pressure distribution on the bottom surface. Figure 13 shows that the pressure on the bottom surface of the tip seal is 0 MPa. It means that the leakage through under the tip seal is sealed at an inside edge of the tip seal.

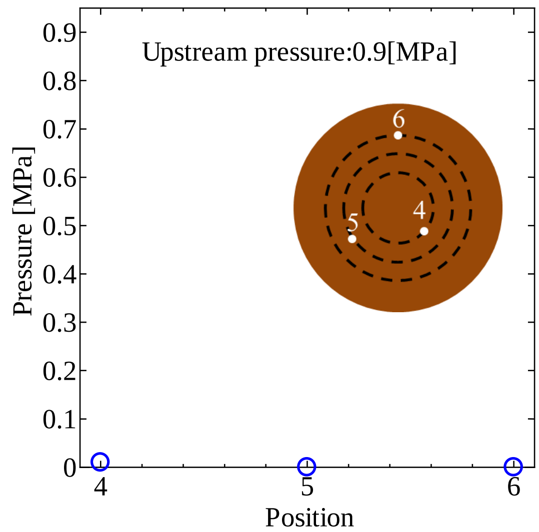

Figure 13: Pressure distribution on bottom surface

Based on the results of the pressure distribution on the upper surface and the bottom surface of the tip seal, the contact force is determined. The contact force is shown in Fig. 14 against the upstream pressure and almost equal to the force acting on the upper surface of the tip seal, since the pressure on the bottom surface of the tip seal is almost 0 MPa and the pressure force acting on the bottom surface is negligible.

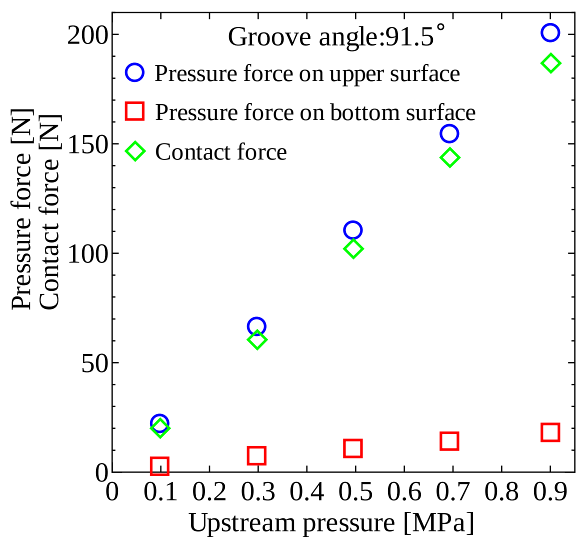

Figure 14: Contact force

The coefficient of friction is obtained from ratio of the frictional force and the contact force and is shown in Fig. 15. The coefficient of friction between the tip seal and the base plate is found to be between 0.08 and 0.13. The coefficient of friction slightly increases with decreasing the upstream pressure. Since the experiment is carried out consecutively with reducing the upstream pressure from 0.9 MPa to 0 MPa and no oil is supplied during the experiment, the lubricating oil flows away from a contact surface between the tip seal and the base plate and the lubrication condition gradually becomes worse with the elapsed time of the experiment.

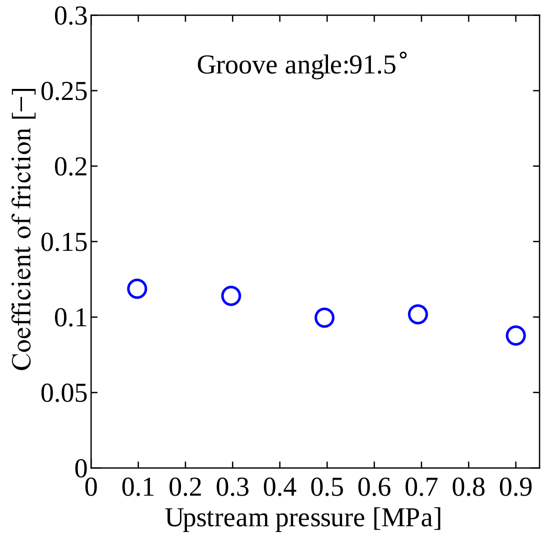

Figure 15: Coefficient of friction

4. CONCLUSIONS

In this study, an experimental apparatus which can evaluate leakage across a tip seal and frictional force simultaneously is developed. The influence of specification of a seal groove on the leakage is examined. The following conclusions are obtained.

- The leakage across the tip seal, pressure distribution around the tip seal and the frictional force are measured by the experimental apparatus.
- When groove angle is slightly larger than 90°, the leakage across the tip seal is suppressed. On the contrary, little sealing effect is obtained with a test piece which has the groove angle smaller than 90°.
- When the groove angle is larger than 90°, since the pressure on outer side of the tip seal becomes the same as downstream pressure, the tip seal is pressed against the seal groove by the pressure difference between both sides of the tip seal. On the other hand, when the groove angle is smaller than 90°, the pressure on both sides of the tip seal is the same as the upstream pressure, and the seal does not work well.
- Coefficient of friction between the tip seal and a base plate is found to be between 0.08 and 0.13.

REFERENCES

Ancel, C., Lamoine, P., Didier, F., 2000, Tip Seal Behavior in Scroll Compressor, *International Compressor Engineering Conference at Purdue*, Paper 1452.

Inaba, T., Sugihara, M., Nakamura, T., Kimura, T., Morishita, E., 1986, A Scroll Compressor with Sealing Means and Low Pressure Side Shell, *International Compressor Engineering Conference at Purdue*, Paper 577.

LEE, B.C., Yanagisawa, T., Fukuta, M., Choi, S., 2002, A Study On The Leakage Characteristics Of Tip Seal Mechanism In The Scroll Compressor, *International Compressor Engineering Conference at Purdue*, Paper 1586.

Youn, Y., Cho, N.K., Lee, B.C., Min, M.K., 2000, The Characteristics of Tip Leakage in Scroll Compressors for Air Conditioners, *International Compressor Engineering Conference at Purdue*, Paper 1465.