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The Characteristics of Tip Leakage in Scroll Compressors for Air Conditioners

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Abstract

This Paper describes the characteristics of tangential and radial leakage which is occurring at micro tip clearance in a scroll compressor for an air conditioner (R22) under actual operating condition. It is well known that leakage phenomena have a large effect on the performance of a scroll compressor. But the leakage phenomena of a scroll compressor under actual operating condition were not clear because of a complex sealing mechanism and two phase flow. To define complex tip leakage phenomena under actual operating condition, experimental research was executed by using indirect flow rate measuring method. And analysis model of tip leakage was made for analyzing tangential and radial leakage occurring at grooves and contact points of a tip seal. In case of no oil, it was also validated as theoretical result was compared with experimental result. Therefore the quantity of tip leakage with pressure ratio, orbiting angle, discharge pressure, tip clearance, and leakage point was found out. Also it was known that tip leakage at tip part occurs somewhat although a tip seal has sealing effect for radial leakage.

Nomenclature

A	: Leakage area	P_{up}	: Up stream pressure
A_{tsb}	: Tip seal bottom area	P_{dn}	: Down stream pressure
A_{tsbs}	: Tip seal bottom side area	R	: Gas constant of refrigerant
A_{tss}	: Tip seal side area	T_{up}	: Up stream temperature
A_{wt}	: Wrap tip area	w_{ts}	: Tip seal width
$A_{tstc,t}$: Tip seal top contact area, tangential	w_{wt}	: Wrap tip width
$A_{tssc,t}$: Tip seal side contact area, tangential	ϕ_a	: Involute starting angle
$A_{tstc,r}$: Tip seal top contact area, radial	θ	: Orbiting angle
$A_{tssc,r}$: Tip seal side contact area, radial	δ_{tsb}	: Tip seal bottom clearance
a	: Base circle radius	δ_{tss}	: Tip seal side clearance
C	: Flow coefficient	δ_{tstc}	: Tip seal top contact clearance
h_{ts}	: Tip seal height	δ_t	: Tip clearance
k	: Specific heat ratio	δ_{tssc}	: Tip seal side contact clearance
$L_{l,in}$: Inner leakage length	\dot{m}	: Leakage mass flow rate
$L_{l,out}$: Outer leakage length	L_{tsl}	: Tip seal leakage length

Introduction

Scroll compressors have been widely built in room and packaged air-conditioners because of higher performance, lower noise, and lower vibration. In a scroll compressor, a sealing mechanism is needed for preventing flank and tip leakage between pockets during the compression process. For example, the back pressure or the tip seal mechanism is generally adopted for preventing tip leakage at tip(axial) clearance. And the variable radius crank mechanism is widely used for reducing flank leakage at flank(radial) clearance. Studies on sealing mechanisms for reduction of leakage loss have been made.⁽¹⁾⁻⁽³⁾ But studies on leakage phenomena under actual operating conditions and the sealing effect of the tip seal mechanism are very insufficient because of the complex structure of the compression part, the complicated mechanism of the tip seal, and the two-phase flow of the working fluid. In this study, the quantity of tip leakage was measured in actual operating conditions by an experimental apparatus using an indirect flow rate measuring method. An analysis model of tip leakage was made for analyzing tangential and radial leakage occurring at grooves and contact points of a tip seal.

Experiment

The experiment was performed to find out the characteristics of the tip leakage between pockets under actual operating conditions of a scroll compressor. Fig.1 is a schematic diagram of the experimental apparatus. The experimental apparatus consists of three parts; a modified test compressor part, a modified air conditioner part, and a multi flow rate measuring device part. Fig.2 is a sectional view of the modified test compressor. And Fig.3 represents the positions of bypass holes at the top of a fixed scroll. The modified test compressor has the same structure as a real scroll compressor except that the driving motor is removed. The modified air conditioner is a device to supply high pressure refrigerant to the modified test compressor continuously. The multi flow rate measuring device was made for measuring flow rate at several points with a mass flow meter.

It is impossible that the tip leakage only is measured due to the rotation of an orbiting scroll. The leakage mass flow rate of tip and flank at an orbiting angle for a sample can be totally measured. Therefore, the leakage mass flow rate of tip is obtained by subtracting that of flank from that of flank and tip.

Theoretical analysis

Fig.4 represents tangential and radial leakage of tip occurring at tip clearance between a fixed and an orbiting scroll. And Fig.5 represents tangential and radial leakage model of a tip seal. The tangential leakage occurs at surrounding clearance of a tip seal; top, bottom, left side, right side, and bottom left side clearance of a tip seal, clearance between tip of a wrap and plate of a scroll. And the radial leakage occurs at top contact and side contact clearance of a tip seal.

The leakage lengths of tip between 720° and 990° of orbiting angle can be expressed as

$$L_{l,in} = \pi \times a \times \frac{(\phi_a - \pi - \theta)}{2} \quad (1)$$

$$L_{l,out} = \pi \times a \times (\phi_a + 1.5\pi - \theta) \quad (2)$$

And leakage areas of tip can be defined as

$$A_{tsb} = w_{ts} \times \delta_{tsb} \quad (3)$$

$$A_{tsbs} = \delta_{tss} \times \delta_{tsb} \quad (4)$$

$$A_{tss} = \delta_{tss} \times (h_{ts} + \delta_{tsc}) \quad (5)$$

$$A_{wt} = w_{wt} \times \delta_t \quad (6)$$

$$A_{tsc,t} = w_{ts} \times \delta_{tsc} \quad (7)$$

$$A_{tssc,t} = \delta_{tssc} \times h_{wg} \quad (8)$$

$$A_{tsc,r} = L_{tsl} \times \delta_{tsc} \quad (9)$$

$$A_{tssc,r} = L_{tsl} \times \delta_{tssc} \quad (10)$$

The tangential and radial leakage mass flow rate of tip can be theoretically obtained by using the flow coefficient equation of steady state one-dimensional compressible fluid, assuming leakage flow as single phase and isentropic nozzle flow.

$$m = \begin{cases} CAP_{up} \sqrt{\frac{2k}{(k-1)RT_{up}} \left[\left(\frac{P_{dn}}{P_{up}}\right)^{\frac{2}{k}} - \left(\frac{P_{dn}}{P_{up}}\right)^{\frac{k+1}{k}} \right]} & \left(\frac{P_{dn}}{P_{up}}\right) \geq \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}} \\ CAP_{up} \sqrt{\frac{k}{RT_{up}} \left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}} & \left(\frac{P_{dn}}{P_{up}}\right) < \left(\frac{2}{k+1}\right)^{\frac{k}{k-1}} \end{cases} \quad (11)$$

The analysis model of tip leakage was made by using above equations, flow coefficient, and tip seal contact clearance on condition of no oil.

Results and Discussion

The Condition of pressure, Tip Clearance, and Tip Leakage Length with Orbiting Angle

Fig.6 shows the upstream and downstream pressure condition of a leakage part with orbiting angle at different suction and discharge pressure. As known from Fig.6, downstream pressure condition with orbiting angle is constant because the discharge pressure has no effect on it. On the other hand, upstream pressure condition is constant at 720 ° and 765 °, but variable at 900 ° and 990 ° due to the connection between a compression pocket and a discharge pocket. Fig.7 represents tip clearance condition with orbiting angle at different tip clearance. Every tip clearance has constant clearance with orbiting angle. Fig.8 shows variation of tip leakage length with orbiting angle. The tip leakage length is linearly reduced with increase of orbiting angle. Therefore it is known that the tip leakage area decreases as orbiting angle increases in case of constant tip clearance.

Oil Concentration

Fig.9 represents the variation of oil concentration of mixture with measuring number at the inlet of a test compressor. Although the value of oil concentration measured by an oil sampler has some fluctuation, it is about 0.5%. Therefore it is known that oil has little effect on leakage of tip between pockets in this experiment.

Effect of Pressure Ratio

Fig.10 shows the comparison of tip leakage with pressure ratio between experimental and theoretical value. In that case, the pressure ratio is defined as the pressure ratio of upstream to downstream. In experimental result, the leakage mass flow rate of tip is obtained by subtracting that of flank from that of flank and tip on condition of the same clearance and temperature. On the other hand, the theoretical value of tip leakage is directly calculated by analysis model of tip leakage using flow coefficient and tip seal contact clearance. As known from Fig.10, the theoretical result of analysis model of tip leakage has a good agreement with experimental value. Thus the analysis model of tip leakage is validated through that comparison. And the leakage mass flow rate of tip in case of tip clearance $37\mu\text{m}$ is linearly proportional to pressure ratio in condition of the same temperature.

Fig.11 shows the comparison of tip leakage with pressure ratio defined as the pressure ratio of downstream to upstream at different tip clearance between experimental and theoretical value. The theoretical result of tip leakage has a good agreement with experimental value of tip leakage. Thus it is known that the analysis model of tip leakage has validity and tip leakage with pressure ratio at any clearance reveals typical choking phenomenon of compressible fluid. Also it is clear that oil of mixture has little effect on tip leakage from this analysis.

Tip Seal Contact Clearance

Fig.12 represents the variation of tip seal contact clearance with pressure ratio at top and side of a tip seal. The value of tip seal contact clearance is theoretically obtained by comparing theoretical value with experimental value of tip leakage in Fig.10. In case of tip clearance $37\mu\text{m}$, it is found out that the value of tip seal contact clearance at top and side of a tip seal is nearly constant and about $2.5\mu\text{m}$ as known from Fig. 12.

Effect of Orbiting Angle

Fig.13 and Fig.14 show experimental result of tip leakage with orbiting angle at tip clearance 37 and $52\mu\text{m}$ respectively in case of discharge pressure 21. The tip leakage is nearly constant between 720° and 765° because increase of upstream pressure has effect of increase to it, but decrease of tip leakage length has effect of decrease to it. And the tip leakage sharply increases between 765° and 900° due to sharp increase of upstream pressure in spite of decrease of tip leakage length. Also the tip leakage a little decreases between 900° and 990° due to reduction of pressure difference between pockets and tip leakage length. Tip leakage in case of tip clearance $52\mu\text{m}$ reveals the same trend as that in case of tip clearance $37\mu\text{m}$.

Effect of Discharge Pressure

Fig.15 shows the comparison of tip leakage with orbiting angle at different discharge pressure between experimental and theoretical value. Tip leakage with discharge pressure is constant at 720° and 765° because of the same pressure and area condition. On the other hand, tip leakage with increase of discharge pressure reveals linear increase at 765° and 900° due to increase of upstream pressure as shown in Fig.6. Although there is some deviation, theoretical result has a good agreement with experimental result.

Effect of Tip Clearance

Fig.15 represents shows the comparison of tip leakage with orbiting angle at different tip clearance between experimental and theoretical value. Tip leakage with increase of tip clearance linearly increases with over all angle. It reveals that total leakage area of tip is linearly proportional to tip clearance. Therefore it is clear that in spite of sealing effect of a tip seal, the more tip clearance increases, the more tip leakage increases.

Conclusions

In this study, the tip leakage of a scroll compressor was measured by using experimental apparatus under actual operating condition. And leakage of tip and contact clearance of a tip seal were theoretically analyzed by analysis model of tip leakage. Finally, the following conclusions were obtained from above research.

- (1) The analysis model of tip leakage in case of oil was validated by comparing theoretical result with experimental result of tip leakage.
- (2) The tip leakage with pressure ratio at any tip clearance reveals typical choking phenomenon of compressible fluid.
- (3) The value of tip seal contact clearance at top and side of a tip seal has no variation with pressure condition and orbiting angle, and is about $2.5\mu\text{m}$ at tip clearance $37\mu\text{m}$.
- (4) At any tip clearance and discharge pressure, the tip leakage is nearly constant between 720° and 765° , sharply increases between 765° and 900° , a little decreases between 900° and 990° .
- (5) Tip leakage with increase of discharge pressure is constant at 720° and 765° , reveals linear increase at 765° and 900° .
- (6) Although a tip seal has sealing effect for radial leakage, tip leakage with increase of tip clearance linearly increases with over all angle.

Acknowledgement

We would like to express our great thanks to LG electronics Co. Ltd., for their financial and technical support in carrying out this research.

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Figures

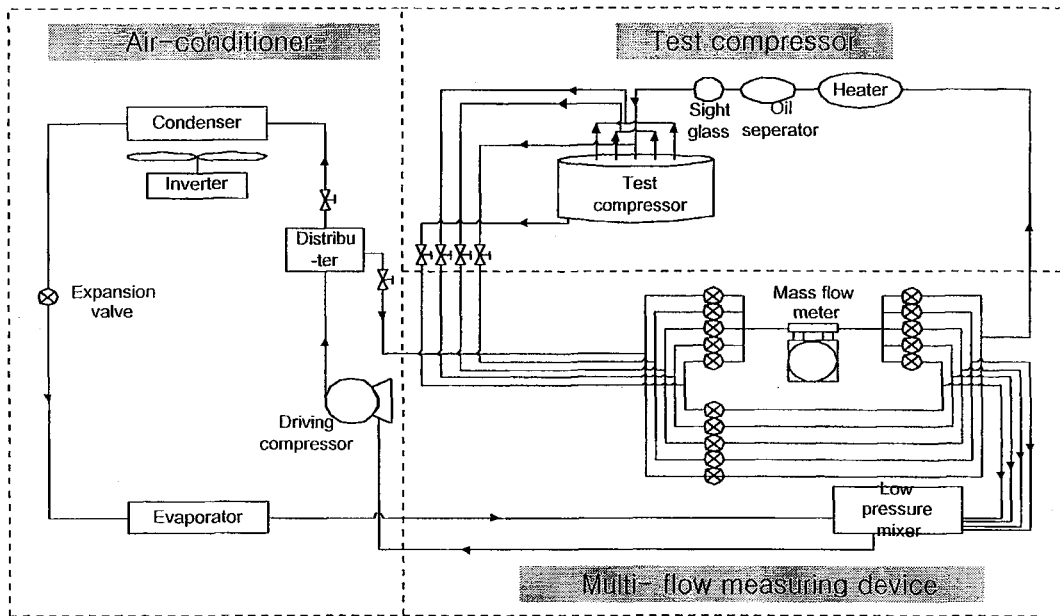


Fig.1 Schematic of experimental apparatus

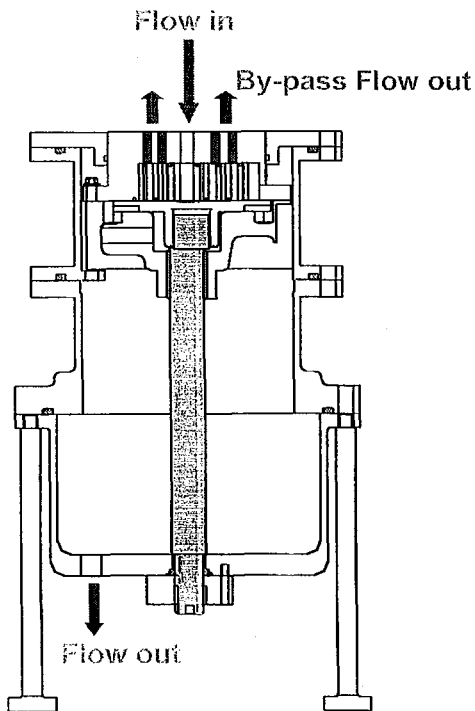


Fig. 2 Test compressor

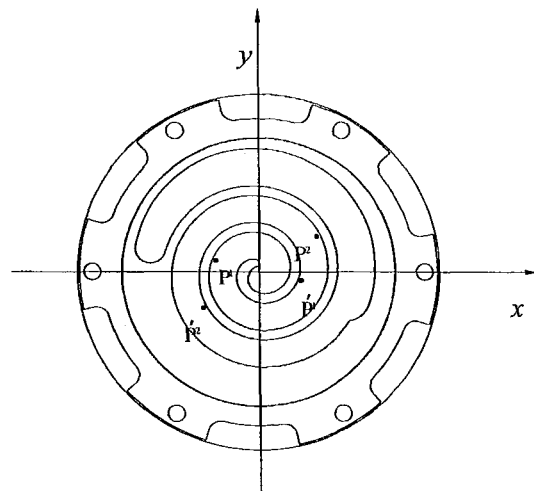


Fig. 3 Bypass holes

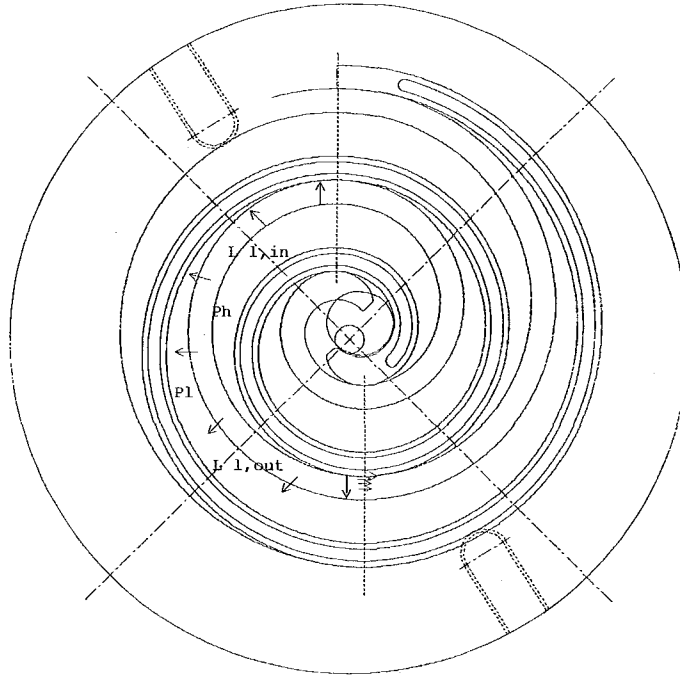


Fig. 4 Tip leakage of a scroll compressor

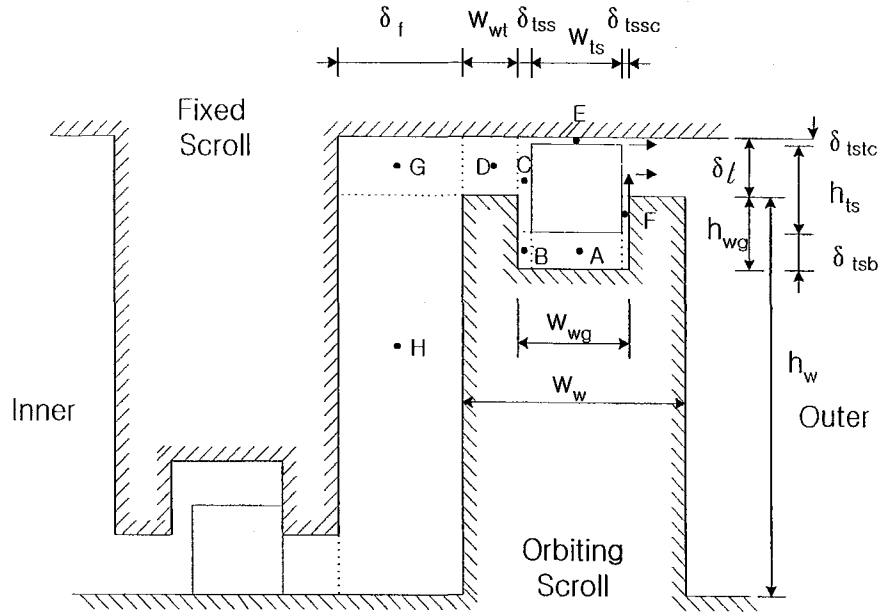


Fig. 5 Leakage model of a tip seal

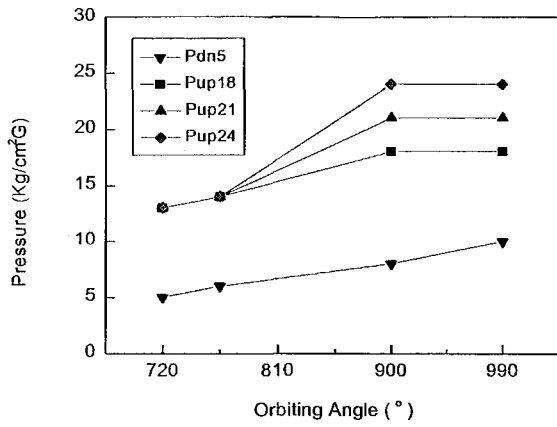


Fig. 6 Pressure condition

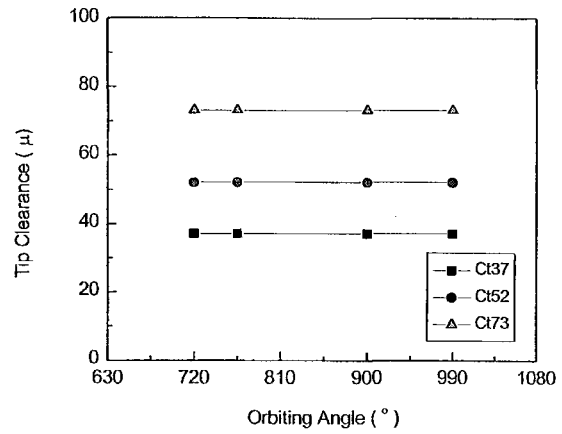


Fig. 7 Tip clearance condition

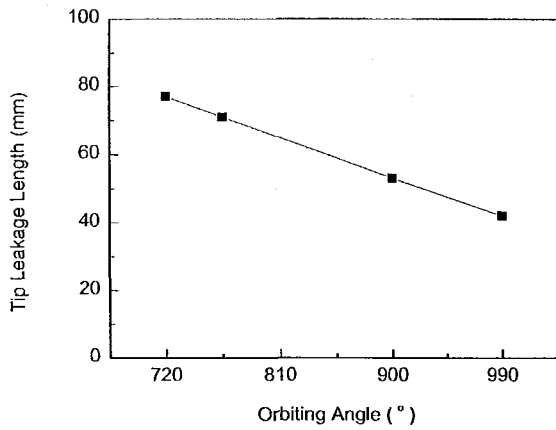


Fig. 8 Tip leakage length condition

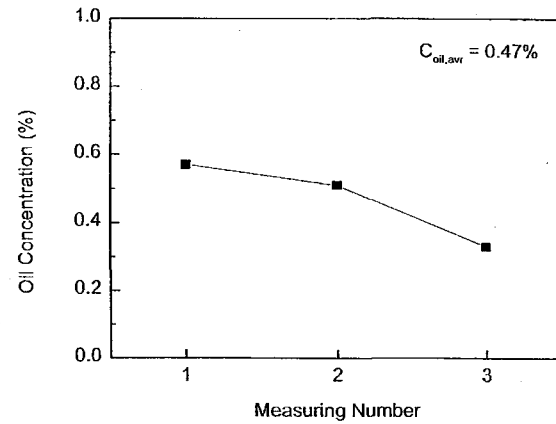


Fig. 9 Measured oil concentration

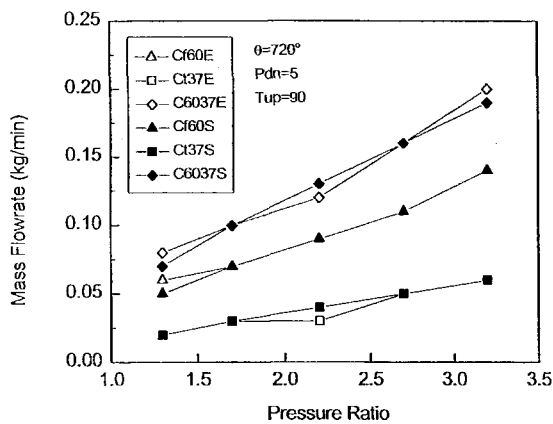


Fig. 10 Theoretical and experimental result of tip leakage with pressure ratio

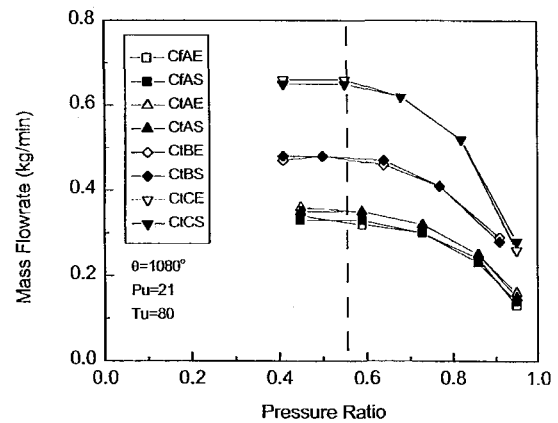


Fig. 11 Theoretical and experimental result of tip leakage with pressure ratio at each tip clearance

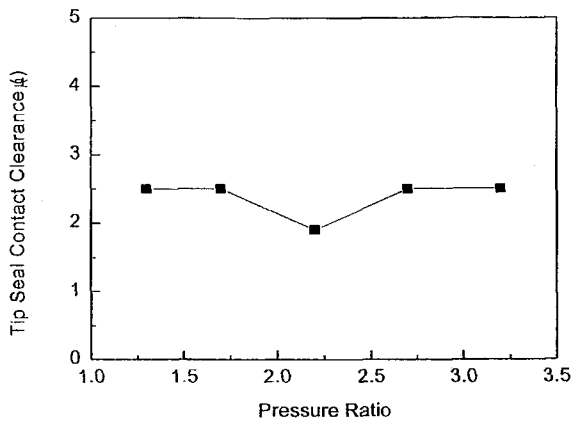


Fig. 12 Tip seal contact clearance at tip clearance 37 μm

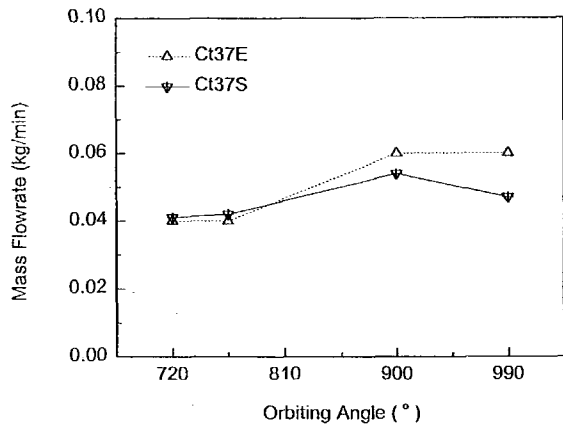


Fig. 13 Experimental result of tip leakage with orbiting angle at tip clearance 37 μm

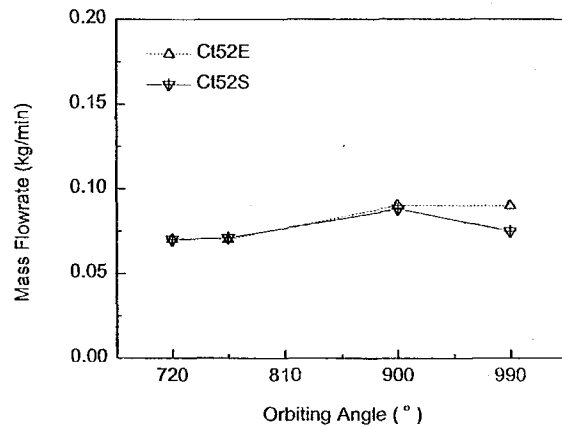


Fig. 14 Experimental result of tip leakage with orbiting angle at tip clearance 52 μm

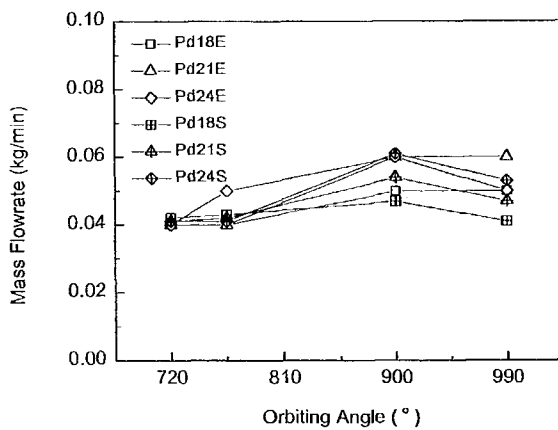


Fig. 15 Theoretical and experimental result of tip leakage with discharge pressure at 37 μm

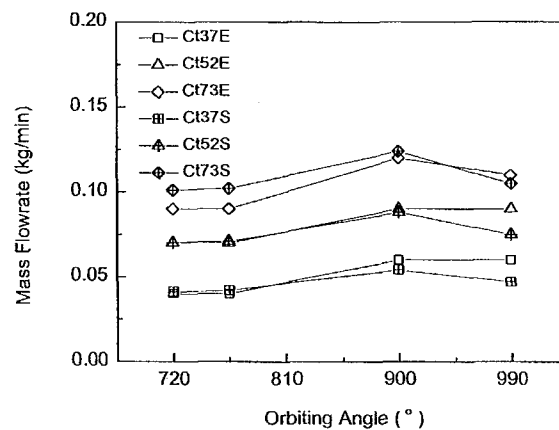


Fig. 16 Theoretical and experimental result of tip leakage with tip clearance at Pd 21

