# Compressor
# with Turning Paired Vane and Piston

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# Contents

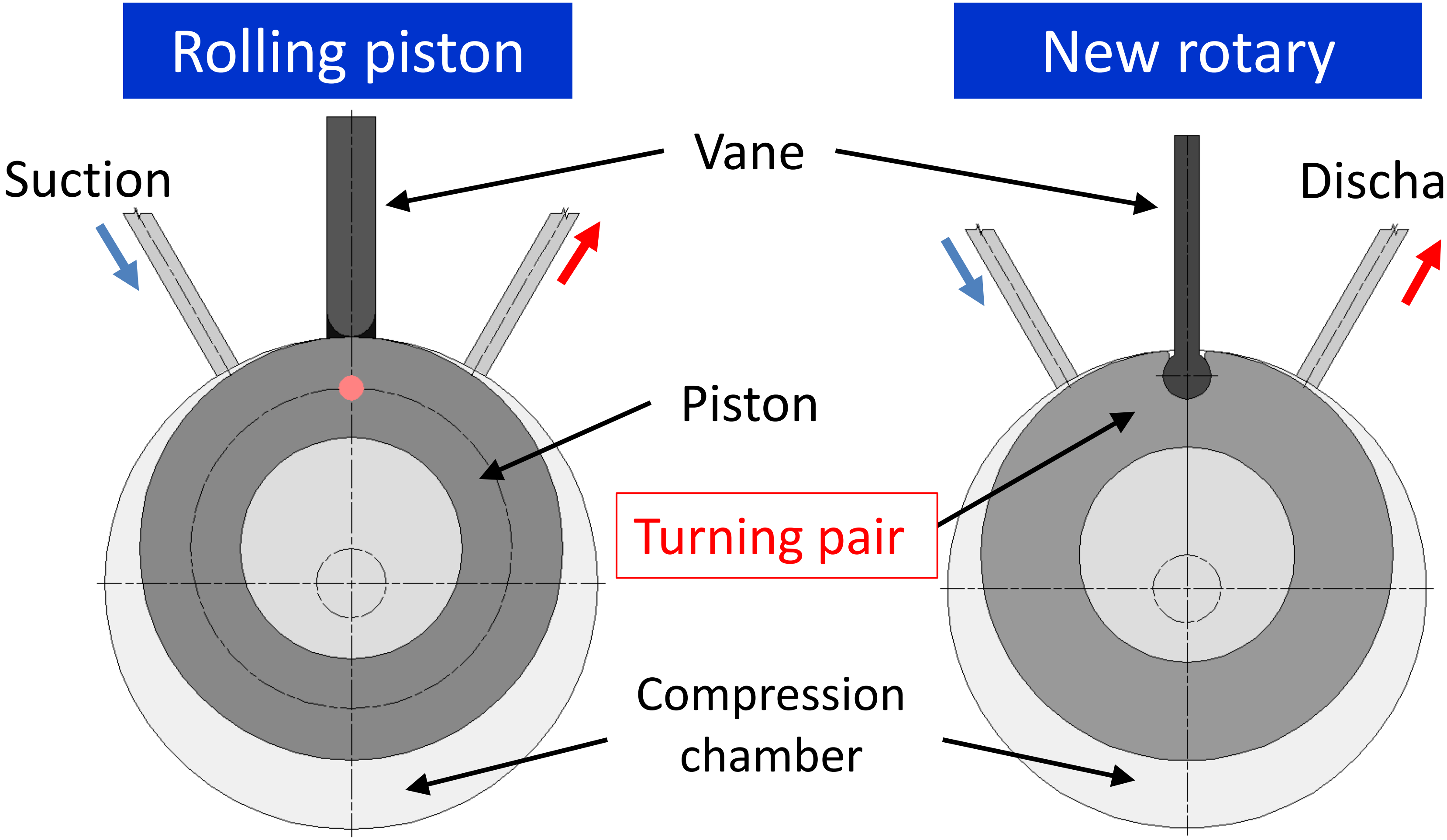
# Introduction



- To prevent global warming, energy saving is required from the society.
- In Japan, air conditioners consume a quarter of the electric power of households.
- To reduce power consumption, we proposed a new rotary compressor with turning paired vane and piston.
- We performed a dynamics analysis of the new rotary and obtained the mechanical characteristics.

# New Rotary Compressor

- The new rotary has a turning pair of vane and piston




This mechanism limits the rolling motion of the piston, controls heat transfer, and reduces heating loss.

# Process of Dynamics Analysis



■Purpose: To obtain the mechanical characteristics of the new rotary

Prepared analytical model for the new rotary

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Formulated equations of motion for three moving parts (vane, piston, crankshaft)

↓

Performed numerical calculation

→ Obtained mechanical characteristics

# Analytical Model for the New Rotary



- Analytical model with forces acting on three moving parts

Vane

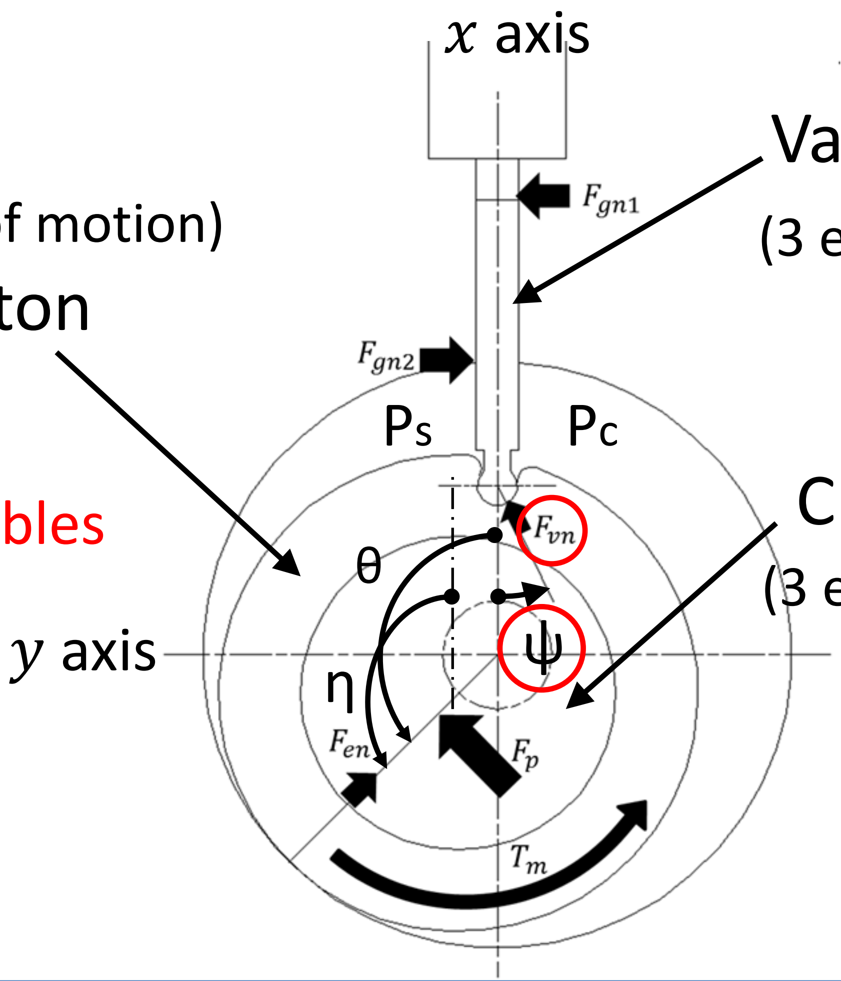
(3 equations of motion)

Piston

(3 equations of motion)

Crank shaft

(3 equations of motion)




Nine unknown variables

$\theta$ , $F_{gn1}$, $F_{gn2}$

$F_{vn}$ , $\psi$, $\eta$, $F_{en}$

$F_{gx}$ , $F_{gy}$

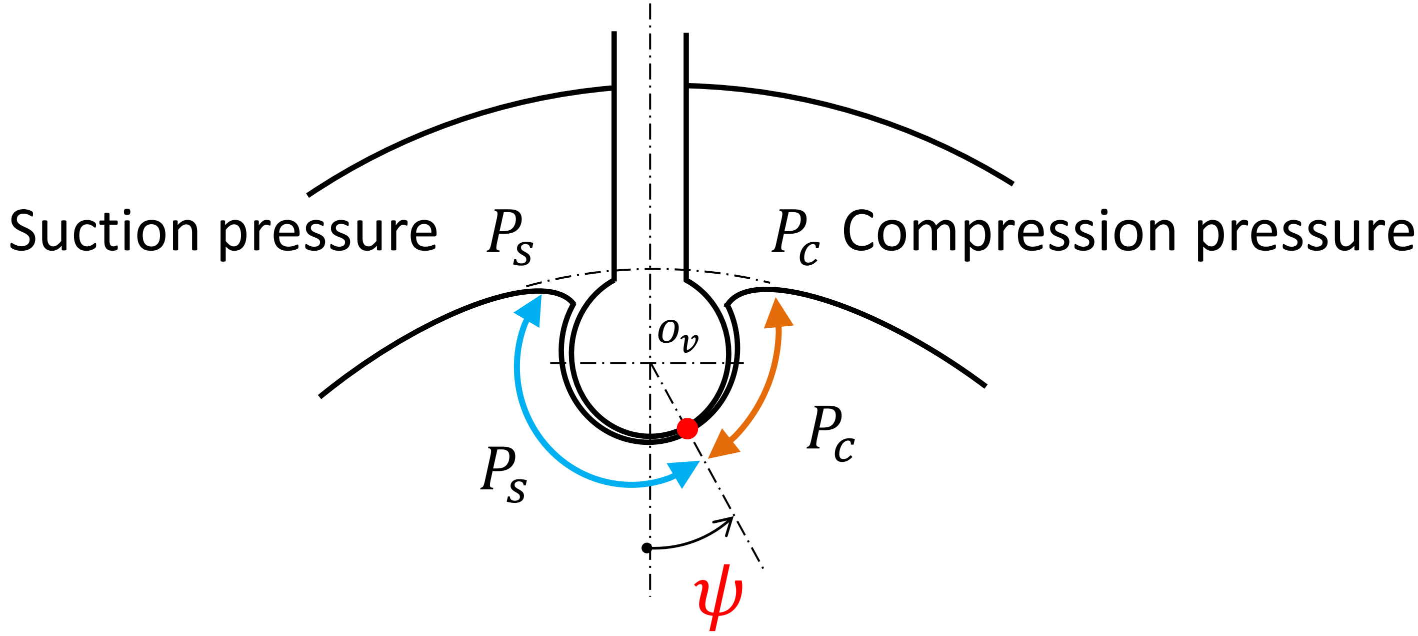
We formulated nine equations of motion for three moving parts.

# Contact Point of Vane and Piston



Assume that the vane tip and piston contact at angle ψ.

[ Pressure distribution around the contact point (ψ) ]



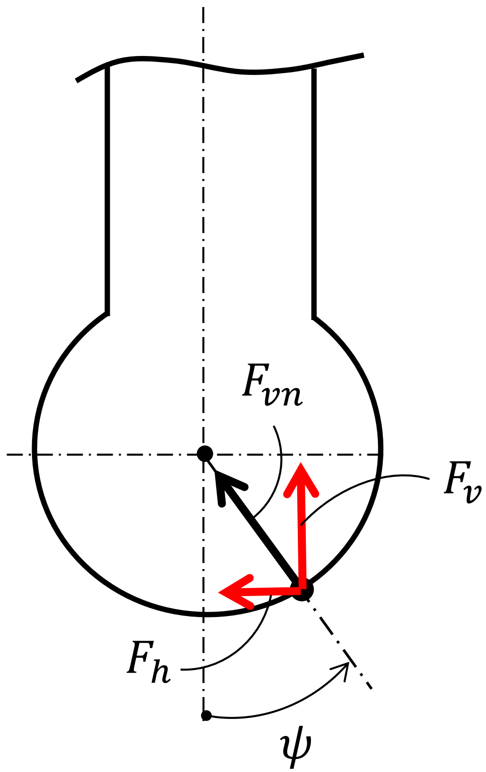

In the analysis, we treated the contact angle Ψ as an unknown variable.

# Contact Force between the Vane and Piston



We have transformed the force $F_{vn}$ into two components.

Contact force $F_{vn} \rightarrow F_v, F_h$

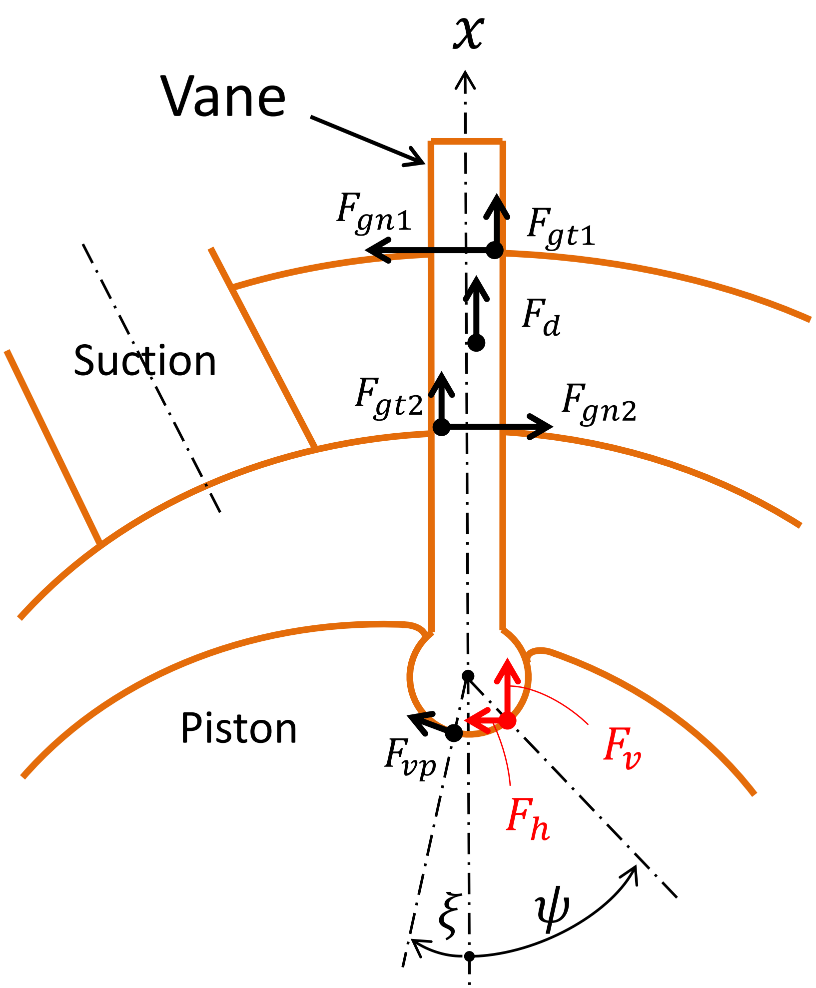



$$F_v = F_{vn} \cos\psi$$

$$F_h = F_{vn} \sin\psi$$

ψ does not appear as the trigonometric function in these equations.

# Equations of Motion for the Vane




- $x$-axis direction

$$m_v \ddot{x}_v = F_{qx} + F_{gt1} + F_{gt2} + F_v + F_{hf} + F_d + F_{vp} \sin\xi$$

- $y$-axis direction

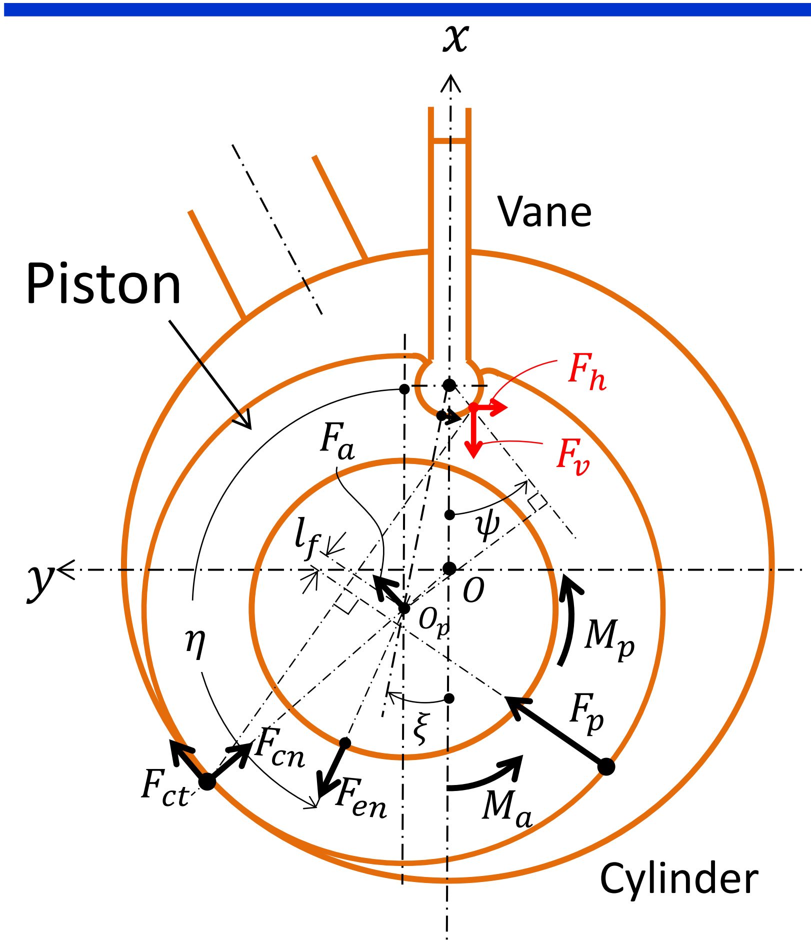
$$F_{qy} - F_{vf} + F_h + F_{gn1} - F_{gn2} + F_{vp} \cos\xi = 0$$

- Rotational

$$(R + b - x_v)F_{gn1} + aF_{gt1} - (R - x_v)F_{gn2} - aF_{gt2} + M_q - r_v F_{vp} + r_v \sqrt{{F_{vf}}^2 + {F_{hf}}^2} = 0$$

# Equations of Motion for the Piston






- $x$-axis direction

$$m_p \ddot{x}_{op} = F_{en}\cos\eta - F_v - F_{hf} - F_{cn}\cos\theta + F_{ct}\sin\theta + F_p \sin(\beta+\gamma) + F_a \sin\theta - F_{vp}\sin\xi$$

- $y$-axis direction

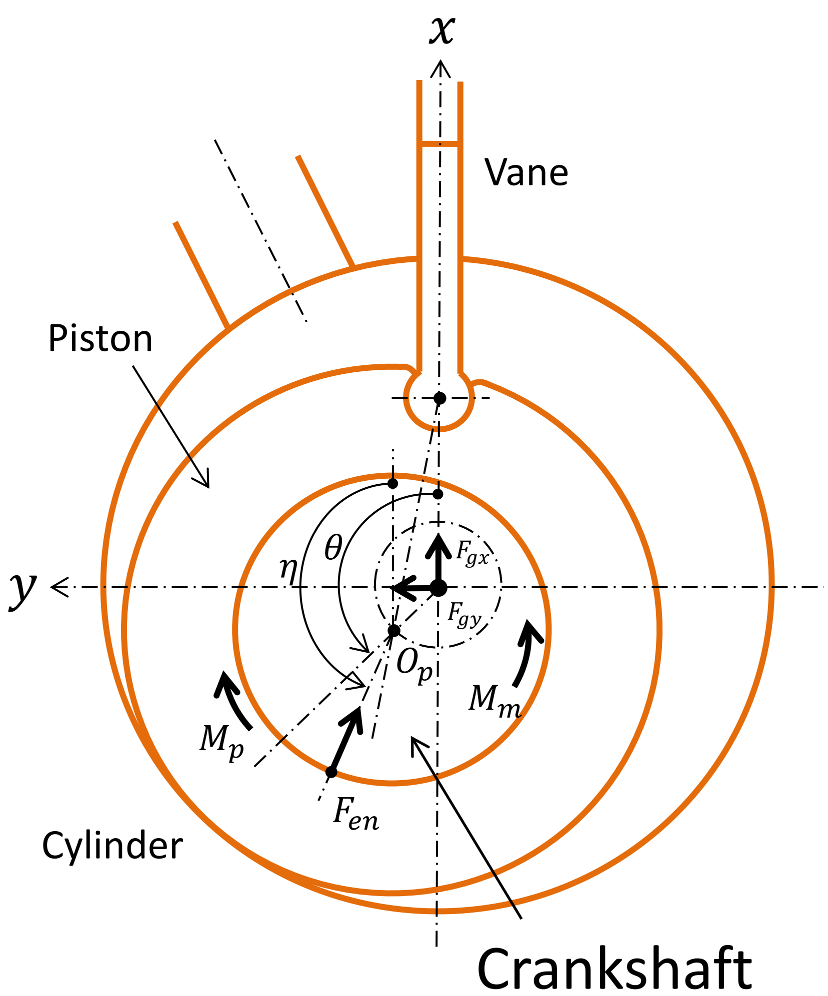
$$m_p \ddot{y}_{op} = F_{en}\sin\eta - F_h + F_{vf} - F_{cn}\sin\theta - F_{ct}\cos\theta + F_p \cos(\beta+\gamma) - F_a\cos\theta - F_{vp}\cos\xi$$

- Rotational

$$(r-h_p)\{\sin\xi - \delta_5\mu_v\cos\xi\}F_v + (r-h_p)\{\cos\xi + \delta_5\mu_v\sin\xi\}F_h = I_p\ddot{\xi} - l_{go}F_p - (r-h_p-r_v)F_{vp} - rF_{ct} + M_p + M_a - r_v\delta_5\mu_v\sqrt{F_v{}^2 + F_h{}^2}$$

# Equations of Motion for the Crankshaft






- $x$-axis direction

$$m_c \ddot{x}_{oc} = F_{gx} - F_{en} cos\eta$$

- $y$-axis direction

$$m_c \ddot{y}_{oc} = F_{gy} - F_{en} sin\eta$$

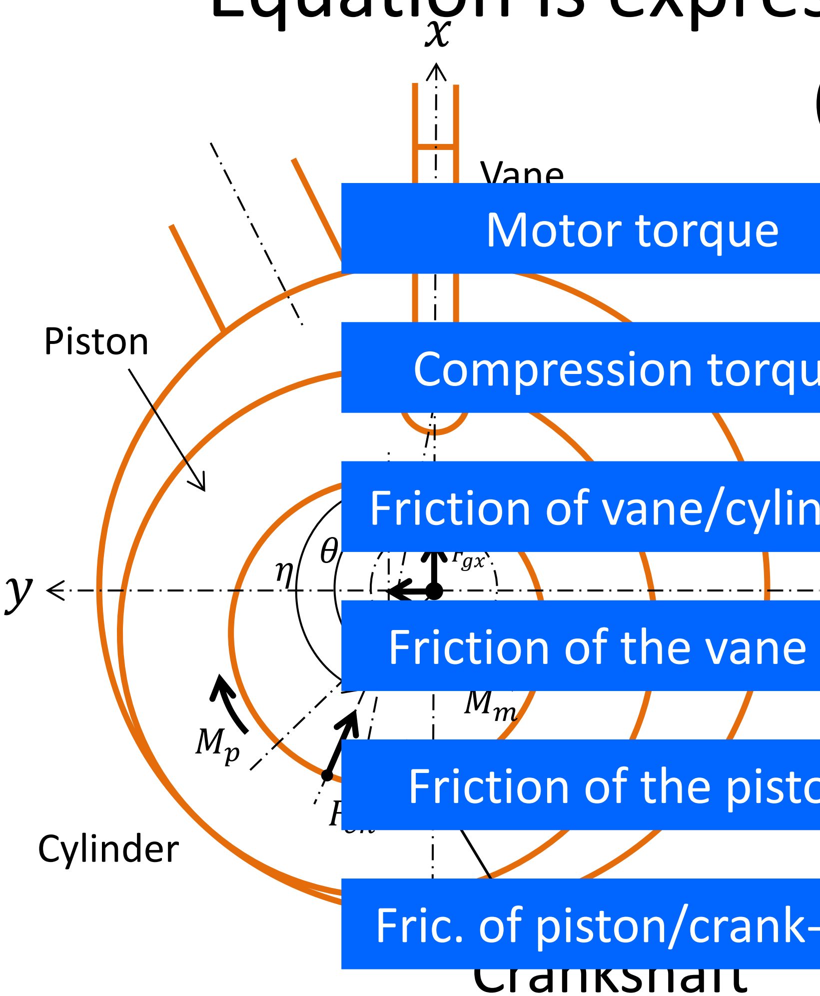
- Rotational

$$I_0 \ddot{\theta} = M_m - eF_{en} sin(\eta - \theta)$$
$$-M_p - M_s$$

# Transformed Equation for Crankshaft (1)



- Equation is expressed by each torque term




$$\left(I_o + m_p e^2\right)\ddot{\theta}$$

$$-M_m + e\frac{\sin(\theta-\psi)}{\cos\psi} m_v \ddot{x}_v$$

Motor torque; Inertia torque of vane

$$-e\cos\alpha \cdot F_p - e\frac{\sin(\theta-\psi)}{\cos\psi} F_{qx}$$

Compression torque

$$e\frac{\sin(\theta-\psi)}{\cos\psi}\left(F_{gt1} + F_{gt2} + F_d\right)$$

Friction of vane/cylinder

$$-e\frac{\cos\theta}{\cos\psi}\left\{\cos(\xi+\psi)\cdot F_{vp} - F_{vt}\right\}$$

Friction of the vane tip

$$eF_{ct} - eF_a$$

Friction of the piston

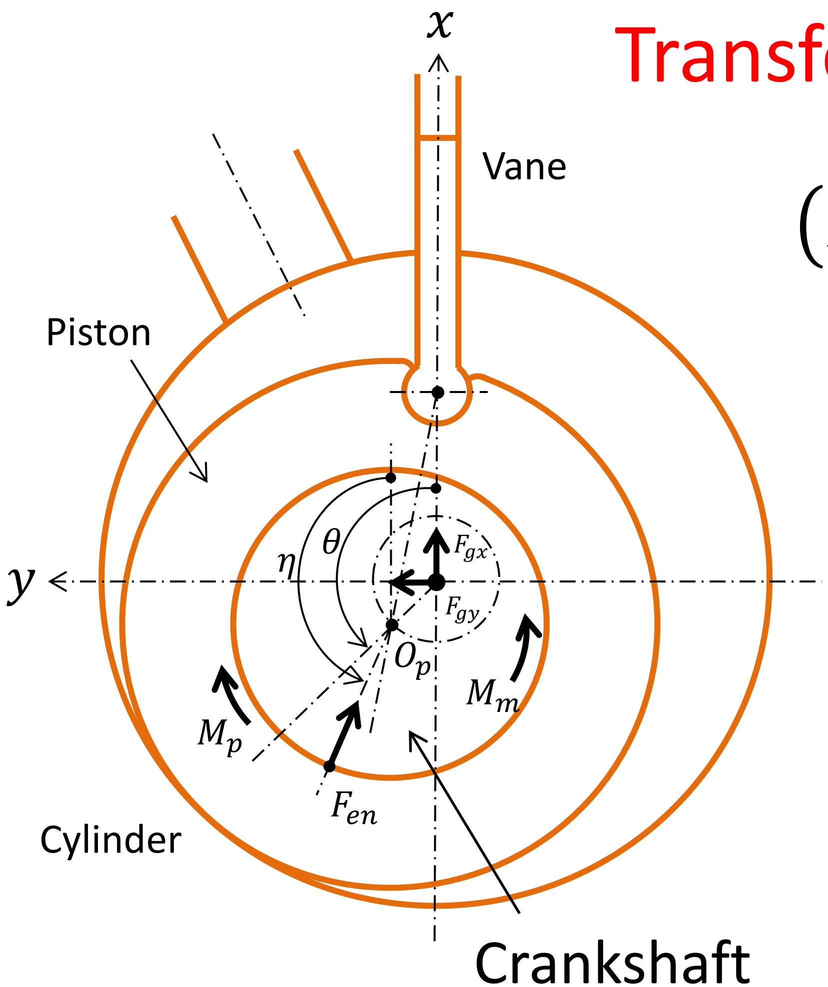
$$-M_p - M_s$$

Fric. of piston/crank-pin; Friction of crankshaft

$1/\cos\psi$ becomes infinite when $\psi$ goes to 90°.
→ $\psi$ should disappear from the equation.

# Transformed Equation for Crankshaft (2)






Transform $F_{vn}, \psi \rightarrow F_v, F_h$

$$\left(I_o + m_p e^2\right)\ddot{\theta}$$

$$= M_m + e\left(F_v + F_{hf}\right)sin\theta$$

$$-e\left(F_h - F_{vf}\right)cos\theta$$

$$-eF_{ct} - eF_p \cos\alpha - eF_a$$

$$-eF_{vp}\,cos(\theta + \xi)$$

$$-M_p - M_s$$

- Solved this equation by Runge-Kutta method.

→ Obtained the rotational behavior of the crankshaft.

# Process of Numerical Calculation



(1) Simultaneously solved four linear equations of the four forces $F_{n1}$ , $F_{gn2}$ , $F_v$ , $F_h$.

(2) Solved the equation for the crankshaft by the Runge-Kutta method. ( $\theta = 0\,°\rightarrow\ 360\,°$)

(3) Obtained convergence solutions in which initial value of $\dot{\theta}$ $(\theta = 0\,°)$ coincided with final value $\dot{\theta}$ $(\theta = 360\,°)$.

# Calculation Results

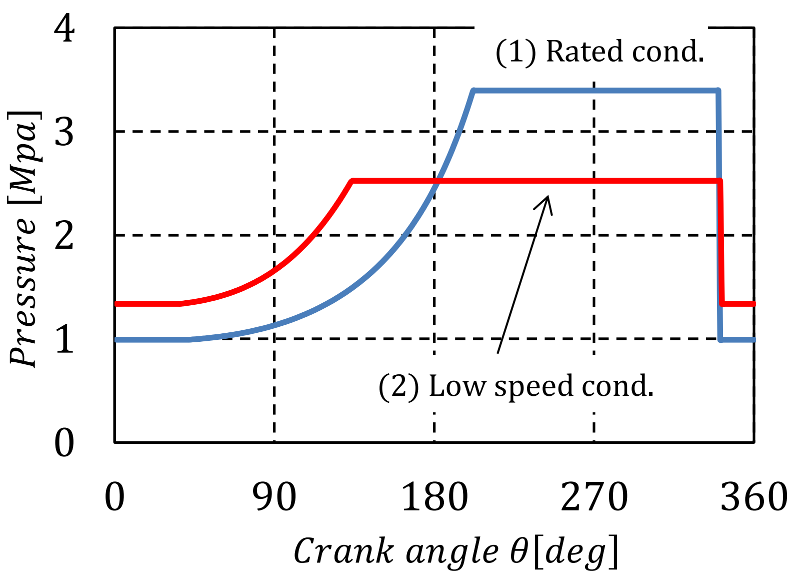
## Comparison of the new rotary and rolling piston rotary

# Compressor Specifications and Analysis Conditions

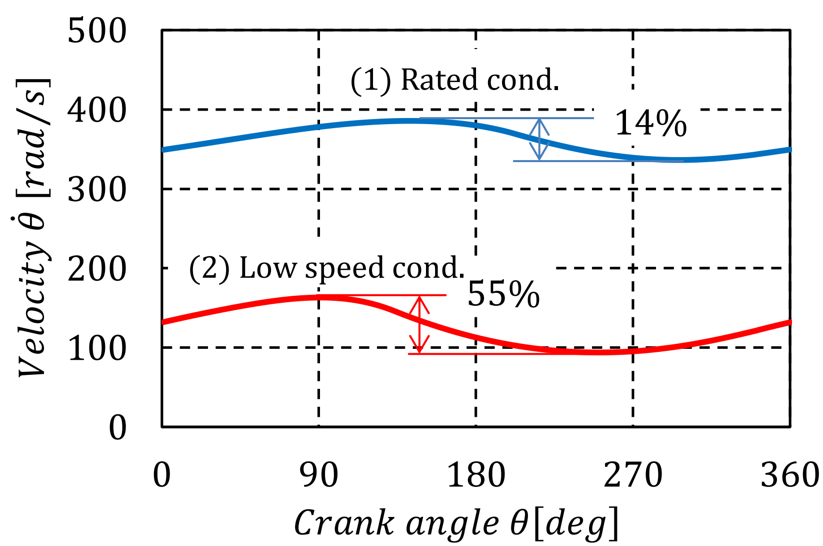


- Refrigerant ： R410A
- Cylinder volume ： 13.5 $cm^3$/rev
- Analysis conditions

(1) Rated cond. 55.5 Hz (2) Low speed cond. 20 Hz



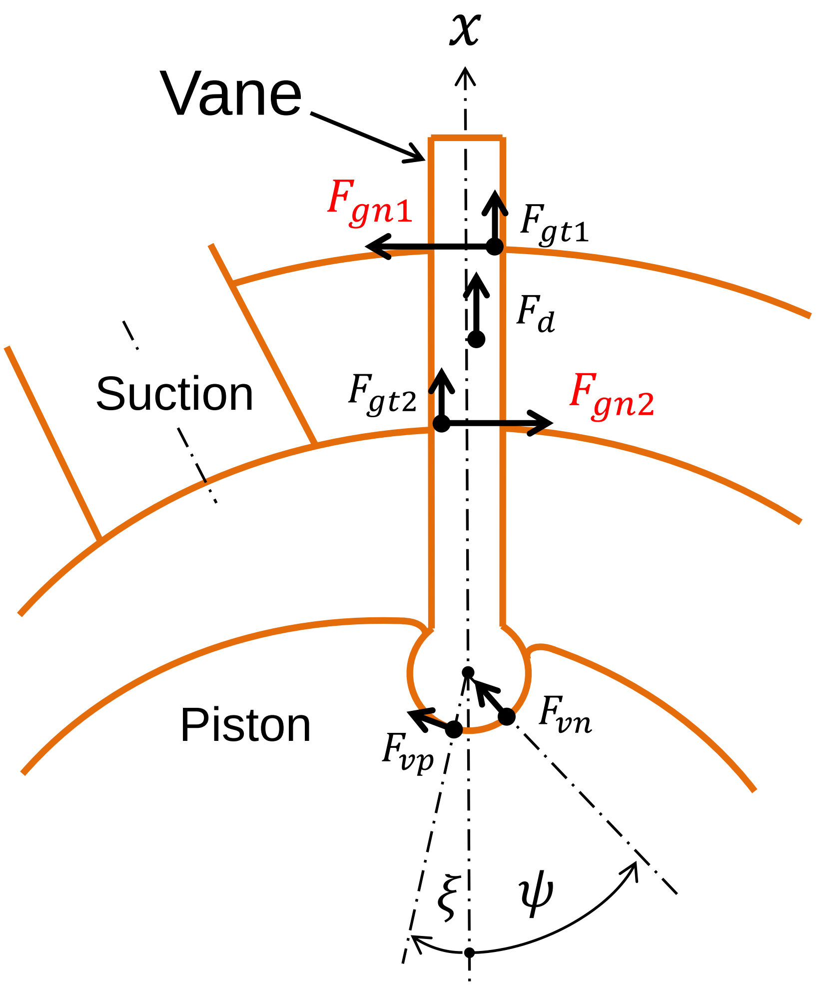

【Suction and discharge pressure】

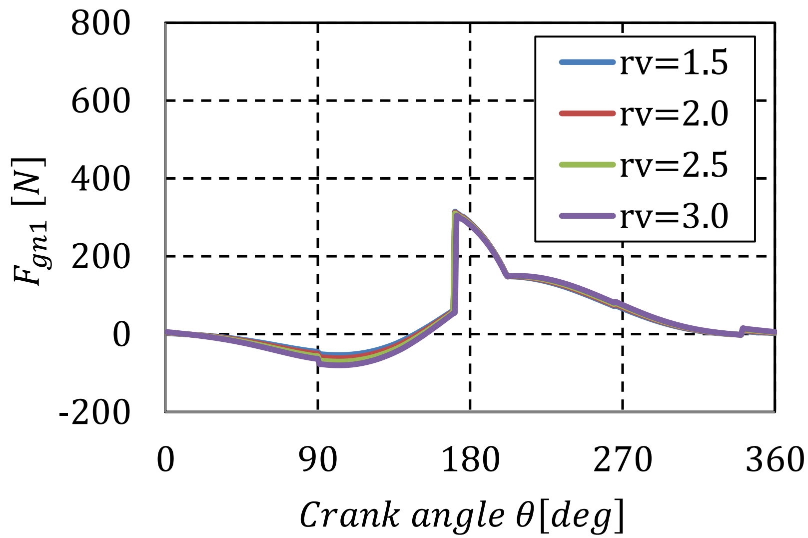


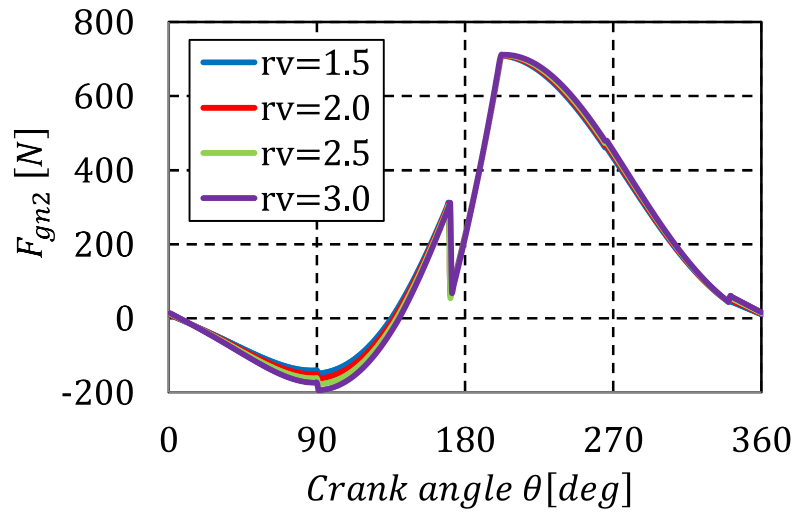

【Angular velocity of the crankshaft】

- Gas compression torque and rotational behavior of the crankshaft are the same on the new rotary and rolling piston rotary.

# 【New Rotary】 Contact Force between Vane and Cylinder



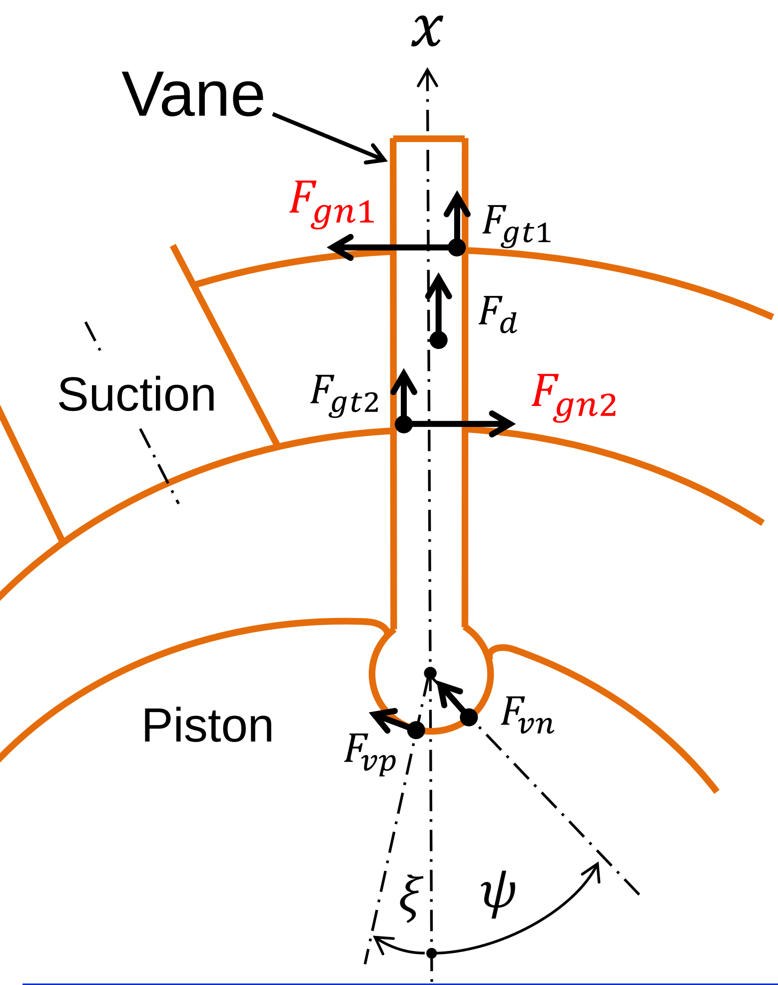



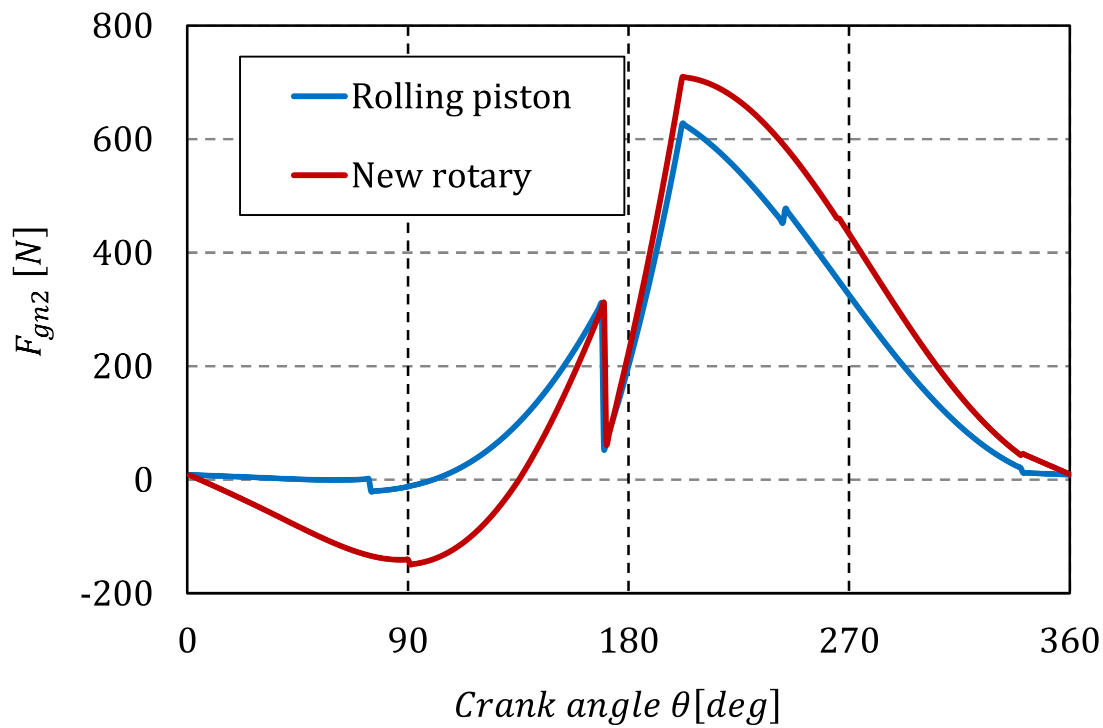

- Even if vane tip radius changes, contact forces between vane and cylinder remain unchanged.

# Comparison of Contact Force (Vane/Cylinder)






Comparison of contact force $F_{gn2}$

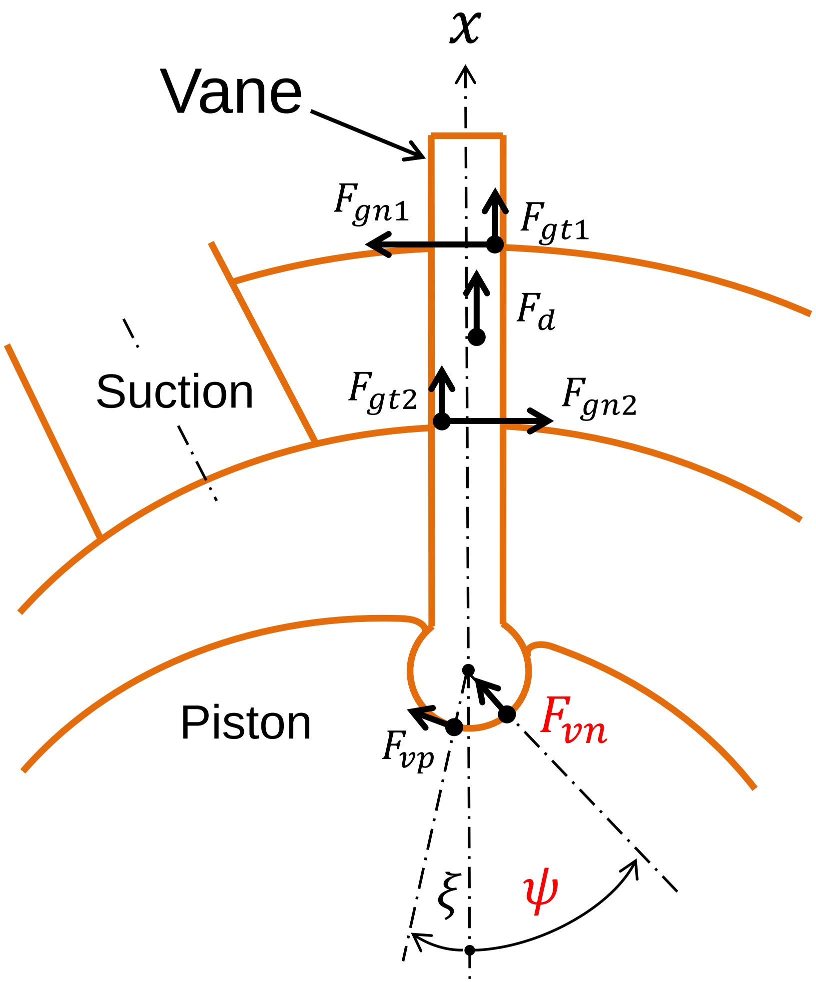


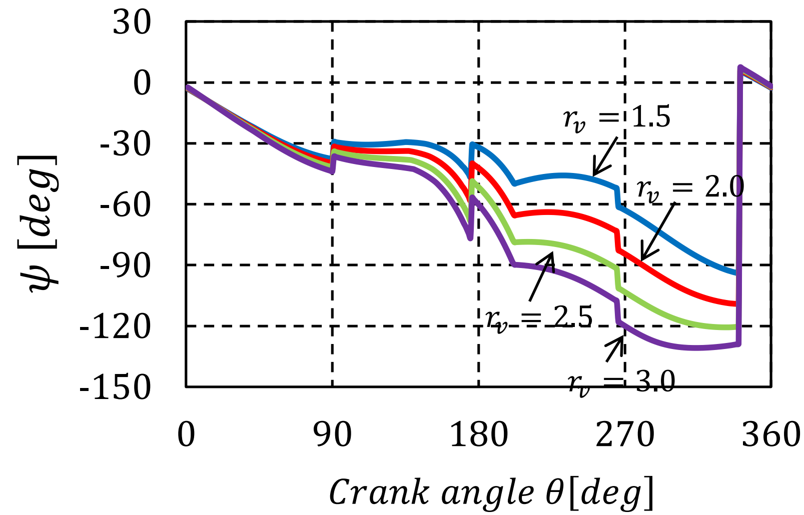

- The contact force between the vane and cylinder on the new rotary is larger than that on the rolling piston rotary.

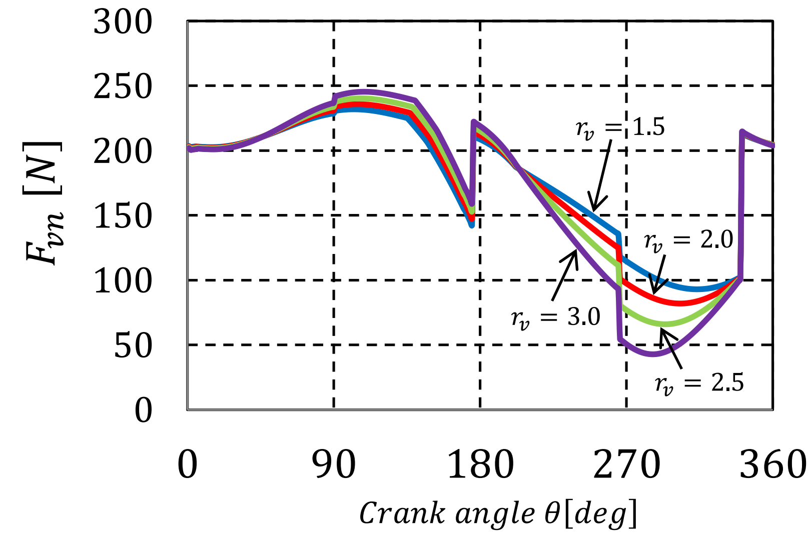
→ The friction loss on this part slightly increases on the new rotary.

# Contact between Vane and Piston





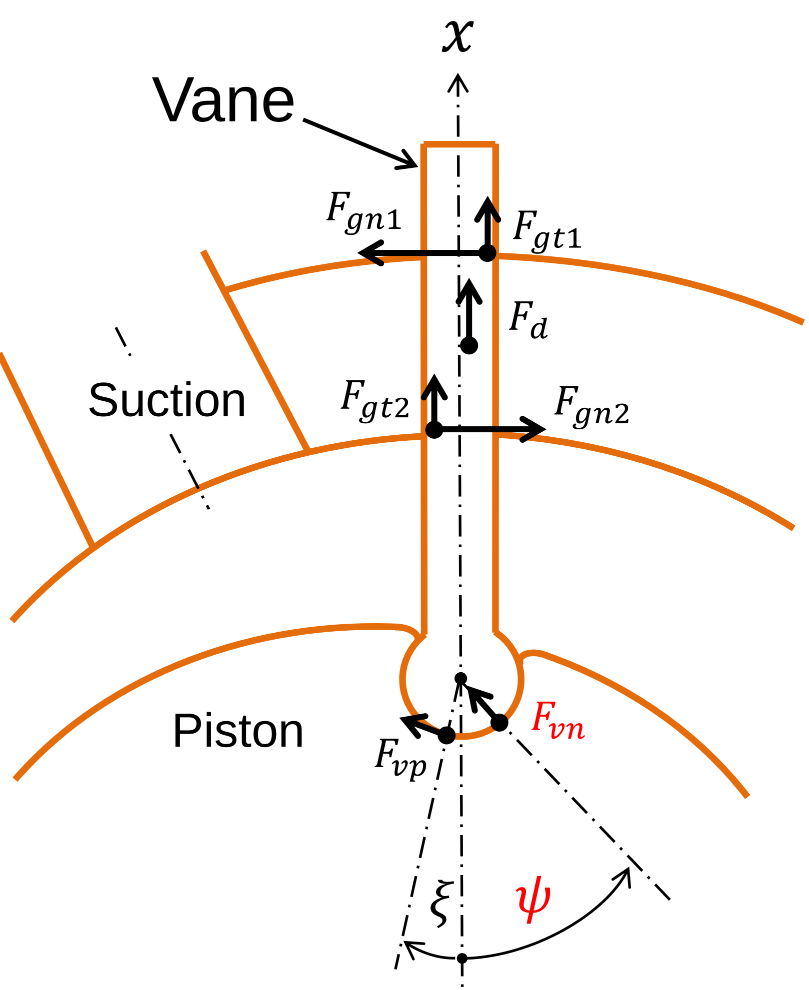



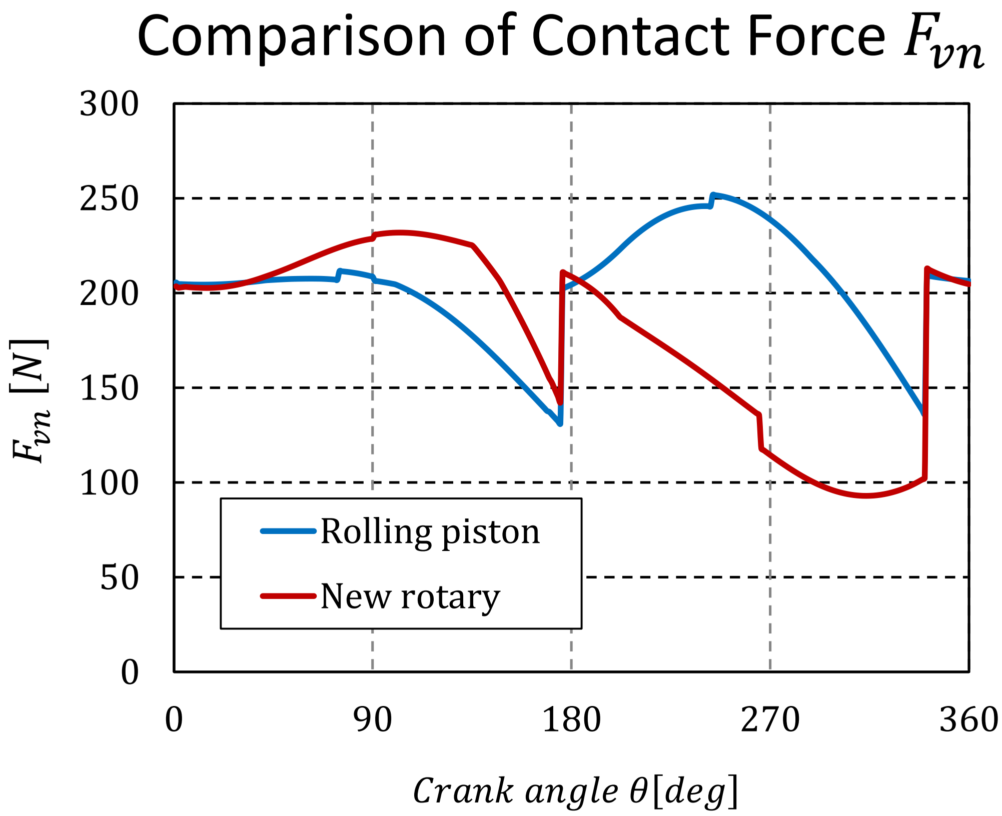




- When the pressure increases, the contact point between the vane and piston moves to the suction side and the contact force decreases.

# Comparison of Contact Force (Vane/Piston)






Lower possibility of vane tip wear

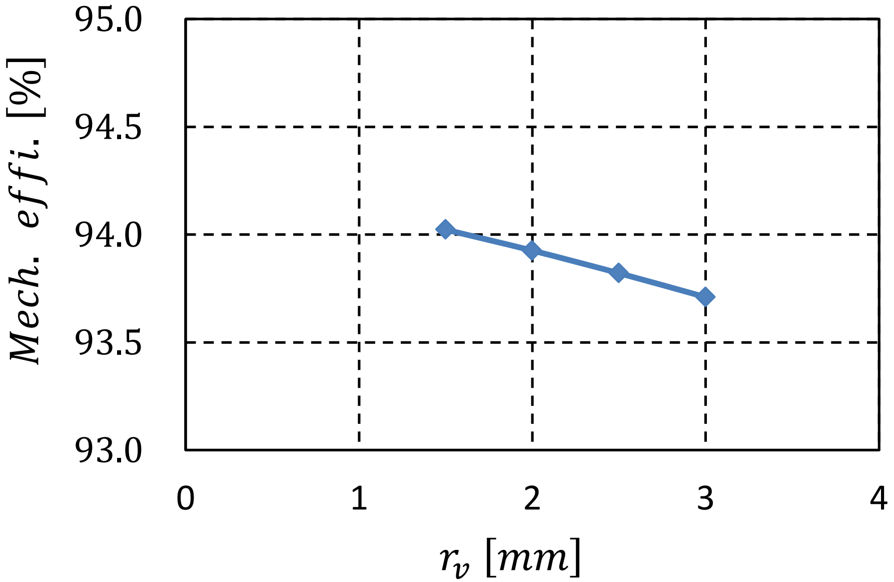
- The contact force between vane and piston on the new rotary is smaller than that on the rolling piston rotary.

→ The friction loss on this part decreases on the new rotary.

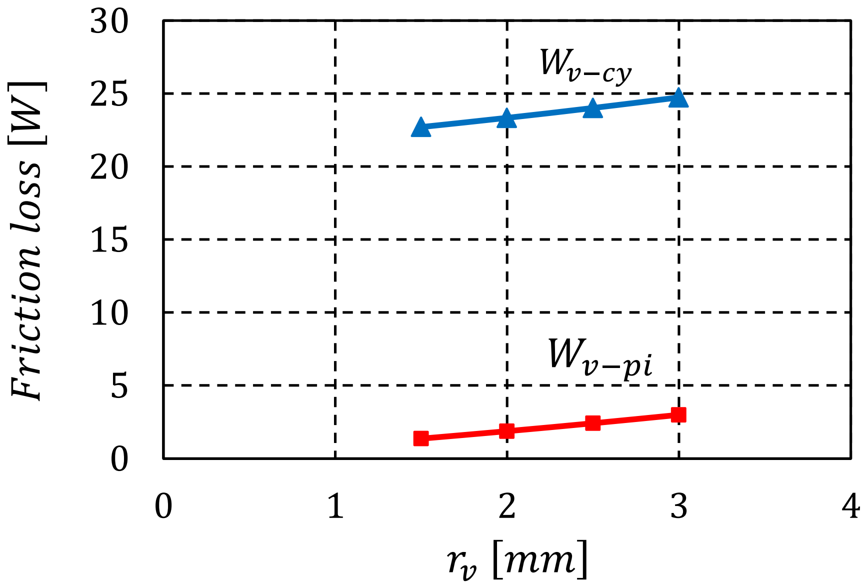
# Mechanical Efficiency of the New Rotary



## ■ Relation between the vane tip radius and mechanical efficiency.




【Relationship between mechanical efficiency and vane tip radius】




【Relationship between friction loss around vane and vane tip radius】

・The friction loss around the vane decreases as the vane tip radius decreases.
→ Mechanical efficiency would improve.

# Comparison of Losses and Mechanical Efficiency



| Mechanical loss (Power) | (1) Rated condition | | (2) Low-speed condition | |
|---|---|---|---|---|
| | New rotary | Rolling piston | New rotary | Rolling piston |
| Theoretical compression power | 1029.7 | 1029.0 | 239.6 | 239.4 |
| Crankshaft bearing loss | 36.8 | 36.7 | 7.9 | 7.8 |
| Friction loss at vane/piston | 1.4 | 11.2 | 0.2 | 0.1 |
| Friction loss at vane/cylinder | 22.7 | 16.0 | 3.5 | 3.3 |
| Friction loss at piston/crank-pin | 3.9 | 4.0 | 0.5 | 0.5 |
| Friction loss at piston end face | 0.65 | 0.65 | 0.08 | 0.08 |
| Friction loss at vane end face | 0.05 | 0.05 | 0.006 | 0.007 |
| Total power | 1095.0 | 1097.7 | 251.7 | 251.3 |
| Mechanical efficiency $= \frac{Theoretical\ comp.\ power}{Total\ power}$ | 0.940 | 0.937 | 0.952 | 0.952 |

# Conclusions



We performed the dynamics analysis of the new rotary compressor and compared the mechanical characteristics with the rolling piston rotary compressor.

(1) The mechanical efficiency of the new rotary compressor improves as the vane tip radius decreases.

(2) The mechanical efficiency of the new rotary compressor would be a little higher than that of the rolling piston rotary compressor.

# Appendix

# Conclusions



- The new rotary compressor, by restricting the rolling motion, controls the heat transfer through the piston and thereby reduces heating loss in the suction process, which means it would have higher compression efficiency.